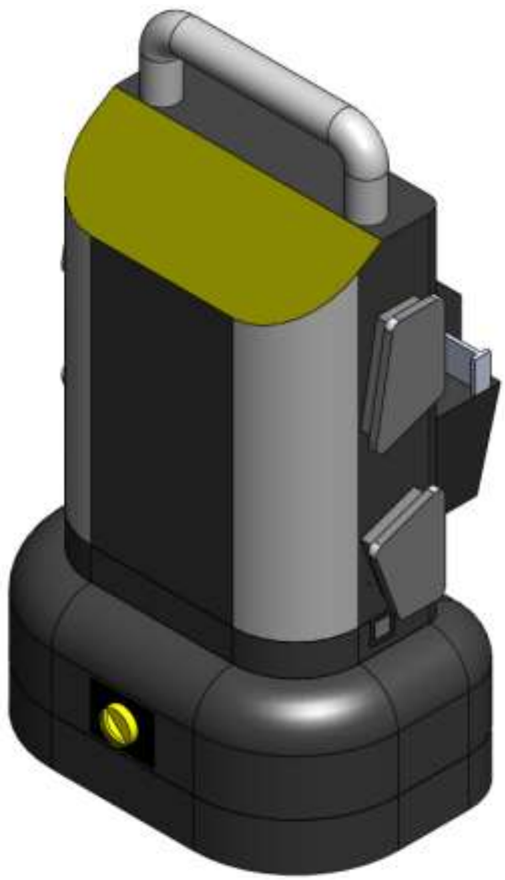
EML4501 – Senior Mechanical Design

Design Report 3

Stanley Jump-Starter and Air Compressor



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Introduction

This report focuses on the design and analysis of a portable jump start and air compressor unit that is capable of working on any vehicle ranging from a small riding lawn mower, all the way up to a tractor trailer. The scope of the analysis in this report includes, but is not limited to: fluid mechanics, heat transfer, Von Mises stress analysis, materials, life analysis, friction, and expansion. The goal of this study is to effectively design a system that has a wide range of functionality and is within a very reasonable price range for mass production.

Functional Requirements

The jump starting unit will need to meet several functional requirements.

Compressor Controller

A compressor controller must be designed such that its functionality meets or surpasses the ability to fill four evenly exhausted tires, in succession, to a user defined pressure. All tires must be filled within the same amount of time.

Use on Tractor Trailer

The jump starting system must be fully capable of functioning on a tractor trailer. The compressor must also be able to fill tractor trailer tires in a reasonable amount of time.

Product Manufacturing

The product must be "Made in America." This significantly increases the manufacturing and assembly costs as the minimum wage is increased from ~$1.50/hr overseas, to $20.00/hr.

Product Cost

The product must sell for $150.00 with a 25% mark-up. This leaves $112.50 for total cost of creation.

Product Specifications

The Jump-Starter 2000 should combine a jump-starter, air compressor, emergency LED light, USB port, 12 V DC charger into a single unit. The unit should be small enough to be carried in the trunk of a small car or toolbox of a pickup truck. The tool should be designed such that no harm or injury comes to the user under any circumstances, and so that no damage to the user's vehicle occurs during normal use. The tool should be designed and constructed such that no part will break, undergo significant wear, or fail under normal appropriate use. The design and material selection, as well as the manufacturing process, should emphasize cost effectiveness while fulfilling the functional requirements listed below for each individual function. In many cases, it might be more cost effective to purchase components off the shelf rather than manufacture them; this is acceptable as long as the functional requirements are met.

Jump-Starter

The jump-starter feature of the unit is, as the unit name suggests, the most important feature and that which the entire unit is built around. Usually, when a vehicle battery "dies" (or is discharged to the point that it is no longer able to crank the engine) the user "jump-starts" the vehicle by connecting a working car battery in another vehicle to the "dead" vehicle's electrical system. However, the jump-starter system allows the user to start the dead vehicle without another vehicle present, by using the charge in a smaller, more portable battery. This system must be able to jump-start vehicles ranging in size from a small lawn mower, to a tractor trailer.

Most vehicles run off of a 12 V power supply. In order for the jump-starter to be effective, the jump-starter battery must be able to provide at least 300 amps (A) at 12 V for five seconds, based on average original equipment manufacturer (OEM) cranking amperage requirements. Most vehicles pull between 200 and 350 A during cranking at room temperature, however as temperature decreases, cranking requirements increase exponentially. This is because not only does battery performance decrease as temperature increases, but the cranking power of the starter must increase due to the increased viscosity of engine fluids at lower temperatures. This has led to a common rating for cold cranking amps (CCA) in the automobile battery industry, which is the maximum current the battery is able to maintain for 30 seconds at a temperature of 0°F. Most high-quality automobile batteries have CCA ratings upwards of 600 A. However, the jump-starter is an emergency tool and must be portable and meet the requirements for use in a normal operating environment, thus the requirements are not as high as those for an automobile battery, which must be able to crank the vehicle under any condition.

A 24 V system is used to power tractor trailers. This means that a standard 12 V battery jump starter would not be sufficient for turning over the starter. In addition to the higher voltage power source, tractor trailers require a much higher amperage input to power the starter. A standard tractor trailer requires 600 cranking amps to be maintained for 5 seconds in order to turn over the engine. By connecting two of the aforementioned batteries in series we can achieve a 24 volt output with 2000 peak amps and 600 amps sustained for 5 seconds. This sufficiently meets the requirements for jump-starting a tractor trailer.

Car batteries are also designed to provide power to auxiliary features within the car while the engine is off; therefore they have large capacities, typically between 30-40 amp-hours (Ah), with some above 60 Ah. This correlates roughly to a reserve capacity (another industry-standard rating describing the length of time the battery is able to provide 25 A before its voltage drops below 10.5 V) of one to two hours. However, the jump-start battery is designed to crank a vehicle under emergency conditions and not run auxiliary functions on the vehicle, so it requires less capacity than a standard automobile battery. With this in mind, no specific capacity requirement applies to the jump-starter battery to provide auxiliary power, however it should provide enough capacity to allow the user to crank the engine at least five times in case it doesn't start on the first try. Assuming an average crank time of one second, this should correlate roughly to a five-second discharge at the required current output.

In addition to the battery, the jump-starter must include cables to connect the battery to the vehicle's electrical system. The cables should be similar in design to standard jumper cables, with large alligator clips (color-coded black and red for negative and positive) on the end of each cable to connect to both terminals of the car battery. The cables should be at least six feet long to allow them to reach the battery while the unit sits on the ground next to the vehicle. The cable size should be large enough to safely transmit the design current at 12 and 24 volts.

Air Compressor

The air compressor allows the user to add air to any desired object with a Schrader valve. The system should consist of an electrically driven compressor, a hose with a Schrader valve adapter to deliver air to the tire, a pressure regulator (to control desired pressure), and a gauge displaying the tire pressure.

The compressor should be internal to the unit, and should be a positive-displacement type compressor with an electric motor driven from the main battery used in the jump-starter system. The system should be designed to produce at least 120 psi, since some smaller applications like bicycle tires routinely require such high pressure. The flow rate should be sufficient enough to inflate an average SUV tire in less than five minutes, and a tractor trailer tire within 15 minutes. With these design requirements in mind, the system and motor should be sized for the minimum current draw, so the user can fill all four tires of a vehicle on a singular battery charge.

Noise level of the compressor is not a design requirement, since the unit will most likely be used on the side of a busy road.
In addition to the motor/compressor system inside the overall unit, the compressor outlet should be attached to an external air hose at least six feet in length so the user can fill any tire with the unit resting on the ground. The hose should have a Schrader valve adapter on the end with a clamp so that no air flows unless the hose is clamped onto the valve stem. Any attachments should be able to be clamped into the same mechanism for use.

The pressure gauge should be linked to the system at any point downstream of the compressor outlet and should be mounted on the outside of the overall unit. The gauge should have a clearly marked scale with both metric and U.S. standard pressure markings around the outside, with a resolution of at least 2.5 psi and 0.5 bar.

The air compressor system also contains a pressure regulator that gives the user the ability to set a target pressure. Once the desired pressure is set, the compressor will inflate the object to that pressure. When the target pressure is reached, the regulator trips an electrical connector which shuts off the compressor and will not fill up the object any longer. The user can fine tune the desired pressure by tightening or loosening the fastener at the top of the regulator. When the fastener is completely backed out, the target pressure is zero psi. Each full turn of the fastener will increase the target pressure by 20 psi. The fill time for an 18 L (tractor trailer) tire from 0 psi to 120 psi is 15 minutes. Therefore, it is safe to assume that all wheels will take less than or equal to 15 minutes to fill.

USB charging outlet

The USB charging outlet allows the user to charge any device with a USB-type charging cable. The outlet should be a standard USB port with power connections and no data connections. The port should provide the standard 5 V DC signal at a current of no less than 500 mA. This is the minimum allowable current for a Dedicated Charging Port according to the USB Battery Charging Specification of 2007.

12 V DC charging outlet

The 12 V DC outlet is used to charge peripheral devices such as cell phone and music players. The outlet should be the standard cigarette lighter type outlet, providing a current of at least 5 A in order to charge a variety of devices.

The unit should also be able to receive a charge using the 12 V DC outlet. This will require a cord with a charging plug on both ends so the user can connect the unit to the vehicle's 12 V DC charging port.

Flashlight

The flashlight should be an LED light to minimize the current draw on the battery, and should be movable so that the user can direct the light in the desired direction without moving the entire unit.

12 – 24 Volt Functionality

The device should be capable of switching between a 12 and 24 V power supply. When the unit is in the 24 V mode, the 12 V circuit board should be bypassed by one of the batteries as to ensure not to burn up the circuit board.

Other Requirements

The unit should have a standard 110 V charging plug so the user can charge the unit using a standard extension cord. The electrical system should have the circuitry necessary to allow the user to leave the unit plugged in without over-charging and damaging the battery. Appropriate switches should be used for each function to ensure no current is flowing when not in use, and to prevent accidental shock. There should also be a battery capacity meter that clearly displays the battery's state of charge.

In order to prevent fire and severe damage to one or both batteries, the unit should have a polarity light that displays whether the jumper cables are attached to the correct battery terminals before the batteries are connected electrically.

The complete unit should be as compact as possible and have a handle for the user to carry the unit easily. The outside should be rugged enough to withstand normal wear and tear and protect the internals such as the compressor, battery, and circuitry from impact.

Operational Procedure

This product has many functions for various applications. There are two main features of this product, the jump-starter, and the air compressor.

Charging the Unit

The unit can be charged in two different ways. The first option is to use the 12 Volt DC outlet. The system comes with a double sided 12 volt DC accessory outlet. NOTE: This method can lead to overcharging of the battery. For this reason, do not leave the unit alone when charging with this method.

1. Insert the gold-tipped 12 volt DC charging adapter plug into the vehicle's 12 volt DC accessory outlet.
2. Insert the silver-tipped end plug into the 12 volt DC accessory outlet on the front panel of the unit.
3. Charge the unit until the green FULL indicator is lit up (will occur when the "Battery Power Level" button is pressed)
4. Remove charging cords.

The other option for charging the unit is using the 120 volt AC charger and a standard, self-supplied, extension cord. NOTE: This method cannot overcharge the battery.

1. Lift the AC adapter cover on the back of the unit and connect the extension cord to the unit. Plug the other end of the extension cord into a 120 volt wall outlet.
2. Charge the unit until the green FULL indicator is lit up (will occur when the "Battery Power Level" button is pressed)
3. Remove charging cords.

Jump-Starter

The jump start system is extremely user friendly. There are two components to this system. The first component is the Main unit. The main unit contains everything necessary to jumpstart vehicles ranging in size from a small lawn mower, to a full size pickup truck. The optional modular battery pack provides the user with the ability to jumpstart any vehicle up to a tractor trailer. The jump-starting process is extremely simple, but can very easily cause damage if done incorrectly. Please follow the following procedure when jump-starting any vehicle.

1. Verify that the battery in your vehicle is actually dead and this is the reason that you are unable to start your vehicle. If you determine another possible cause for the problem, please contact your vehicle manufacturer as soon as possible to determine the necessary course of action. If you are unsure of the actual issue, please seek expert advice.
2. Locate the battery in your vehicle. The battery is generally under the hood, near the front of the vehicle. See your vehicle manual if you are unable to locate your battery. If necessary, remove any caps that may be covering the positive and negative terminals on the battery.
3. Identify the positive and negative terminals

   a. The positive terminal will usually have red wires attached and marked with a (+) sign
   b. The negative terminal will usually have black wires attached and marked with a (-) sign
4. Unclip red and black jumper cables from the back of the original unit. Unwind cables to full length.
5. If the modular battery pack is attached, verify that the proper setting is selected on the “12/24 Volt” switch.
6. Connect the jumper cables to the battery terminals in the following order:
   a. Connect the red jumper clamp to the positive terminal of the battery
   b. Connect the black jumper clamp to a piece of grounded metal on the car. If this is not practical, you may connect this clamp to the negative battery post. NOTE: This does set the small risk of igniting hydrogen gas coming off of the battery.
7. Verify that there are no loose cables coming into contact with parts of the engine that will start moving when turned on.
8. Check the polarity light on the jump-start system. If the “switch polarity” light is lit up, please remove the two jumper cables, black first, red second, and place them in the exact opposite position.
9. Turn the “on/off” switch to the “on” position.
10. The car battery will now receive a charge from the jump-start system.
11. Let the battery charge for two to five minutes.
12. Try to start your vehicle. If the vehicle does not start, wait five more minutes and try again.
13. If the problem persists, please contact professional help as a more serious issue may be occurring.
14. Once the car has been started, remove the jumper cables from the battery, black first, followed by red.
15. You are now set to operate your vehicle in a normal capacity.

Air Compressor

1. Unwind the air compressor hose. Verify that there are not any kinks in the hose system as this will decrease the ability for air to flow through the hose and will cause issues when filling your desired object.
2. Back the pressure regulator valve all the way out. This will set the desired pressure to zero psi.
3. Set your desired pressure by tightening the fastener on the pressure regulator. One full rotation equates to 20 psi.
4. NOTE: The max pressure that the system can attain is 120 psi.
5. Once the desired pressure is set, attach the Schrader valve to the object that you wish to inflate.
6. Turn the “on/off” switch to the “on” position. The system will now inflate your object to user defined pressure. Once the pressure is achieved, the electrical connection is broken, and the system will shut off until it is reset by the user.
7. In order to reset the system, flip the “on/off” switch to the “off” position. Once the switch is turned “on” again, the system will be activated and will work as normal.

8. Repeat the process as necessary. NOTE: If you desire to change the “fill to” pressure, back the fastener all the way out and tighten down for as many rotations as necessary to set to the newly desired pressure. One full rotation equates to 20 psi.

USB Power Port

1. Push the USB Power Button to turn on the USB Port. The USB power indicator will light up.
2. Lift the USB port cover.
3. Plug in the USB-powered device and operate device as usual.

Emergency Area Light

The light can be used in any low light situation as necessary for the user. A switch is located on top of the light. Make sure that the light is kept off when not in use. Leaving the light on will slowly drain the battery.

12 Volt DC Portable Power Supply

This portable power source is also for use with all 12 volt DC accessories equipped with a male accessory outlet plug and are rated up to 5 amps.

1. Lift up the cover of the unit‘s 12 volt DC outlet.
2. Insert the 12 volt DC plug from the appliance into the 12 volt accessory outlet on the unit. DO NOT EXCEED A 5 AMP LOAD.
3. Switch on the appliance and operate as usual.
4. Periodically press the battery charge level pushbutton to check battery status.

Part Descriptions

On-Off Knob – This part is part of the front panel. It is used to turn the system on and off. It allows the user to turn the system on and off by rotating the knob ninety degrees. This part must be able to withstand the wear and tear of being turned at least twice every time the device is used. It essentially serves as a protective cover for the on off switch.

Fig. 1 – On/Off Knob

Manufacturing Technique- This part was created using injection molding. Plastic testing was performed in order to determine the type of material. When a soldering iron was pressed to the material it softened. When a piece was placed in water it sank. A sample was burned. It continued to burn and dripped. It produced a blue flame with yellow edges, black smoke and soot. It burned slow and smelled acrid. This means it is made of Acrylonitrile Butadiene Styrene. Injection molding was chosen because it is easy to perform when mass producing the device. It allows for a quick production with low production cost.

On-Off Back Piece – This part is the intermediate part for the on off knob. The on-off knob snaps onto this piece so that it can be articulated. It serves as a connecting piece between the knob and the shaft.

Fig. 2 – On/Off Backpiece

Manufacturing Technique – This piece was injection molded. A plastic test was performed to determine the material type. It softened when a soldering iron was pressed to it. When it was placed in water it sank. A sample was then burned. The sample self-extinguished. The test results show that it is made of polyphenylene ether. This production technique was selected because it allowed for the part to be made fast and cheaply.

Main Body 1 – This piece is one of two pieces for the housing of the on-off switch. It has a central hole where the on off switch goes through and also has 4 fastener holes. These holes are for fasteners, which secure the two housing pieces together to keep the on off switch together.

Fig. 3 – Main Body 1

Manufacturing Technique- This piece was created by injection molding. Plastic testing was conducted to determine the material type. When a soldering iron was applied to the material it softens. When a sample was placed in water it sank. When an attempt was made to burn the sample it self-extinguished. These results mean it was made out of polyphenylene ether. This piece was created by injection molding because it allows for the piece to be made quickly and efficiently.

Main Body Two – This piece is an intermediate piece for the body of the on off switch. It is the second part to the housing of the on off switch. It has a center hole where the switch shaft goes through, along with two mounting screws which mount to the housing of the main device. It also has four fastener holes.

Fig. 4 – Main Body 2

Manufacturing Technique – This part was made by injection molding. Plastic testing was performed to determine the material type. It softened when a soldering iron was pressed against it. When placed in water it sank. When the sample was burned it burned self-extinguished. These results show it is made from polyphenylene ether. Injection molding was used because it is fast and precise enough for the application. The two mounting screw holes were drilled.

Main Body Back Plate – This part is the back plate to the main body housing. It has a bubble where the switch shaft fits along with four bubbles where the fasteners attach. This allows for the screws that go through the main body one and two to fasten the entire housing together.

Fig. 5 – Main Body Back Plate

Manufacturing Technique – Injection molding was used to produce this part. Plastic identification tests were conducted to determine what the part was made of. When a soldering iron was placed on it, it melted. When placed in water, the sample sank. When burned, it did not melt and self-extinguished. This means the part was made out of polyphenylene ether. Injection molding was selected because it allows for the part to be produced fast and for a low price. The holes for the fasteners were drilled.

Switch Shaft – The switch shaft is the part that the On-Off knob articulates. It turns within the main body housing and turns on the system. It is housed within the main body and has two different springs that go around the shaft. It has a large head on it, which pins the large spring between the metal plate and the shaft. It also has a step-down on the shaft where the small spring is held.

Fig. 6 – Switch Shaft

Manufacturing Technique – This part is turned on a lathe. It is made of steel. The tolerances on this piece do not need to be incredibly accurate because all of the fits associated with it are not incredibly exact.

Small Spring – This is the small spring used in the on off switch button. It adds resistance when the button is pushed. The coil must be large enough to fit around the step down on the switch shaft but small enough so it does not interfere with the large spring.

Fig. 7 – Small Spring

Manufacturing Techniques – the wire stock is drawn into rods and then the spring is formed through mechanical deformation of the wire. It was determined that the spring is made from steel.

Large Spring – The Large spring goes around the entire switch shaft. It adds a restoring force to on off knob. It must be large enough to not interfere with the small spring while also not interfering with the main body housing.

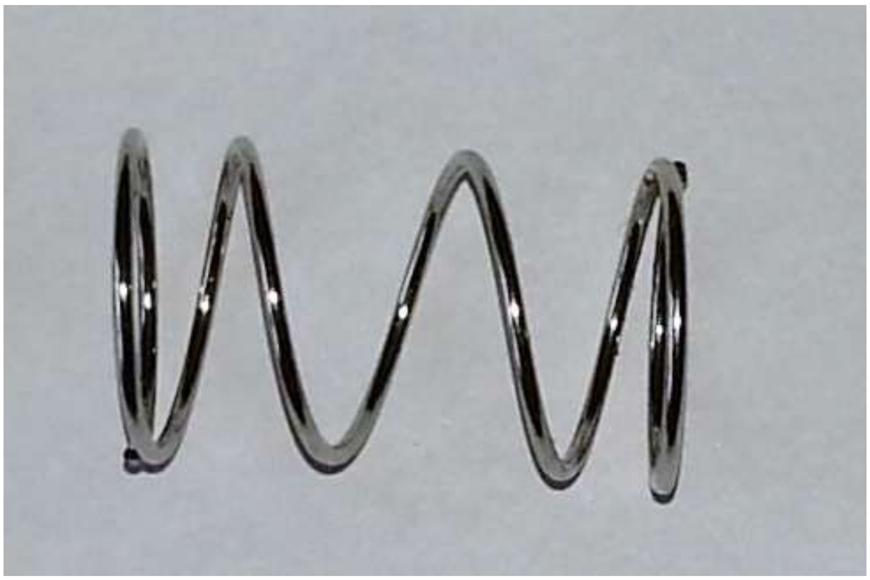


Fig. 8 – Large Spring

Manufacturing Techniques - This spring was created by first drawing wire stock. Once the wire stock is created it is mechanically deformed by feeding it through a machine, which bends the spring and cuts it to the appropriate length. It was determined that the spring is made of steel.

Metal Plate – This piece is a metal plate with a hole in the center of the plate. The switch shaft's lower end goes through this hole and is secured on the other side with a clip. The hole also has a lip on it to account for the step up in the switch shaft. This shaft serves as a place for the springs to apply their force in order to move the switch.

Fig. 9 – Metal Plate

Manufacturing Techniques – This plate was punched out of sheet metal. It was determined that the plate is made out of steel. The center hole was also punched out. Some grinding was also necessary to produce this part once it was punched.

Hold in Knob – This piece is part of the On/Off Switch Knob assembly. It interacts with the shaft.

Fig. 10 – Hold in Knob

Manufacturing Technique – This part was created using injection molding. This technique was selected because when mass producing the parts, it was cheap and efficient. The material type was determined using a plastic identification test. When a soldering iron was pressed to the sample it melted. When the sample was placed in water it sank. When the sample was burned it produced a blue flame with yellow edges and a smell similar to acrid. It burned fast and also melted. Using these results along with the plastic identification chart it was determined to be made out of Acrylonitrile Butadiene Styrene.

C-Clip – This clip serves as a fastener for the switch shaft. The shaft is threaded through the two springs for the on off knob and then through the metal plate. The c clip is then placed around the switch shaft on the other side of the metal plate. It must be able to fit around the switch shaft and remain in place.

Fig. 11 – C-Clip

Manufacturing Technique – This clip was produced by stamping it out of sheet metal. The clip was made out of metal. It was identified to be steel because the metal was ferrous.

On-Off Knob Back Plates – These back plates serve as supports for the on off switch assembly. There are two plates, which mirror each other. They hold everything in place including the housing. They provide the rigid structure necessary to keep the assembly in place when the knob is being turned.

Fig. 12 – On/Off Knob Back Plates

Manufacturing Technique – These plates are punched out of sheet metal. This method was selected because it is cheap and accurate enough. The holes were also punched out of the blanks punched from sheet metal. It was determined that the plates were produced from steel.

Back Plate Spacers – These spacers attach to the back plates and ensure the housing and plates are spaced properly. These pieces are important because they insure the spacing is proper which affects the operation of the springs for the on-off knob. Therefore proper size is necessary.

Fig. 13 – Back Plate Spacer

Manufacturing Technique – These spacers are made of an unknown composite. When a plastic identification test was performed, an outside layer burned exposing some form of matrix. This shows that it is made of some form of composite.

Front Plate – The front plate serves as the housing for all the interfaces for the device. It houses the lights, buttons, and inputs for the device. The indicators include a light to show the USB port is on, a light to display if the polarity of the battery is reversed, and three lights on the front to display the charge status of the battery; two are red for low to medium and one is green to signify a high charge. There are two buttons; one to use when assessing the battery status and one to power the USB port. Lastly there is the large On-Off knob and a cover for the USB port and DC outlet.

Fig. 14 – Front Plate

Manufacturing Technique – The front plate was created using injection molding. Plastic testing was done in order to determine the material the part was made of. When a soldering iron was pressed to the sample it melted. When it was placed in water it sank. A sample was burned which dripped and produced blue flames with yellow edges. It produced a smell similar to acrid. It also produced black smoke and soot. These results were used with the plastic identification chart to determine that it was made from Acrylonitrile Butadiene Styrene. This manufacturing technique was selected because it allows for fast and efficient manufacturing when being mass produced.

DC Outlet Shaft – This part is what supplies an external device with power. It serves as part of the connection between the device's battery and the external device. It must be able to conduct an electrical current between the battery and the external device. It must also be the right size so that a standard DC outlet plug will fit in it. It has two prongs on it. One of these prongs has a ground connected to it, which is why it must be able to carry a current. Soldered onto the one prongs is a wire, which serves as the ground.

Fig. 15 – DC Outlet Shaft

Manufacturing Technique – This shaft was created by first stamping a template out of thin sheet metal. The template was then rolled using mechanical deformations to form its cylindrical shape. Lastly the two prongs were then mechanically deformed radially outward. It was determined that the shaft is made out of steel.

DC Outlet Back – This part is what connects the DC outlet to the battery through the circuit board. This part is where the current runs through to connect to the DC outlet to be battery. It must be able to handle any current a user apples to it so that the device does not cause an electrical fire. It is composed of a resin material with a metal plate on it, which comes in contact with the DC cable. The plate has four holes in it so it can be mounted within the device.

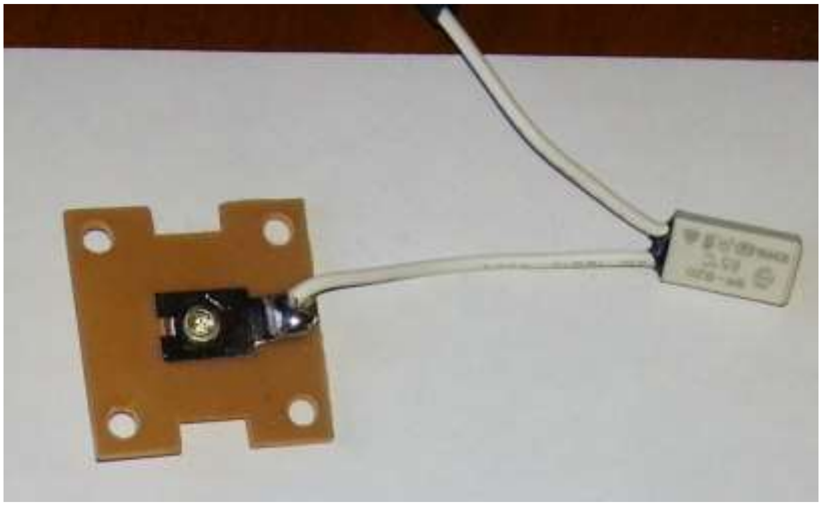


Fig. 16 – DC Outlet Back

Manufacturing Technique – This part has numerous materials. The first is the circuit board. It was determined that it is made of a resin that was insulated. The second part is the actual connection that the DC cable connects to. It was determined to be made out of steel and was stamped from sheet metal.

DC/USB Cover – This part is required to protect the DC and USB outlets on the device.   It has one end that snaps into place over the DC and USB outlets and the other end has a tab, which remains within the device so that the cover stays attached to the device when it is removed from the outlets.

Fig. 17 – DC/USB Cover

Manufacturing Technique – This part was created using injection molding. It allowed for the part to be mass produced cheaply and efficiently. Plastic identification was performed to determine the material type of the part. When a soldering iron was pressed to the material it melted. When a sample was placed in water it sank. The sample was then burned. When it was burned it continued to burn when the flame was removed and dripped. It produced blue flames with yellow edges, smelled acrid, and black smoke with soot. These results mean the part was made from Acrylonitrile Butadiene Styrene.

Button – This button is for checking the battery charge. It uses the spring's restorative force in order to push outward again once a user has depressed it. On the inside of the button it has a hole which the spring must be able to fit into. The tolerance on this hole does not need to be very exact because the rubber can be easily deformed to fit the spring inside it.

Fig. 18 – Button

Manufacturing Technique – This part was created using injection molding. This method was used because it allows for many of the parts to be quickly and cheaply made when mass producing this product. A plastic identification test was performed to determine what type of material the part was made from. A soldering iron was placed to the sample and it caused it to soften. When a sample was placed in water it sank. When the sample was burned it continued to burn and dripped. It produced a blue flame with yellow edges, smelled acrid, and made black smoke with soot. It was determined that the part is made from Acrylonitrile Butadiene Styrene.

Button Spring – This spring fits within the battery check button. It supplies the restorative force to allow the button to return once it has been pushed in.

Fig. 19 – Button Spring

Manufacturing Technique – This spring is created by first drawing wire. Once a straight wire is drawn it can then be mechanically deformed by running it through a device, which bends the wire into its final shape of a spring. The device then cuts the wire then it has been deformed to the correct length.

USB Button – This button is what allows for the USB outlet to be used. It has the main button portion along with a shaft that is connected to it. When the button is depressed then shaft then comes in contact with the circuit board and it causes the device to light up the LEDs on the front to display the battery power.

Fig. 20 – USB Button

Manufacturing Technique – This part was created using injection molding. This technique was selected because it is fast and efficient. Plastic identification test were performed to determine the material the part was made with. A soldering iron placed on the material caused it to melt. When the sample was placed in water it sank. When it was burned it continued to burn when the flame was removed and also melted. It produced black smoke with soot, a smell similar to acrid, and a blue flame. These results mean the part was made of Acrylonitrile Butadiene Styrene.

Pressure Gauge Housing – This part surrounds the pressure gauge on the device. It must protect the gauge form the wear and tear the device experiences. It has two ports on the back for the gauge and also has two mounting screw holes. It must be able to also fit the gauge front plate for the gauge.

Fig. 21 – Pressure Gauge Housing

Manufacturing Technique – This part was created using injection molding. This technique was used because it allows for easy mass production of the part. Tests were performed to determine the type of material the part was made from. When a soldering iron was placed on the part it softened. When a sample was placed in water it sank. When the material was burned with a flame it continued to burn, dripped, and produced a blue flame with yellow edges. It also produced a smell similar to acrid and black smoke with soot. It was determined that the part was created from Acrylonitrile Butadiene Styrene.

Pressure Gauge – The pressure gage is one of the fundamental parts of the device. It allows for the user to see what the pressure is in the container that is being filled. It has a needle that rotates around the center of the face. It gives a read out of the pressure in both PSI and Bars. The Bar scale goes from zero to 8.2 Bars. The PSI scale goes from zero to 120 PSI. The gauge functions by allowing the gas in question to fill a tube. This tube then deforms after being filled and rotates a small gear. This gear is connected to the pin on the face of the gauge and this rotation gives the pressure reading.

Fig. 22 – Pressure Gauge

Manufacturing Technique – Due to the complexity of the gauge it was determined that the gauge would be purchased from a retailer. This is because the coil, which deforms within the gauge, would require calibration and it would cost less to purchase the gauge instead of buying the raw materials and making it.

Gauge Front Plate – This plate serves to protect the pressure gauge. It is there to ensure the needle is not damaged in anyway. It must be translucent so that the needle and scales can be viewed. It must also fit within the housing. It must also be able to withstand the abuse that the device will receive over its lifetime without cracking or breaking.

Fig. 23 – Gauge Front Plate

Manufacturing Technique – This part is created using injection molding. When using the plastic identification test the sample burned instantly and produced large tape like strands when dripping. It is believed to be made of cellophane.

Compressor Top – This is the portion of the compressor that connects to the hoses. It has a valve that allows for air to enter the compressor chamber when the piston pulls backwards. It connect to the compressor body. It also has fins on it in order to dissipate heat. This is because when the compressor is compressing air the process generates heat. Fins were put on this part in order to increase heat dissipation. It also contains a seal to interface with the compressor body.

Fig. 24 – Compressor Top

Manufacturing Technique – injection molding was used to create the main portion of this part. This was determined by inspecting the piece and the remaining excess material can be seen. This is typical of a piece that was molded.   The remaining accessory parts were then attached to the part. It was determined that this part was made of steel because it is ferrous.

Compressor Body – This is the portion of the compressor that holds the air. It must be able to withstand the pressure generated by the compressor without failing. It connects the housing for the motor and the compressor top. It has chamfered ends to increase the quality of the seal with the compressor top and housing.

Fig. 25 – Compressor Body

Manufacturing Technique – This part was cut from a stock hollow tube. This method was selected because it was better to just buy the stock tube than to invest in machines to extrude the raw material necessary to create the part. The ends of the cylinder were chamfered in order to ensure there was a better seal with the housing and compressor top.

Piston Shaft – This part is what connects the piston for the compressor to the compressor shaft. It is what transfers the energy from the motor to the piston in order to compress the air. It must be able to withstand the forces from the motor without failing. On either end it has a hole to connect to the compressor shaft and the piston. All edges of the shaft have been chamfered.

Fig. 26 –Piston Shaft

Manufacturing Technique – This part was manufactured out of steel. The manufacture started with raw material and removed material until it met the required specifications. It was determined that the part was made out of steel by seeing if the part was ferrous.

Piston – This is the part of the compressor that compresses the air. It is a cylindrical piece with an end cap on it. This end cap secures a seal on the end of the piston. This seal is necessary to ensure the volume of the compressor body is sealed. It slides back and forth within the compressor body.

Fig. 27 – Piston

Manufacturing Technique – This part was created through the use of casting. The seal and ring were then placed onto the end of the piston. It was determined that the part was made of steel because the part is ferrous.

Piston Pin – This is a pin that goes through the Piston and piston shaft. It kept the piston engaged with the piston shaft. It serves as a fastener. There is no picture of the pin because it was destroyed while disassembling the device.

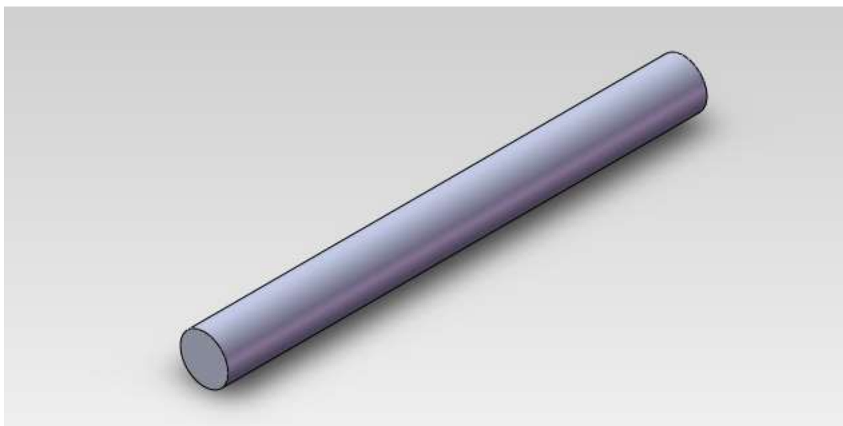


Fig. 28 – CAD rendition of the piston pin (original was destroyed during disassembly)

Manufacturing Technique – This pin was created from bar stock. It was determined that the pin was made of steel because it was ferrous.

Rubber Spacers – These spacers went around the screws that secured the compressor within the main housing of the device. Their main purpose was to act as a washer for the screws and to dampen the vibrations created by the compressor when it compresses air.

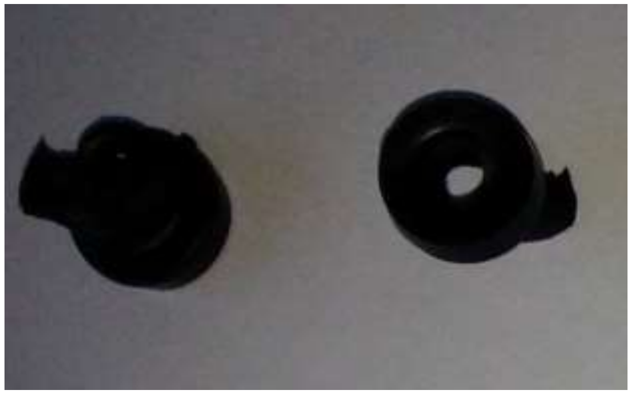


Fig. 29 – Rubber spacers

Manufacturing Technique – These spacers were created using injection molding. This method was used because it is fast and cheap when mass producing a product. A plastic identification test was performed to determine the material type. When a soldering iron was placed on the sample it melted. When the sample was placed in water it sank. The sample was burned which produced a smell similar to acrin. It also produced a blue flame and melted as it burned. It was determined that the parts were made out of Acrylonitrile Butadiene Styrene.

Compressor Shaft – The compressor shaft is what the motor spun in order to move the piston. It has a cam to give the shaft rotational momentum when spinning. The piston shaft connects to a pin at the end of the cam. It allows the piston shaft to convert the radial motion into linear motion in the compressor body.

Fig. 30 – Compressor Shaft

Manufacturing Technique – To make the compressor shaft a blank is first cast for the cam. A shaft was machined to give the correct diameters and then pressed into the counterweight and. This method is selected because it ensures the shaft will have the necessary strength. The different diameters in the shaft must then be created. The different diameters are created on the part by turning it in a lathe.

Compressor Housing – This part is what connects the compressor to the motor. It has multiple mounting spots. It has mounting for the motor to connect to the housing. It also has mounting to connect the compressor body and top to it. There is a brass bushing that is likely oil impregnated to provide lubrication for the shaft. Lastly it has mounting to connect the housing of the compressor to the overall housing of the device. The compressor shaft goes through this part to connect the motor and the piston shaft.

Fig. 31 – Compressor Housing

Manufacturing Technique – This part was created using casting. If the part were to be manufactured from a blank it would take significant time and would cost a lot of money. Therefore some of the accuracy that would come with machining is sacrificed for the simplicity of injection molding. It was determined that the part as made of low quality steel because the material was ferrous.

Motor Gear – This gear is used to convert the power from the motor to the compressor shaft. It is used in order to increase the torque to the shaft. This is because the gear has a large radius and torque is the product of the force and distance. By using a larger radius gear it increases the distance, which in turn increases the torque.

Fig. 32 – Motor Gear

Manufacturing Technique – This part is created using injection molding. This method was selected because it is cheap and efficient when mass producing parts. It was determined that the part was made from Acrylonitrile Butadiene Styrene.

C – Clip – This part holds the Motor gear onto the compressor shaft.

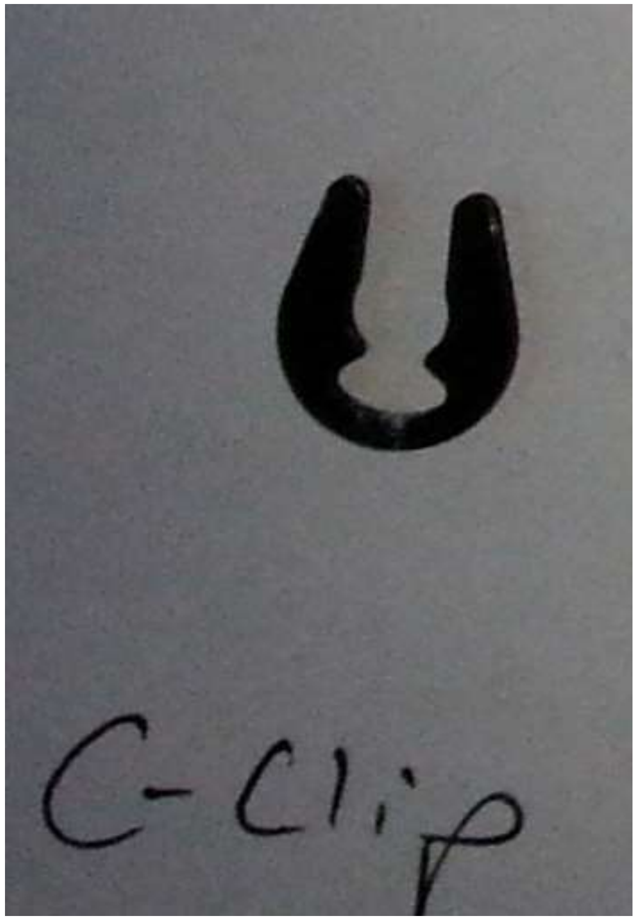


Fig. 33 – C-Clip

Manufacturing Technique – This clip was produced by stamping it out of sheet metal. These metal clips were made of steel. This was determined by applying a magnet to the part.

Motor – The motor is what supplies the mechanical work for the compressor. The mechanical work turns the crank shaft which moves the piston. This mechanical work is then used to compress the air with the piston. The motor operates at 12 V with a maximum output power of 350 W. It provides the capabilities to fill an 18 L tire from 0-120 psi in just 15 minutes.

Fig. 34 – 12V 350W motor (photo source: http://www.alibaba.com/product-gs/297286809/Brush_12V_DC_Motor_60ZY_/showimage.html)

Manufacturing Technique – The motor will be purchased from a retailer.

Thermal Protector – The thermal protector used in the system in an EngFee C17AM thermal protector design to prevent the motor from overheating. The device is rated for operating temperatures between 65°C and 160°C. For the purpose of this application, the thermal protector will be used to keep the motor below its safe operating temperature of 140°C.

Fig. 35 – EngFee C17AM thermal protector

Manufacturing Technique – The motor will be purchased from a retailer.

Heat Sink – The heat sink is designed to increase the surface area of the motor into order to increase the cooling efficiency due to free convection and radiation. The heat sink is permanently fixed to the shell of the motor and wraps around 180° and has 40 small fins spanning the length

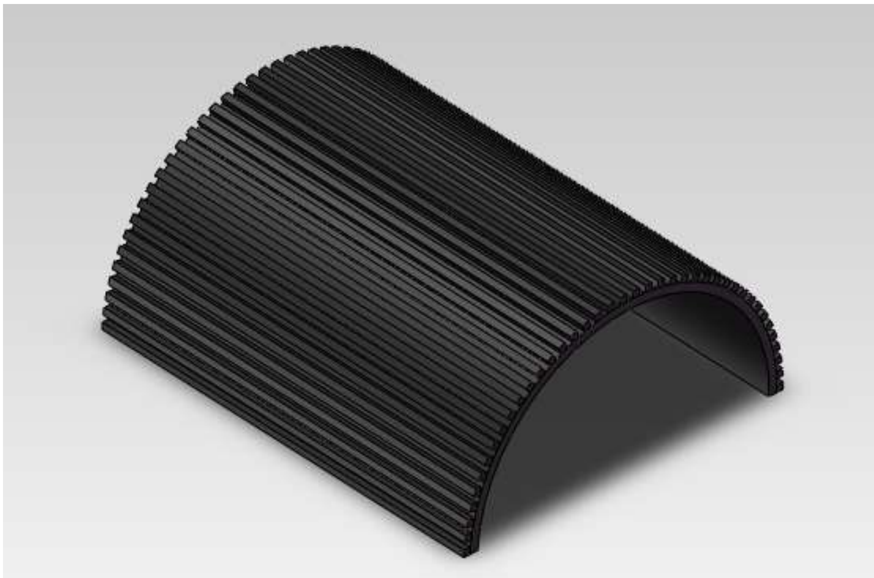


Fig. 36 – CAD rendition of the heat sink

Manufacturing Technique – The heat sink is made from iron and manufactured via casting. Casting is a very commonly used technique for products made of iron as it is quick and produces accurate results.

Motor Spacer – This spacer was used in the securing of the motor and compressor to the housing of the device. It ensured the spacing of the motor was accurate within the housing.

Fig. 37 – Motor Spacer

Manufacturing Technique – This part was created using injection molding. This method was selected because it can be done quickly and due to the parts irregular shape. The material used for this part was found by using the plastic identification chart. When a soldering iron was placed on the material it melted. The sample sank in water. When the sample was burned it produced a blue flame and smelled like acrin. When burning it was observed that the sample melted. These results show that the part is made of Acrylonitrile Butadiene Styrene.

Grip – This part has two different layers. The first layer is the internal portion. It is rigid and provides structural integrity for the part. The second part is the external grip portion. It is pliable and provides grip for the handle. The combination of the two materials allows for the grip to both be sturdy while also providing a good gripping surface.

Fig. 38 – Grip

Manufacturing Technique – The internal portion of the grip was created using injection molding. It was determined that this portion was made of Acrylonitrile Butadiene Styrene. This was found by conducting a plastic identification test. When the sample came in contact with a soldering iron it softened. When the sample was placed in water it sank. The sample was burned and produced a blue flame and smelled like acrid. The sample also dripped and produced black smoke and soot. The external portion was cut from a sheet of rubber. Once the correct shape was cut out it was then glued on the outside of the internal rigid part.

Corner Bumpers – These parts serve to protect the metal frame of the handle. They serve no functional purpose except to prevent the metal handle frame from being damaged.

Fig. 39 – Corner Bumpers

Manufacturing Technique – These parts were created using injection molding. Plastic identification test were performed to find out what type of material the bumpers were made of. When a soldering iron was placed on the material it softened. When a sample was placed in water it sank. The sample was then burned and continued to burn when the heat source was removed. It produced a blue flame with yellow edges and a smell like acrid. When the sample was burned it also dripped and produced black smoke with soot. These results meant the parts were made of Acrylonitrile Butadiene Styrene.

Handle Brackets – These brackets served as structural supports within the handle. They are rigid bars that are within the handle. The ends were chamfered in order to remove any rough edges.

Fig. 40 – Handle Brackets

Manufacturing Technique – These parts were cut from bar stock. The edges of them were then chamfered to round the edges. It was determined that the brackets were made of steel because they were ferrous.

AC Outlet Cover – This part serves to protect the AC cable. This is because the cable has to be on the outside of the device and therefore runs the risk of getting damaged. If the cable gets damaged then the device will no longer be able to function. Therefore a cover was produced to increase the life of the device. It is fastened to the device by a screw and can be pulled off.

Fig. 41 – AC Outlet Cover

Manufacturing Technique – This part was created using injection molding. This method was used due to the irregular shape of the part. The plastic identification chart was used to determine what material this part was made from. When a soldering iron was placed on it the part melted.   The part sank when placed in water. The part self-extinguished when burned. It was determined that the part was made of PVC.

Compressor On/Off Switch – This is the switch that turns the compressor on and off. It is a simple toggle switch that completes the circuit for the power to the compressor when toggled on. It is mounted so it can be used on the outside of the device.

Fig. 42 – Compressor On/OFF Switch

Manufacturing Technique – This part is purchased from a manufacturer. No manufacturing is necessary for the part.

On/Off Spacer – This part is used to position the On/Off switch within the housing. It ensures the spacing of the switch is correct so it fits in the housing properly.

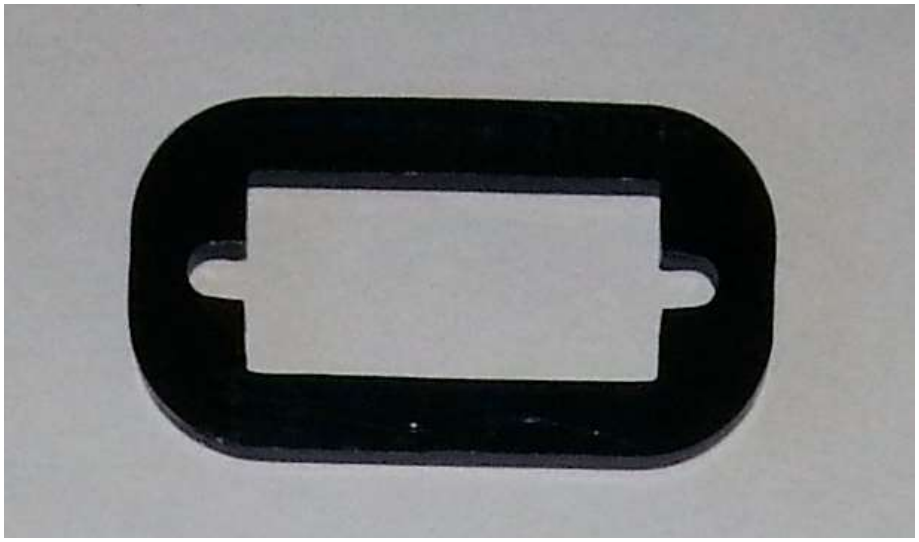


Fig. 43 – On/Off Spacer

Manufacturing Technique – This part was created using injection molding. This method was selected because it is a fast and efficient process. Plastic identification test were done to determine the material the part was made from. When a soldering iron was placed on the sample the material softened. When the sample was placed in water it sank. When the sample was burned it self-extinguished, and did not melt or drip. It was determined that the part was made of polysulfone.

Main Wire Tie Downs – These parts are used on the inside of the housing for the device. This ensures the wires being used by the compressor and circuit board are in the proper position. This is important because when assembling the device if they are not positioned correctly a screw could sever a wire accidently.

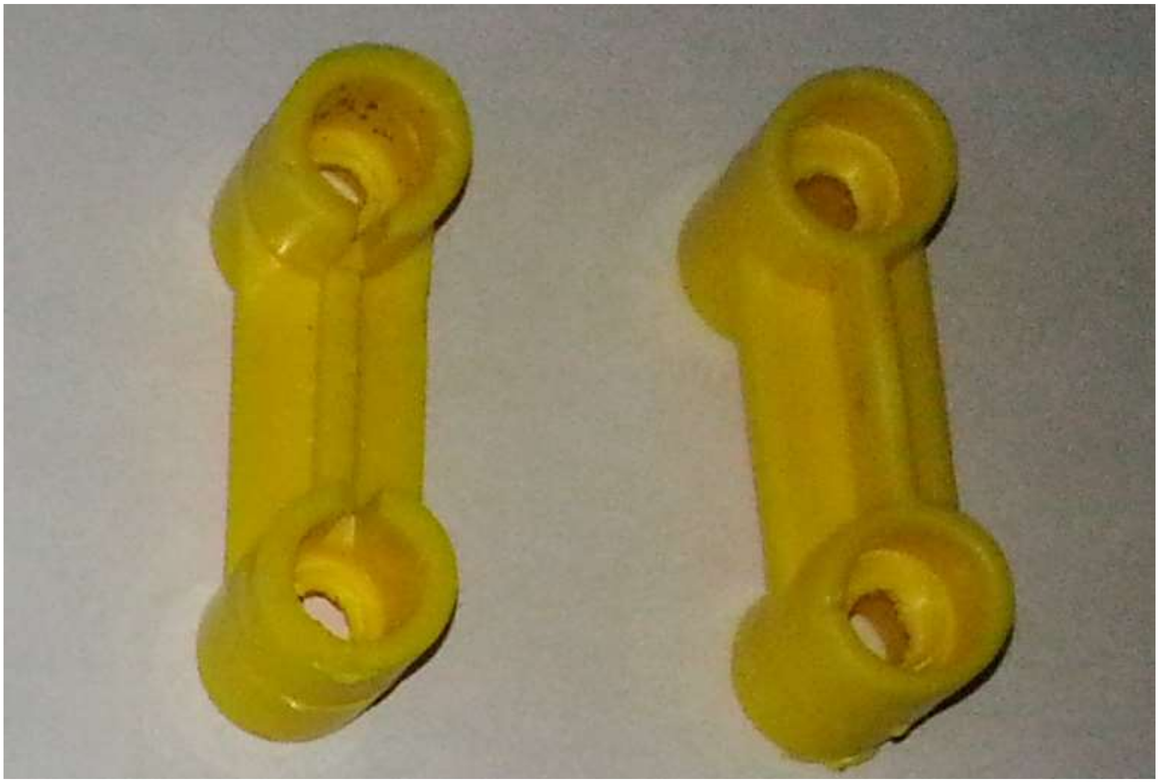


Fig. 44 – Main Wire Tie Downs

Manufacturing Technique – These parts were created using injection molding. This is because it is being mass produced and has an irregular shape. Plastic testing was also performed to determine the material type. When the material was touched with a soldering iron it softened. When the sample was put in water it sank. When the sample was burned it continued to burn and dripped. The burning also produced a blue flame, smelled like acrid, and made black smoke with soot. It was determined that it was created using Acrylonitrile Butadiene Styrene.

On/Off Wire Tie Down – This part is used to position the wires for the compressors' On/Off switch. This is used to make sure the wires do not move within the housing, which could cause problems when assembling the device.

Fig. 45 – On/Off Wire Tie Down

Manufacturing Technique – This part was created using injection molding. This is done because it needs to be mass produced and it has an irregular shape. The material type was determined by the use of plastic identification test. When a soldering iron was pressed to the material it melted. When the material was placed in water it sank. When the material was burned it created blue flames and smelled like acrid. It also continued to burn and dripped when the heat source was removed. It was determined that the part is made of Acrylonitrile Butadiene Styrene.

Pressure Gauge Bracket – The purpose of the bracket is to secure the pressure gauge to the housing. The part must be strong enough to ensure the pressure gauge does not move. It has two holes were the bracket mounts to the housing and a slot where the pressure gauge fits in.

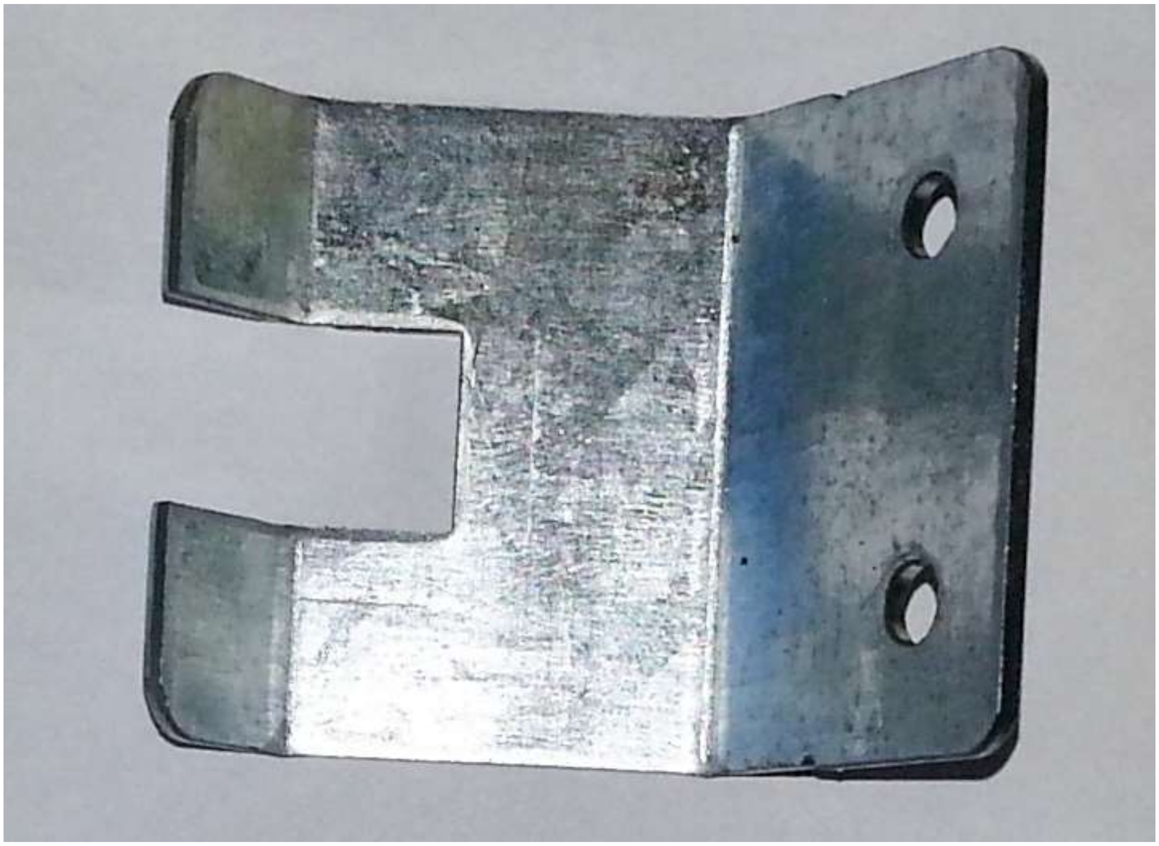


Fig. 46 – Pressure Gauge Bracket

Manufacturing Technique – This part was created by first stamping a blank from sheet metal. It is then mechanically deformed. One end of the blank is bent to the desired angle. Lastly the two holes are drilled so it can be mounted to the housing. It was determined that the bracket was made of steel. This is because the material is ferrous.

Motor Bracket – This bracket is used in order to secure the motor to the housing. It has one space in the bracket to make room for the wires that run to the motor.

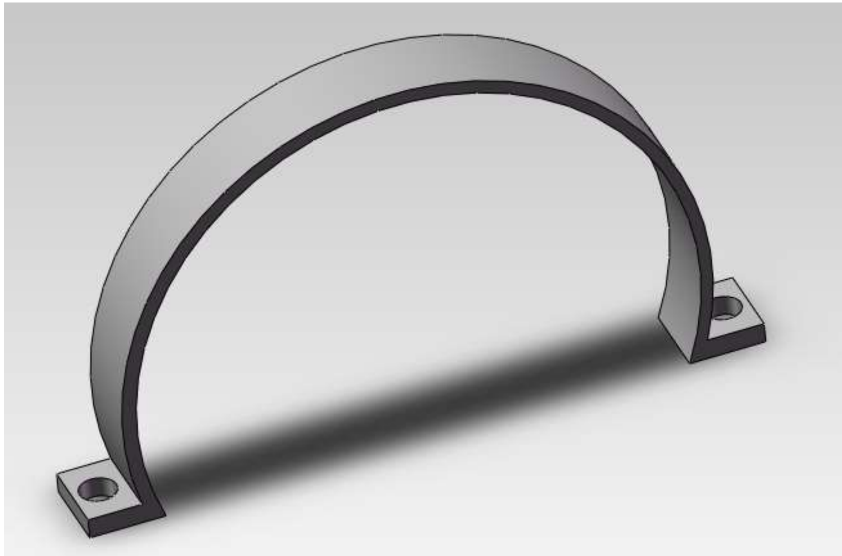


Fig. 47 – Motor Bracket

Manufacturing Technique – This part was created by first stamping a blank from sheet metal. It was then mechanically deformed into the arced shape it has. Lastly holes were drilled through the two ends to provide the mounting holes for the housing. It was determined that the part is steel because the material is ferrous.

AC Module Bracket – This mount is used in order to secure the AC module. It mounts to the housing to ensure the AC module does not move.

Fig. 48 – AC Module Bracket

Manufacturing Technique – This part is created by first stamping a blank from a piece of sheet metal. A machine then mechanically deforms the part into its proper shape. Lastly the two mounting holes are drilled into the part. It was determined that the bracket was made of steel because it is ferrous.

Valve Hose – This is the hose that connects the compressor to the external valve. It must be able to withstand any pressure created by the compressor without failing.

Fig. 49 – Valve Hose

Manufacturing Technique – This hose will be purchased from a retailer. The hose is made of rubber.

Valve – This is the part that interfaces with the actual part being filled. It creates the seal around the valve. It must be able to withstand any pressure output by the compressor. It connects to the valve base.

Fig. 50 – Valve

Manufacturing Technique – This part is created by the technique of injection molding. This process was used because it allows for the part to be quickly produced. This is important when mass producing a product. The material the valve was made with was determined using plastic identification tests. When a soldering iron was placed on the material it softened. When the sample was placed in water it sank. When the sample was burned it continued to burn and dripped. It was determined that the part was made of Acrylonitrile Butadiene Styrene.

Valve Housing – This is the external part that goes around the valve. It serves to protect the housing and also lines up the valve with the container opening it is filling. It also works with the valve lever to create the seal for the valve.

Fig. 51 – Valve Housing

Manufacturing Technique – This part was created using injection molding. This process was used because the part has an irregular shape and needs to be mass produced. It was determined that the part is made of Acrylonitrile Butadiene Styrene. This was determined using the plastic identification chart. When the material was touched with a soldering iron it melted. When a sample was placed in water it sank. When the sample was burned with a heat source it continued to burn and dripped.

Valve Lever – This part is used in order to create a seal for the valve. When the lever is flipped up it pushes the valve into the opening of the container being filled which creates a seal. The two pins that extend out of the part must be strong enough so that they will not break when the lever is being used.

Fig. 52 – Valve Lever

Manufacturing Technique – This part was created using Injection molding. This process was selected because it allows for the part to be produced quickly even though it has an irregular shape.   In order to identify this plastic the plastic identification chart was used. When the material was touched with a soldering iron it softened. When a sample was placed in water it sank. When the sample was burned it continued to burn, produced black smoke, and dripped. It was determined that the part is made of Acrylonitrile Butadiene Styrene.

Gauge Hose – This hose runs between the compressor and the pressure gauge. It must be able to withstand the pressure that the compressor produces.

Fig. 53 – Gauge Hose

Manufacturing Technique – This part was purchased from a retailer. It was determined that the part was made of rubber.

Hose Clamping Springs – These three springs were used to clamp the hoses to their respective connections. The two smaller ones were used on either end of the gauge hose. The third larger one is for the connection of the hose to the compressor.

Fig. 54 – Hose Clamping Springs

Manufacturing Technique - These springs were created by using drawn wire. The wire is then fed through a machine that mechanically deforms the wire into the spring shape. It was determined that the springs were made of steel.

Valve Base – This part connect to the bottom of the valve. It locks the valve hose onto the valve. This made a spring unnecessary at this connection. It must be able to keep the hose on the valve when the compressor is producing pressure

Fig. 55 – Valve Base

Manufacturing Technique – This part was purchased from a retailer

Clamp Handle – This part is used in order to form the clamp, which connects to the battery. The handle must be strong enough to withstand the force generated by the spring, which causes the clamp to close. It has three holes. Two are for the clamp to pivot around and the third is for a screw that secures the lead wire.

Fig. 56 – Clamp Handle

Manufacturing Technique – A blank is first stamped out of a piece of sheet metal. The groves on the back of the clam are then stamped into the part and the two holes that the grips pivot around are drilled. Lastly the sides of the clamps are then folded up to form the clamp and it is painted. The clamp is made of steel.

Clamp Insulator – This part is used to insulate the metal clamp from the lead that runs through the clamp. It must be able to stop the electrical current from running though the clamp. This stops the user from getting electrocuted.

Fig. 57 – Clamp Insulator

Manufacturing Technique – This part is created by the use of injection molding. It was determined that the part was made from polysulfone. This was found using a plastic identification chart. When a soldering iron was placed on the sample it melted. When it was put in water it sank. When the sample was burned with an external heat source it self extinguished. The flame produced by burning it was orange. It also smelled of sulfur.

Clamp Jaw – This part is what comes in direct contact with the battery terminal. It must be able to withstand the force generated by the spring in the clamp. It must also be able to connect to the wire that runs to the battery.

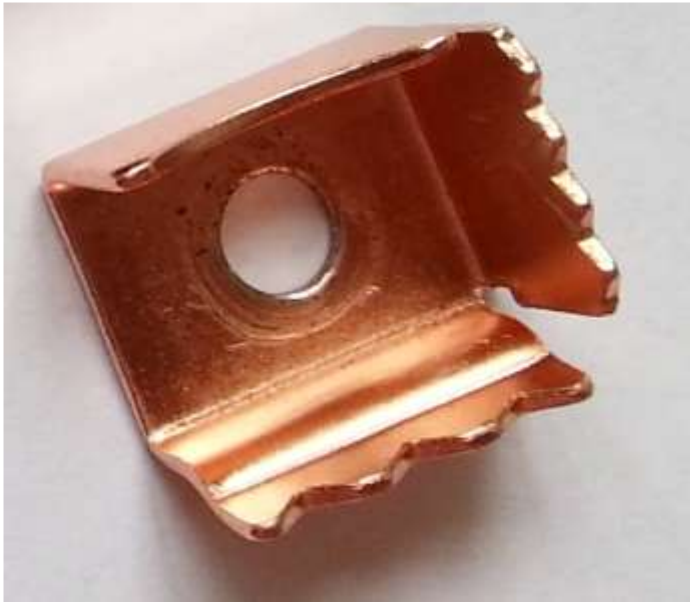


Fig. 58 – Clamp Jaw

Manufacturing Technique – This part was created by first stamping a blank out of sheet metal. The center hole for the screw is then drilled and the ends are then folded up into the correct shape. It was determined that the part was made of copper.

Clamp Spring – This part is what generates the closing force for the clamp. It must generate enough force so that the clamp will not easily fall off of the battery terminal.

Fig. 59 – Clamp Spring

Manufacturing Technique – This part was purchased from a retailer.

Metal Handle – This part is the main structural component of the carrying handle for the device. It carries all of the weight of the device when it is being carried. It must be strong enough so that the device does not deform the part when it is being carried.

Fig. 60 – Metal Handle

Manufacturing Technique – This part is created from hollow bar stock. The different holes in the part are then put in it through a combination of drilling and mechanical deformation. It was determined that the part is made of steel.

External Housing - This is the part that all of the other parts secure onto. It serves as a mounting surface for all other materials. It must be strong enough so it does not fail when dropped or when hit accidently.

Fig. 61 – External Housing

Fig. 62 – Inside of External Housing

Manufacturing Technique – This part was created using injection molding. This was selected because the part has a very unique shape. Plastic identification was done to determine the material type. When a soldering iron was pressed to the material it softened. When a sample was placed in water it floated. When burned it produced a smell similar to diesel fuel. It was determined the part was made from Polypropylene.

Motor/Compressor Shell – The motor/compressor shell houses the motor/compressor system and secures it to the main housing unit. Inside the shell there is a small cradle to help the motor stay in place when in operation. The shell also houses the pressure gauge and provides a cavity for the user to tuck away the fill hose.

Fig. 63 – CAD model of the motor/compressor shell

Manufacturing Technique – Like the rest of the housing unit, the motor/compressor shell is made by injection molding. Also like the main housing, the back shell is manufactured from Polypropylene.

Modular Battery Pack (Bottom) - The bottom section of the modular units function is to hold the addition 12V battery in the modular unit. Each corner of the plate contains a 0.196 in clearance hole to allow four 10-24 UNC bolts to fasten the bottom of the shell to the top. The cutout located in the center of the part is designed to snuggly fit the battery to ensure that it does not slide during operation and potentially causes damage the housing or the circuitry.

Fig. 64 – CAD model of the bottom part of the battery pack

Manufacturing Technique – The part is to be made via injection molding for rapid production at relatively low costs, as well as tight tolerances to ensure that any bottom taken from the production line will fit properly to any top.

Modular Battery Pack (Top) - The top section of the modular unit completes the housing that encases the new additional battery. The part was designed such that it seats comfortably over the battery and leaves room for the small 12V to 24V circuit and the needed wires. Located at each corner on the inner surface is a screw post tapped for a 10-24 UNC fastener in order to secure the top and bottom sections together. Protruding from the top of the part is an AC like plug wired to the battery that allows for the connection between the modular battery and the standard internal battery. Also located on the top of the part are two solid posts with notches cut out from the top that snap into the unit's bottom plate.

Fig. 65 –CAD model of the top part of the battery pack

Manufacturing Technique – For the same reasons as the bottom section, this part is to be made via injection molding. After molding, the four screw posts would need to be manually or mechanically tapped for a 10-24 UNC screw. The metal contacts, for the electrical outlet will be molded directly into the unit.

Modular Bottom Plate -The purpose of the bottom plate is to allow the modular batter pack to fit together with the main unit. The bottom plate secures to the main unit using four 10-24 UNC screws. Again, this part is made through an injection molding process. There are two posts on each side of the part in which the posts from the battery pack top piece fit. This part also houses two spring dependent push button that lock and release the posts from the battery pack. The part also contains a receptacle for the AC style plug on the battery pack. The receptacle is wired directly to the main unit's battery and enables it to be wired together with the modular battery.

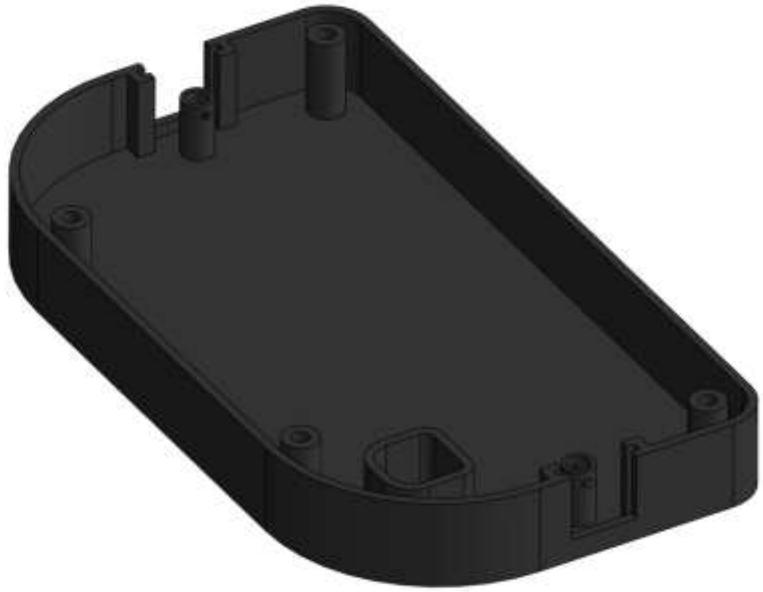


Fig. 66 – CAD model of the modular base plate that holds the battery pack to the main unit

Manufacturing Technique – Like with the others parts in the modular unit, the bottom plate with be manufactured via injection molding, with the metal electrical contact implanted directly into the mold.

Modular Push Buttons - The function of the push buttons are to provide a way for the modular battery pack to lock into the bottom plate. Small springs force the buttons outwards which allows the inner bars to snap into the cutouts located on the modular shell's pins. Like with the other parts, the push buttons are to be manufactured using injection molding.

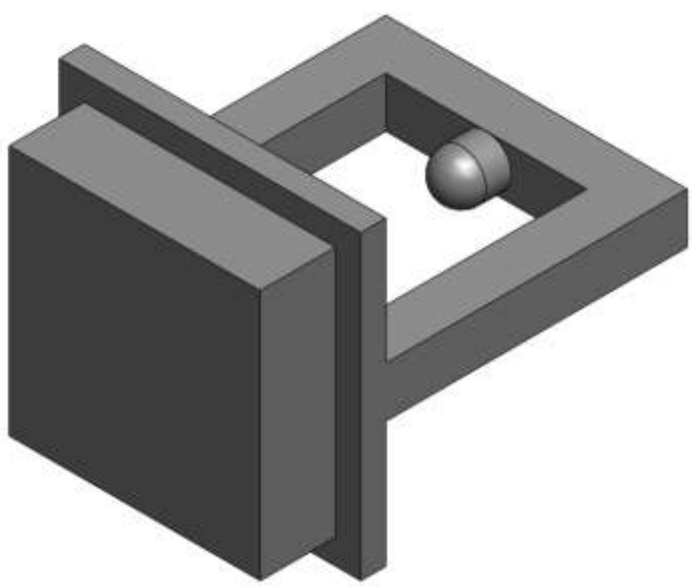


Fig. 67 – CAD model of the push buttons that hold the battery pack to the main unit

Manufacturing Technique – The push buttons will both be made from injection molded abs plastic.

Modular Button Mounts – The modular button mounts hold the plastic push buttons in place on the bottom piece of the unit.

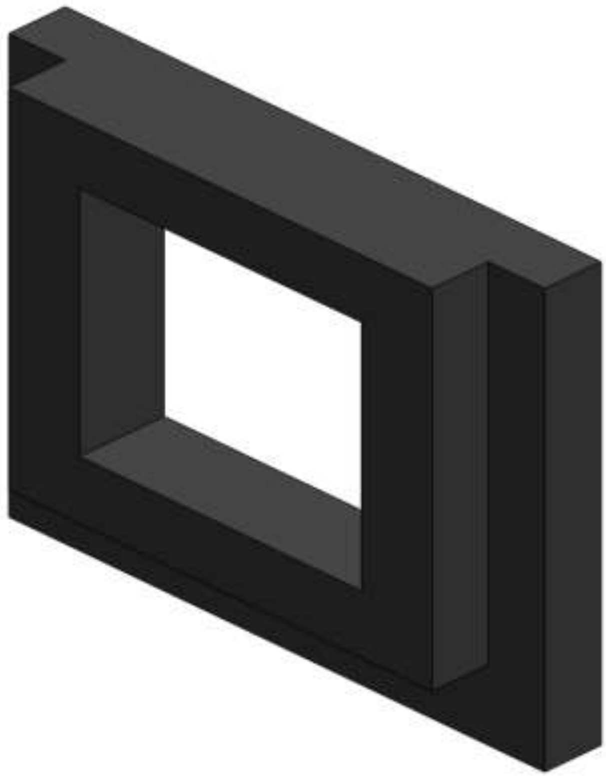


Fig. 68 – CAD model of the push button mounting plate

Manufacturing Technique – Like with the other modular unit parts, the button mounts were manufactured from abs plastic via injection molding.

Modular Button Springs - Each of the push buttons located on the bottom plate are attached to a small spring. The springs functions are to force the buttons outwards in order to allow the battery pack to lock into place. The user can then press the buttons, which compresses the springs and allows the battery pack to be removed from the main unit.

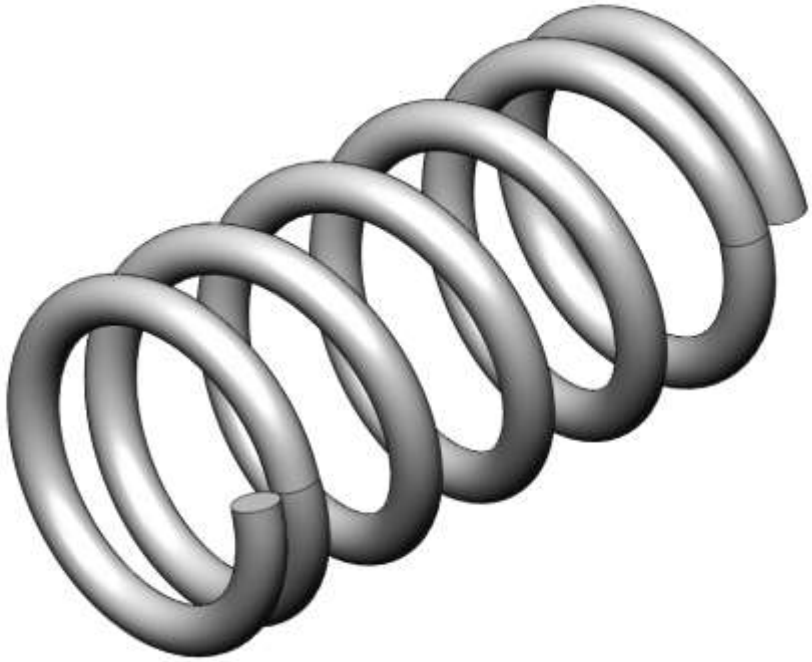


Fig. 69 – CAD model of the push button springs

Manufacturing Technique – The springs are made from standard spring steel and made by machine coiling wire stock and cutting it to length.

Modular Battery Circuit - The battery connection is wired to the circuit which provides the ability for the user to select whether the unit functions as 12 V or 24 V battery. The circuit switches the connection between the two batteries from parallel to series or visa-versa. When wired in series, the battery voltages add together allowing the user to operate in 24 V mode which is needed to jumpstart most large vehicles. When the batteries are connected in parallel, the voltage remains at 12 V, however, the amperage is doubled allowing the user to the ability to charge 12 V object for longer or jump more traditional car batteries. The circuit also contains a small relay that that opens when the board is set to 24 V to ensure that only 12 V makes it to the main circuit in order to prevent damage.

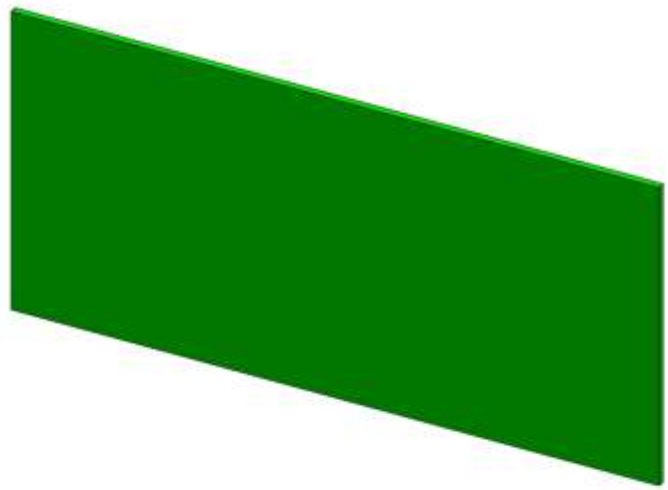


Fig. 70 – CAD model of the small modular circuit board

Manufacturing Technique – The circuit will be purchased by the manufacturing from some outside source.

Modular 12 V-24 V Switch - The small plastic switch on the front of the battery pack allows the user to easily set the unit to 12 V or 24 V mode.

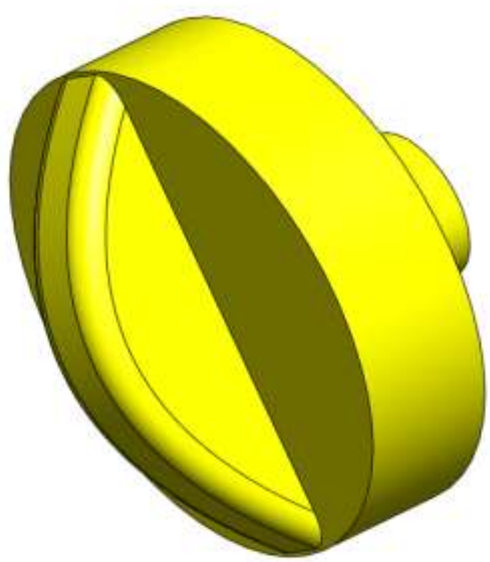


Fig. 71 – CAD model of the 12 V to 24 V switch

Manufacturing Technique – The switch is made by injection molding and made yellow strictly for a more aesthetic appearance and so that it matches the buttons on the main unit.

Modular Unit Material Selection - The part will be manufactured from acrylonitrile butadiene styrene or ABS. ABS is the material of choice for a variety of different reasons. First and foremost, ABS is a very strong and rigid material and will have no problems handling the weight of the battery without flexing or cracking. ABS is also a cheap material and is extremely easy to mold. According the label located on the battery, its safe operating temperature, likely above the max temperature it would ever achieve when in use, is 150°F. ABS is able to maintain constant material properties for temperatures up to 180°F. Another useful property of ABS is the fact that it is resistant to a wide variety of acids and bases. Because this product will be used around automobiles, it is safe to assume that it will likely encounter various fluids and must be able to maintain structural integrity. ABS also has very good electrical resistivity. The modular shell contains a small circuit and a very high powered battery. The resistivity of ABS not only protects the internal components from outside sources, but it may also help protect the user in the event of a short. Finally, the material is very impact resistant. The tool is likely to be placed on hard surfaces multiple times throughout its life. Due to the products heavy weight, the unit will experience moderate impact forces when set down, thus the bottom material must be able to withstand this force without fracturing or experiencing crack propagation.

Pressure Vessel - This part is what hold the pressure, it is also houses the spring and plates that form the blow out valve. It is made of a four inch diameter cylinder that is six inches tall. It has two attachments on either end of the cylinder that connect to the hoses. It also has a hole in it that allows for gas to escape when the pressure builds up. Lastly It has an electrical contact at the bottom of the spring chamber to allow the compressor to be turned off when it reaches it's required pressure.

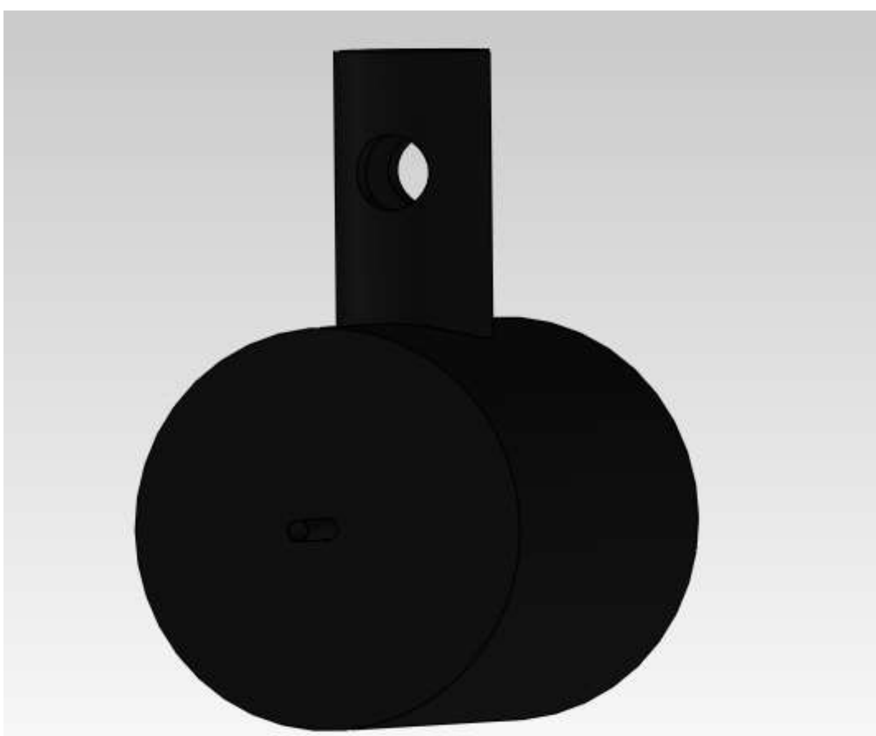


Fig. 72 – CAD model of the pressure vessel

Manufacturing Technique – This part was made of ABS. This material was selected because it is rigid and sturdy. It will be able to stand up to the wear and tear the device receives. The part was created using injection molding.

Gasket – This piece is used to ensure there is a seal between the bottom plate of the blow out valve and bottom of the spring chamber.

Fig. 73 – CAD model of the gasket

Manufacturing Technique – This part was made out of rubber. This was used so that the gasket would be pliable enough so that it would ensure a seal was created between the vessel and the plate. This part was cut from rubber stock.

Top/Bottom Plate – These plates are used to convert the force of the spring and gas. The top plate serves as a stopper for the top of the spring so that the displacement of the spring can be preset with an adjustment screw. The bottom plate is what makes a seal with the gasket and vessel.

Fig. 74 – CAD model of the Top/Bottom Plate

Manufacturing Technique – The plates were created by stamping tenth of an inch sheet metal. It was decided that the plates would be made of stainless steel so that they would be able to be used in any condition with out corroding or deteriorating over time.

Spring – A spring is used in order to generate a force on the bottom plate to counteract the force generated by the gas in the vessel. It was determined that the spring would have a spring constant of 47.1 lbs per inch. The resting length of the spring is 2.5 inches.

Fig. 75 – CAD model of the spring

Manufacturing Technique – This spring was created by mechanical deformation of a rod of steel.

Adjustment fastener – This fastener allows for the blow out pressure of the vessel to be adjusted. It was determined that it would need three threads per inch. Each quarter turn of the fastener equates to a blow out pressure increase of five psi.

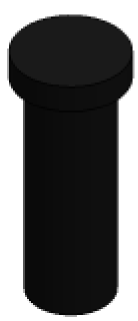


Fig. 76 – CAD model of the adjustment fastener

Manufacturing Technique – This part will be created by first casting blanks and then rolling the proper threads onto the shaft.

Modular Unit Specifications

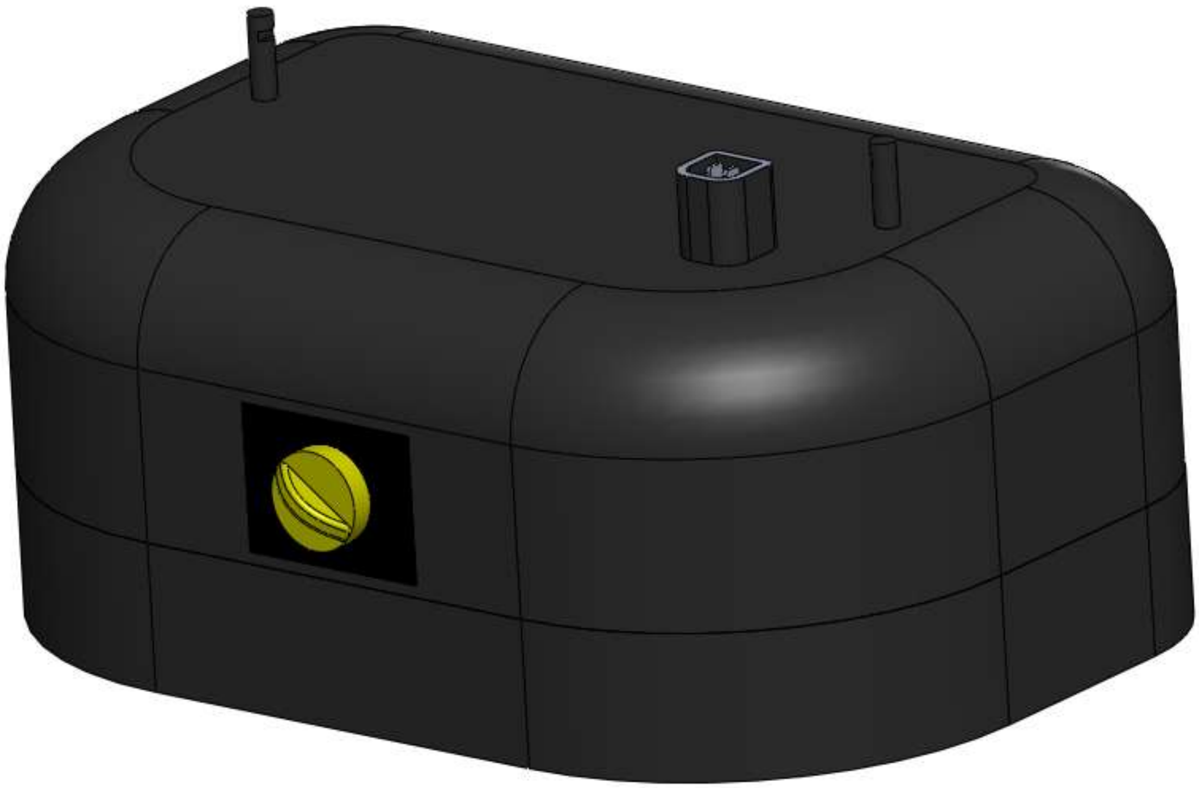


Fig. 77 – CAD model of the modular unit assembly

The modular unit is an optional addition to a standard 12 V jump-starter. The modular unit provides the user one of two options. First, the modular unit provides extended use capabilities for the 12 V system. By using the unit in "12 V" mode, the device will be capable of jump starting twice as many standard 12 V vehicles. It also provides a higher amperage in 12 V mode, this means that the user will be capable of jump starting practically any 12 V vehicle from small lawn mowers to large trucks.

Second, the modular unit provides the user with the capability to jump start vehicles with a 24 V power supply. Tractor trailers and various types of farm equipment often run in the 24 V range. This means that with our modular unit, these vehicles can now be jump started as well. The 24 volt system will provide 2000 peak amps, and 600 continuous cranking amps for five seconds. This is sufficient for jump starting most tractor trailers.

Within this unit, there is a circuit board that provides the capability of switching from 12 to 24 V. The circuit board aligns the two batteries in series (24 volts) or parallel (12 volts) depending on the user's selection. Attached to the circuit board is a relay system that guarantees not to send 12 volts to the main circuit board when in the "24 volt" setting. The circuitry for this capability is shown in the following figure.

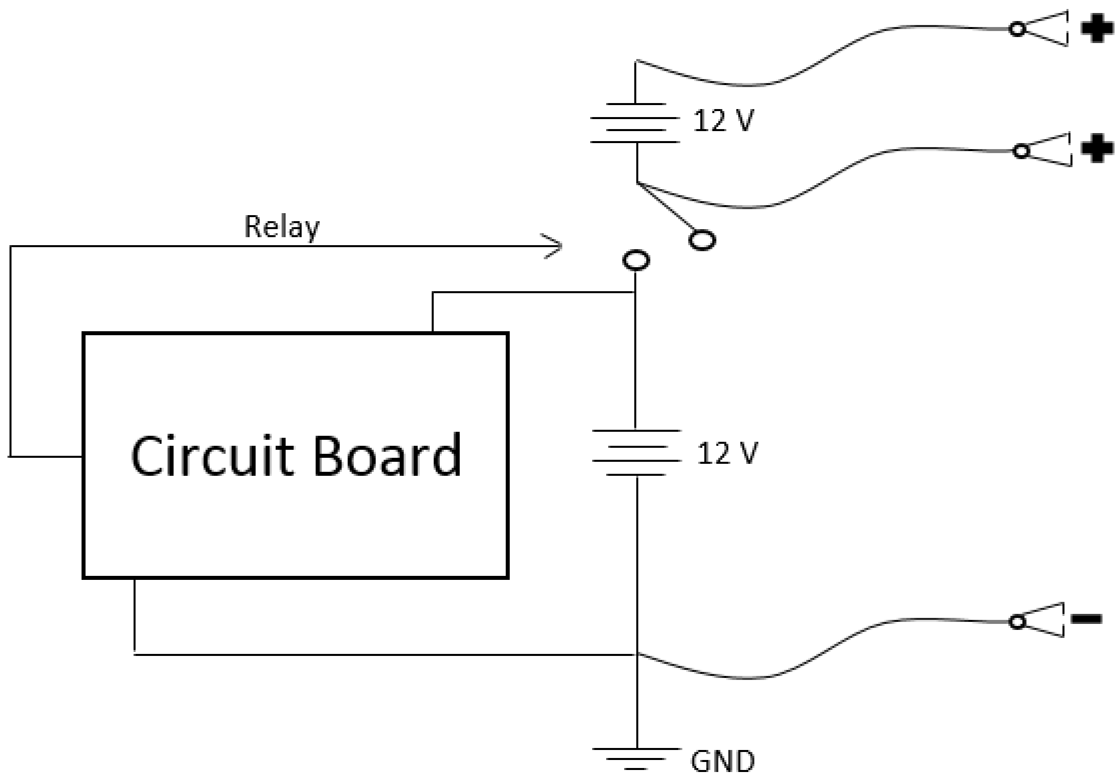


Fig. 78 – 12 to 24 V circuit board

When the 24 volt option is selected, the relay is opened, only allowing one battery to power the main circuit board. This circuitry allows the switching between 12 and 24 volts in a safe and seamless manner.

There is a pressure relay switch that is activated when the modular unit is plugged in to the main unit. This relay ensures that the male plug on the modular unit is only "live" when it is plugged in to the main unit. This feature was added to ensure user safety. When the modular unit is detached from the main unit, the switch is tripped, and the plug becomes dead until reattached for further use.

The modular unit was designed out of abs plastic to encase the additional 12 V lead-acid battery safely and securely. The case is held together by four 10-24 x 1.5" stainless steel Phillip's head fasteners. The abs plastic offered ideal toughness, impact resistance, and insulation. It was also extremely cheap and readily available in the marketplace.

The two connection pegs on top of the modular unit were designed to guarantee solid hold of the modular unit at all times. A Von Mises analysis was performed to analyze the amount of stress that the peg would see in use under a worst case scenario. The Von Mises results can be seen in the figure below.

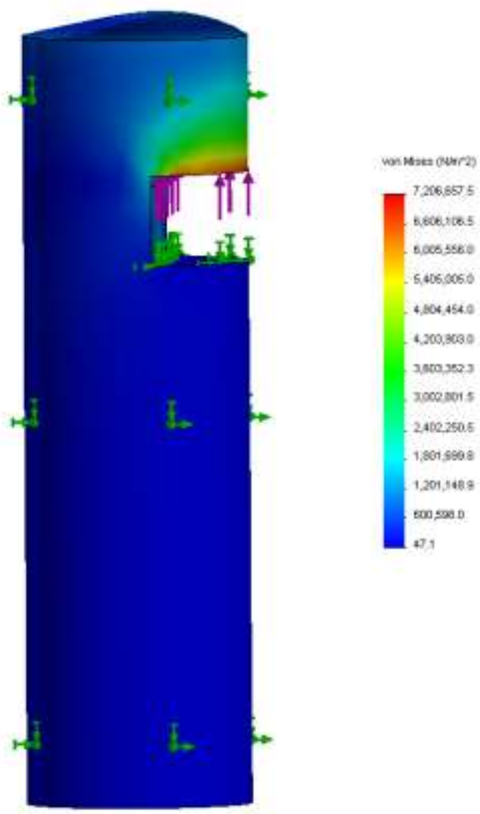


Fig. 79 – Von Mises results of battery peg analysis

The Von Mises testing was done such that all of the weight from the modular unit was held by one peg, in case of a potential failure of the other peg. The results were very satisfactory as the max stress seen in the peg was 7.2 MPa. With the abs tensile strength of 30 MPa, we achieved a factor of safety of 4.17. In actuality, the factor of safety is closer to 8 as the modular unit should always be supported by the two pegs at any time.

Pressure Controller Specifications

<u>Adjustable Mechanical Pressure controller</u>

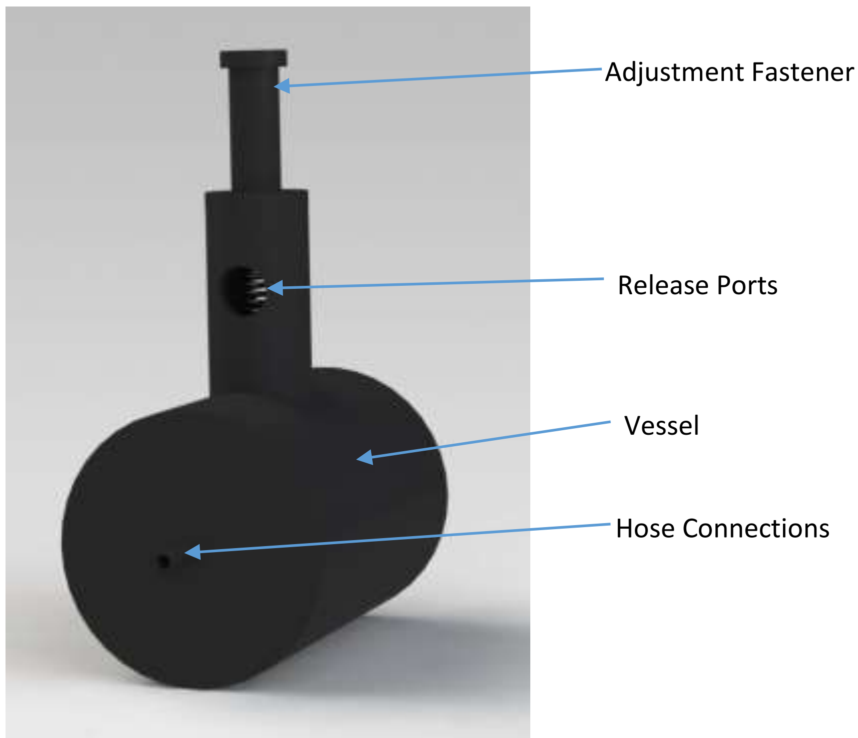


Fig. 80 – CAD model of the pressure controller assembly

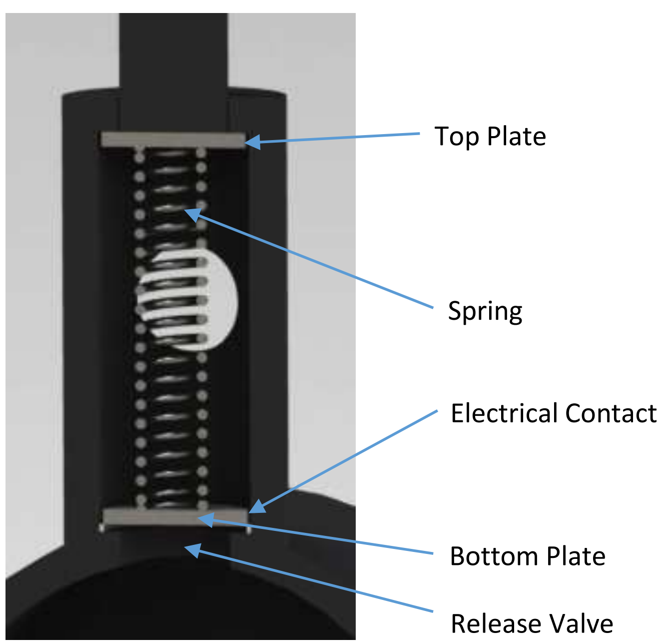


Fig. 81 – Cutaway CAD model of the pressure controller assembly

This is a mechanical solution to regulate the pressure that a tire is being filled to. It has been installed on the device where the original Schrader valve use to be. The original hose connects to one opening of the vessel. The other fitting on the vessel has an extended hose connected to it with the same Schrader valve at the other end of the hose. The volume of the vessel along with the two hoses is one continuous chamber.

This pressure regulator works through the use of a spring with an adjustable length. By adjusting the length, the user can adjust the pressure the vessel can be filled to. This is explained by the following equation

$$F = kx$$

F is the force the spring generates, k is the spring constant which is a property of the spring in use, and x is the linear displacement the spring is compressed from its resting position.

The release screw alters the distance from the top plate to the bottom plate. The distance between the two plates is what determines the displacement of the spring from resting position. The linear displacement of the spring allows for the force in the spring to be calculated using the previously stated equation. The force in the spring can then be used to determine how much force is required to move the bottom plate. The pressure to move the bottom plate is shown by the free body diagram below.

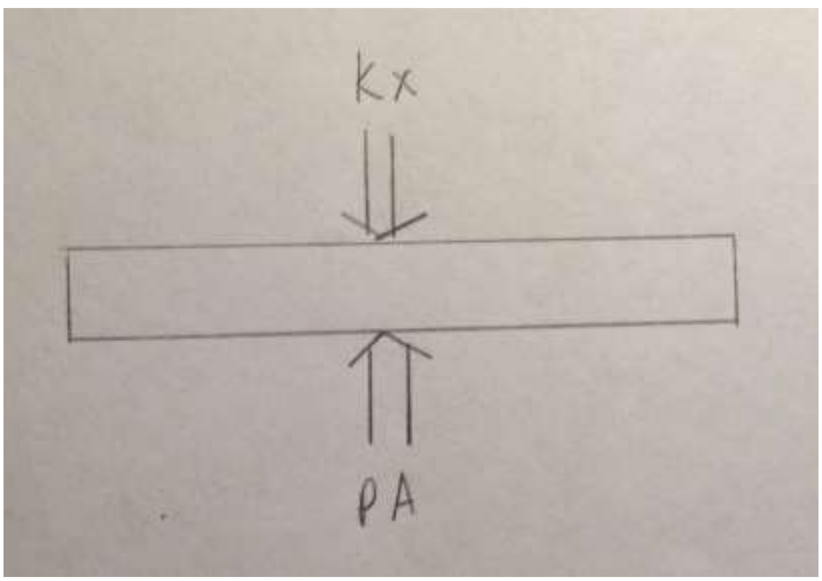


Fig. 82 – Free – Body Diagram of the bottom plate

Because pressure is the force on an object divided by the area the force acts on, the force placed on the bottom plate from the gas in the chamber can be found using the pressure of the gas in the vessel. The force acting on the bottom plate was then found for pressures between zero and one hundred and twenty pounds per square inch. Once this force was found, a spring constant was calculated using this force. The spring constant was found so that one quarter turn of the screw would equate to an increase in the release pressure of the vessel by five psi.

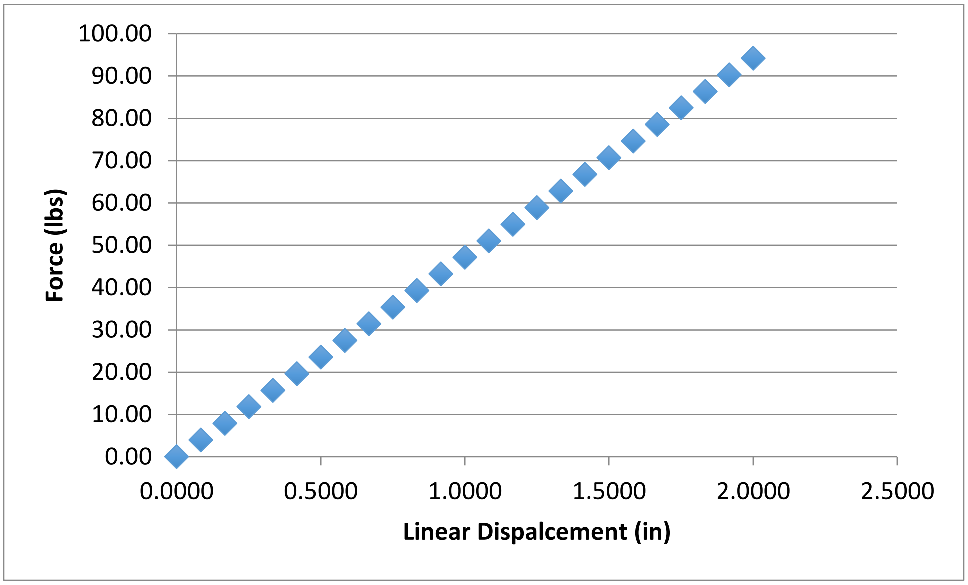
Below is a table that shows the pressure on the plate from the pressure in the vessel and the necessary linear displacement of the spring to match the force on the plate. It also includes the number of turns necessary for the screw to create the spring displacement necessary to match the force

Pressures (psi)	Force Necessary to Move Plate (lbs)	Rotations of Screw	Linear Displacement of Spring (in)
0	0	0	0.0000
5	3.925	0.25	0.0833
10	7.85	0.5	0.1667
15	11.775	0.75	0.2500
20	15.7	1	0.3333
25	19.625	1.25	0.4167
30	23.55	1.5	0.5000
35	27.475	1.75	0.5833
40	31.4	2	0.6667
45	35.325	2.25	0.7500
50	39.25	2.5	0.8333
55	43.175	2.75	0.9167
60	47.1	3	1.0000
65	51.025	3.25	1.0833
70	54.95	3.5	1.1667
75	58.875	3.75	1.2500
80	62.8	4	1.3333
85	66.725	4.25	1.4167
90	70.65	4.5	1.5000
95	74.575	4.75	1.5833
100	78.5	5	1.6667
105	82.425	5.25	1.7500

110	86.35	5.5	1.8333
115	90.275	5.75	1.9167
120	94.2	6	2.0000

Table 1 – Pressure according to linear displacement

This is a graph that shows the force of the spring verses its linear displacement



Graph 1 – Force vs. Linear Displacement

The spring constant can be found form this graph by finding the slope of the line that fits the points. The spring constant was found to be 47.1 pounds per inch.

A spring was selected with a spring constant of 47.1 pounds per inch with upstretched length of 2.5 inches.

The compressor also needed to be turned off once the tire reached its desired pressure. An electrical contact was added to the bottom surface of the spring chamber. This way when the spring was compressing the plate onto the washer it will close an electrical circuit between the plate and the contact. Once the vessel fills to the cut off pressure the gas will push the bottom plate up which lifts the plate off of the contact, and this triggers a cut-off for the circuit and the compressor turns off.

Adjustable Mechanical Pressure Controller Structural Stress Analysis

The following stress analysis was completed to ensure that the vessel would be able to withstand all pressures used by the device. Stress analysis was conducted at the weakest points of the design in order to see where it was most likely to fail.

Max hoop Stress in chamber

The maximum hoop stress in the main chamber of the vessel was found first. A diagram below shows all of the dimensions used

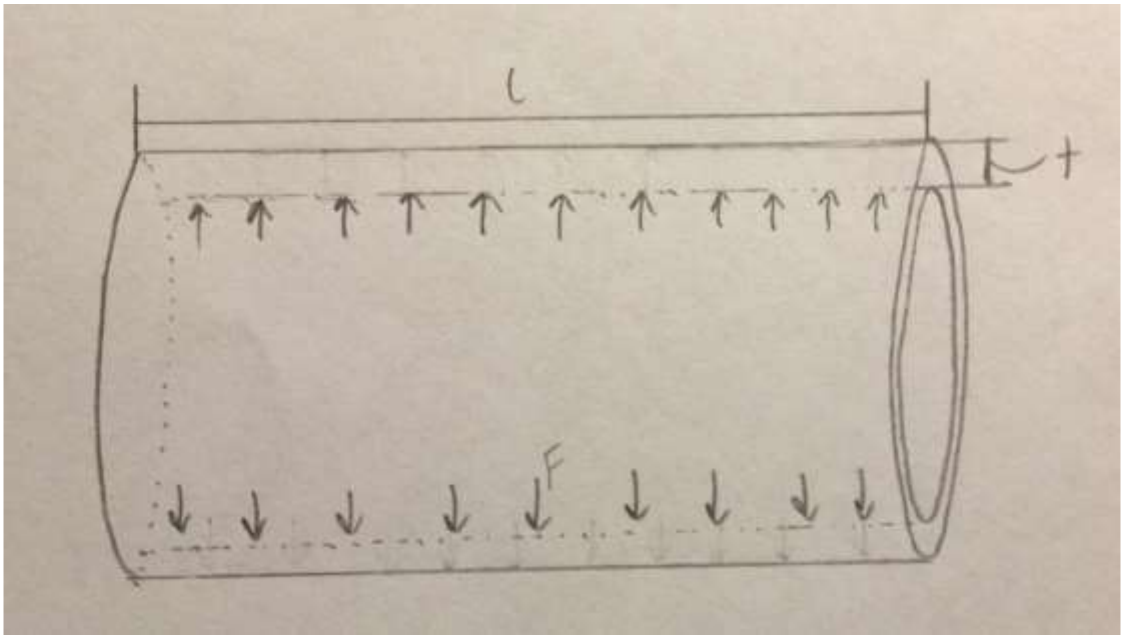


Fig. 83 – Hoop stress of pressure vessel

$$\sigma_{HS} = \frac{Pd}{t}$$

where F is the force acting on the surface

t is the thickness of the chamber

l is the length of the chamber

To find the hoop stress in the chamber we assume it is at its highest pressure allowable.

Where P is the pressure in the vessel d is the diameter of the cylinder and t is the thickness

$$\sigma_{HS} = \frac{120\ psi * 4in}{(.25\ in)} = 1920\frac{lbs}{in^2}$$

This is less than the yield stress for ABS which is 6160 psi. This gives the part a factor of safety of 3.20. With this design the maximum pressure the system would be able to hold would be 480 psi

This was found by plugging in the yield stress for the hoop stress. And backing out the pressure using the following equations

$$\sigma_\theta = \frac{Pd}{t} = 6160\ \frac{lbs}{in^2}$$

$$P_{max} = 385\ \frac{lbs}{in^2}$$

Stress in Axial Direction

The stress in the axial direction for the main chamber of the pressure vessel is described by the following equation

$$\sigma_L = \frac{Pd}{2t}$$

plugging in the pressure, diameter, and thickness of the vessel the axial stress can be found.

$$\sigma_L = \frac{120\, psi\ 4\, in}{2(.25\, in)} = 960\, psi$$

This gives the vessel a factor of safety of 6.41. To find the maximum allowable pressure plug in the yield stress for the axial stress.

$$6160\, psi = \frac{Pd}{2t}$$

The remainder of the variables that define the vessel are plugged in to find the maximum pressure.

$$6160\, psi = \frac{P(4\, in)}{2(.25\, in)}$$

$$P_{max} = 770\, psi$$

Stress if end cap were to break in radial direction

The stress on the end of the cylinder is found in the radial direction. The max stress is found by using the highest pressure the chamber should encounter. The force on the surface is the pressure times the area.

The dimensions of the area in question can be seen in the diagram below

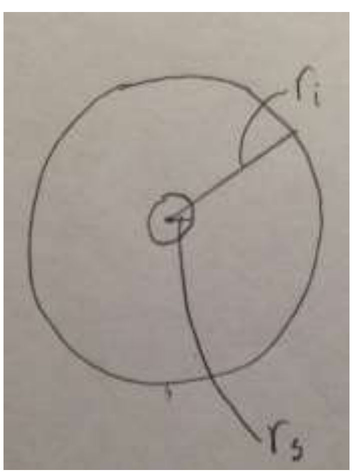


Fig. 84 – End cap dimensions

$$F = P * A$$

Where the max pressure is 120 psi and the area is the inner surface of the cylinder's end cap.

$$F = 120\frac{lbs}{in^2} * (\pi(1.75in)^2 - \pi(.102in)^2)$$

$$F = 1150.61\ lbs$$

we then find the stress in the material by dividing the force by the area of the part that would carry the load

$$\sigma = \frac{F}{A}$$

where the area is the cross sectional area of the end cap

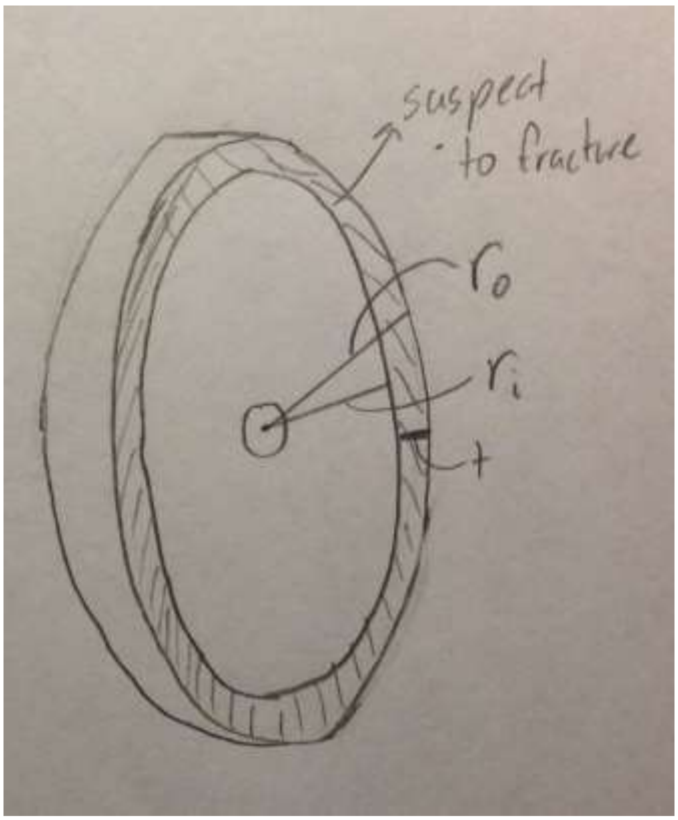


Fig. 85 – Cross sectional area of the end cap

$$A = \pi(2in)^2 - \pi(1.75in)^2 = 2.94\ in^2$$

Plugging in this area for the stress calculation

$$\sigma = \frac{1150.61\ lbs}{2.94\ in^2} = 391.36\ \frac{lbs}{in^2}$$

This gives a factor of safety of 15.73

The pressure that the material would yield at can then be found by plugging in the yield stress

$$6160\ \frac{lbs}{in^2} = \frac{F}{A}$$

$$6160\ \frac{lbs}{in^2} = \frac{F}{2.94\ in^2}$$

$$F = 18110.4\ lbs = P * A$$

$$P = \frac{F}{A} = \frac{18110.4\ lbs}{9.588\ in^2} = 1888.77\ psi$$

<u>Shear Stress in End in Axial Direction</u>

This calculation is similar to the previous calculation but instead the area that the cap would shear at is in the axial direction as show below in the diagram.

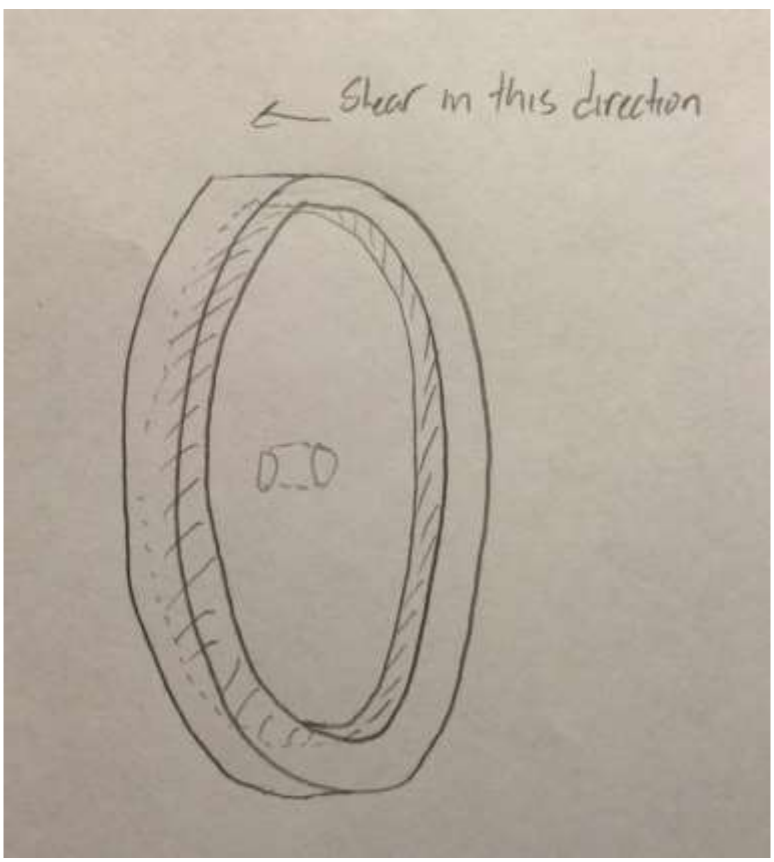


Fig. 86 – Shear stress in axial direction

The force is calculated the same way as the previous calculation

$$F = 120\frac{lbs}{in^2} * (\pi(1.75in)^2 - \pi(.102in)^2)$$

$$F = 1150.61\ lbs$$

The area that would shear in the axial direction is now calculated.

[area of stress applied to axial direction]

$$Area = 2\pi rw$$

$$Area = 2\pi(1.75\ in)(.25\ in) = 2.74\ in^2$$

The stress on the part is then calculated by dividing the force by the area that is being sheered.

$$\sigma = \frac{1150.61\ lbs}{2.74\ in^2} = 419.93\ \frac{lbs}{in^2}$$

This gives this part a factor of safety of 14.66

Next the maximum pressure the part could handle is calculated.

$$\sigma = \frac{F}{A} = 6169\ \frac{lbs}{in^2}$$

$$F = \sigma * A = 6169\frac{lbs}{in^2} * 2.74\ in^2 = 16903.06\ lbs$$

$$P = \frac{F}{A} = \frac{16903.06\ lbs}{9.588\ in^2} = 1762.93\ psi$$

This means the wall would not shear in the axial direction until a pressure of 1762.93 psi was reached which is well above our maximum desired pressure.

<u>Hoop Stress in End Fittings</u>

This is one of the smaller dimensioned pieces for the pressure regulator, therefore stress analysis must be done on the part to ensure it will be able to withstand any stresses it encounters over the life of the part.

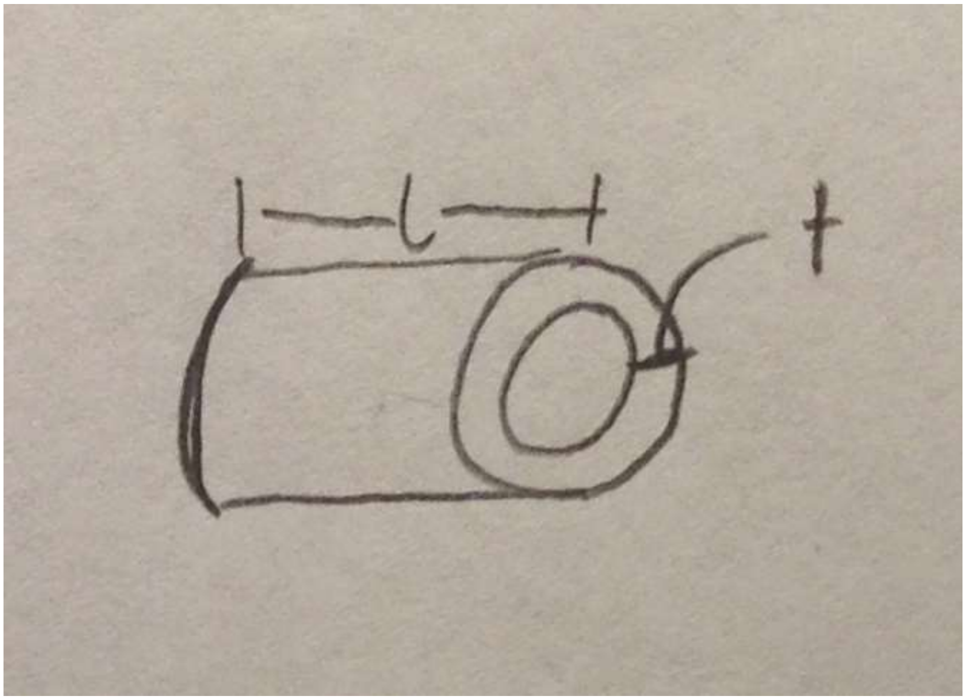


Fig. 87 – Hoop stress in end fittings

Hoop stress is defined by the following equation.

$$\sigma_{HS} = \frac{Pd}{t}$$

The pressure used to calculate the stress is the maximum pressure the system is designed to create.

The hoop stress is then found by plugging in the correct values for the cylinder diameter.

$$\sigma_{\theta} = \frac{120\, psi * \ 4\, in}{(.25\, in)} = 1920\ \frac{lbs}{in^2}$$

This hoop stress gives us a factor of safety of 3.20. The maximum pressure the part could withstand would then be calculated as follows.

$$\sigma_{\theta} = \frac{Pd}{t} = 6160\ \frac{lbs}{in^2}$$

The equation is then solved for the pressure

$$P_{max} = \frac{\sigma_{\theta} t}{d} = \frac{6160\, psi * .06\, in}{.210\, in} = 1760\, psi$$

Therefore the connections for the hoses will not break until a pressure of 1760 psi is reached.

Fastener analysis

Initially when designing this device there was a concern that the pressure adjustment fastener would potentially back out due to the force placed on the fastener from the spring. This was assuming that the pressure would be adjusted between 0 and 120 psi with a half turn of the screw. Instead it was decided that six turns of the screw would be used to adjust the pressure between 0 and 120 psi. This decision was made for two reasons. First it allows for more fine control over the pressure setting. With the six turns, each quarter turn correlates with a raise in pressure of five psi. Therefore the user will be able to adjust the pressure more easily. Secondly, with the eighteen threads there is no worry that the pressure from the spring will be able to back out the screw. This is because the pitch of the threads is significantly lower.

One issue that did arise is the potential for the spring force to strip the threads of the pressure vessel. Analysis was done in order to calculate if the shear stress caused by the spring force would shear the threads of the fastener and or the threads.

Stress is the force acting on the part divided by the area on which it acts. The threads on the device that the fastener connects to are .25 inches wide. The fastener has three threads per inch. To find the area the force acts over the total area of the thread surface must be found.

First the area the threads share with the wall must be found. Using geometry along with the depth of the threads the surface area can be found. This is depicted in the picture below. The width of the threads can be found using the geometry below.

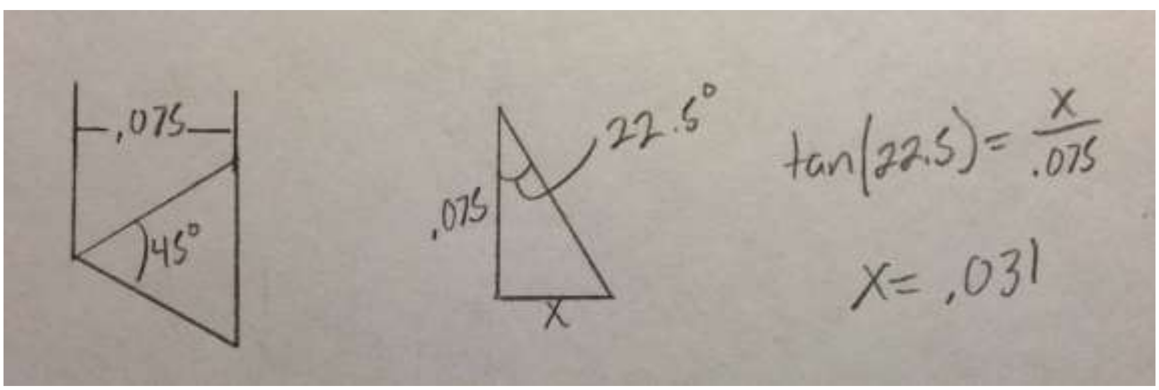


Fig. 88 – Fastener analysis

Through the use of geometry the thread width is found

$$W_{thread} = .062\ in$$

Once the width of the threads is known, the length of the threads in contact with the fastener must be known. It can be found with the below equation.

$$L_{Threads} = Threads\ per\ Inch * Depth\ of\ Threads$$

$$L_{Threads} = 3th\frac{reads}{in} * .25\ in = .75\ threads$$

The number of threads is then used to calculate the length of threads in contact with the fastener. Each thread has a surface area of a cylinder with the minor diameter of the fastener.

$$Area = \pi * D * W_{thread}$$

$$Area = \pi * .75\ in * .062\ in = .10956\ in^2$$

The stress induced in the threads by the spring force is then found with the following equation.

$$\sigma = \frac{F}{A} = \frac{(120\ psi) * (.7853\ in^2)}{.10956\ in^2} = 860.10\ psi$$

The stress found was 860.1 psi which is well below the maximum yield stress of 6160 psi. This gives a factor of safety of 7.16.

Next the pressure the threads will be stripped at is found. The yield stress is plugged into the following equation to determine the force required to strip the threads.

$$6160\ psi = \frac{F}{.10956\ in^2}$$

$$F = 674.88\ lbs$$

This force is then used to calculate the pressure necessary on the plate, which will push on the spring and then on the top plate and fastener.

$$F = P * A$$

$$674.88\ lbs = P * .7853\ in^2$$

$$P = 859.39\ psi$$

This is well above the maximum expected pressure and should never be encountered by the device.

Vessel Expansion Calculations

Calculations were performed to ensure the expansion in the vessel was at an acceptable level. The change in the radius of the vessel was calculated using the following formula.

$$change\ is\ radius = \frac{Pr_i}{E}\left(\frac{1 + \frac{r_i^2}{r_o^2}}{1 - \frac{r_i^2}{r_o^2}} + \upsilon\right)$$

Where P is the pressure in the vessel, r_i is the inner radius of the vessel, r_o is the outer diameter of the vessel, E is the young's modulus of ABS, and υ is the poisson's ratio of ABS. The change in radius can be seen below calculated by plugging in appropriate numbers.

$$change\ is\ radius = \frac{120\ psi * 1.75\ in}{3.80 \times 10^5}\left(\frac{1 + \frac{1.75^2}{2^2}}{1 - \frac{1.75^2}{2^2}} + .35\right) = .004\ inches$$

Therefore the radius will expand by .004 inches. This radial expansion can be used to calculate the change in the pressure release hole. Using the geometry shown below the expansion in the hole is calculated.

Using similar triangles, the new gap can be determined. The geometry is shown in the picture below

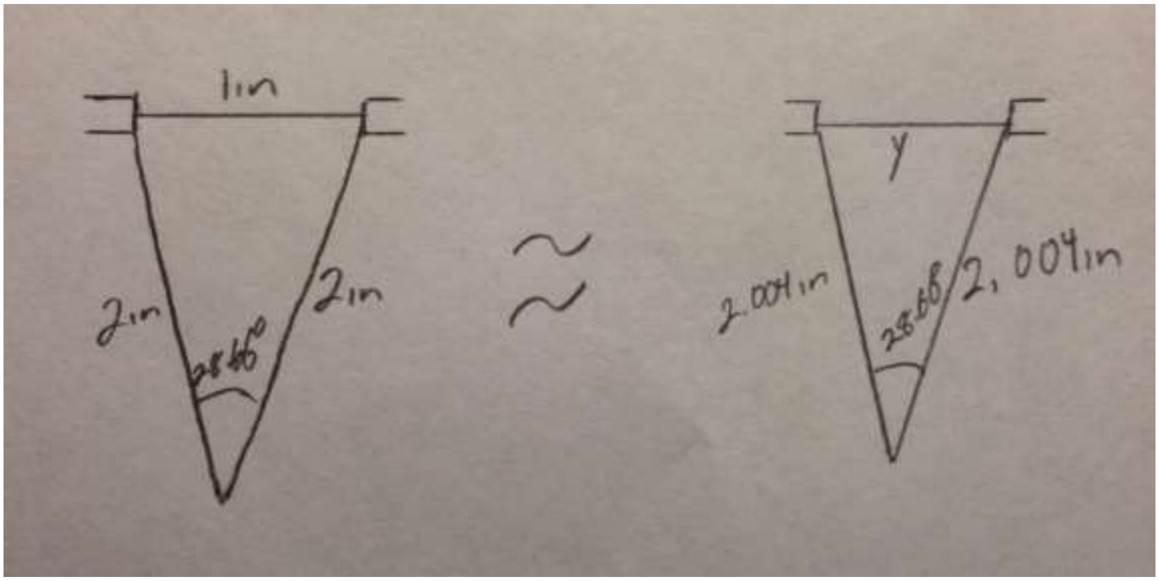


Fig. 89 – Fastener analysis

The new hole with the expanded cylinder has a diameter of 1.02 inches. The gasket that fills the gap is more than thick enough to ensure the expansion will be accounted for.

Blow Off Valve Gasket Analysis

Initially there was concern that friction might be generated by the gasket that seals the vessel. The new design has a gasket that is attached to the vessel where the pressure release valve is. Therefore the gasket does not move and no friction is generated. This is because friction force is given by the equation below.

$$F_{friction} = \mu F_N$$

This equation states that the friction force is generated by the normal force multiplied by a known friction coefficient between the two materials. Because all of the force being exerted on the gasket is in the vertical direction no normal force is generated to rub the gasket on the sides of the cylinder. Therefore no friction force is generated to impede the movement of the plate.

Fatigue analysis

Analysis was done in order to determine the number of life cycles that the vessel would be able to go through before it would cause failure. The vessel material is ABS and was treated as a ductile material. With a wall thickness of .25 inches and a maximum pressure allowable of 120 psi the life span of the vessel was assumed to be infinite but calculations were done to do verify this.

The number of life cycles the vessel can withstand is given by the below equation

$$\frac{\Delta\sigma}{2} = \sigma_a = \sigma_f'(2N_f)^b$$

Where $\Delta\sigma$ is the total strain the material goes through with each cycle. σ_f' is the fracture strength of the material in question. N_f is the number of life cycles the material experiences. b is a coefficient determined from the S-N chart. To determine the life span of the material for the vessel the first σ_a must be determined.

To find σ_a the Von Mises stress must be calculated. This is done by using the two principal stresses which are the hoop stress and axial stress. There is no third principal stress because it is assumed to be in planar stress

$$\sigma_H = 1920\,psi$$

$$\sigma_L = 960\,psi$$

these values are plugged into the following equation to determine the Von Mises stress.

$$\sigma_{VM} = (\sigma_1^2 + \sigma_2^2 - \sigma_1\sigma_2)^{\frac{1}{2}}$$

$$\sigma_{VM} = (1920^2 + 960^2 - 1920 * 960)^{\frac{1}{2}} = 1662.76\,psi$$

We then use this for the stress the vessel is loaded with, we treat the loading as cyclical. The following graph can be generated using this Von Mises stress.

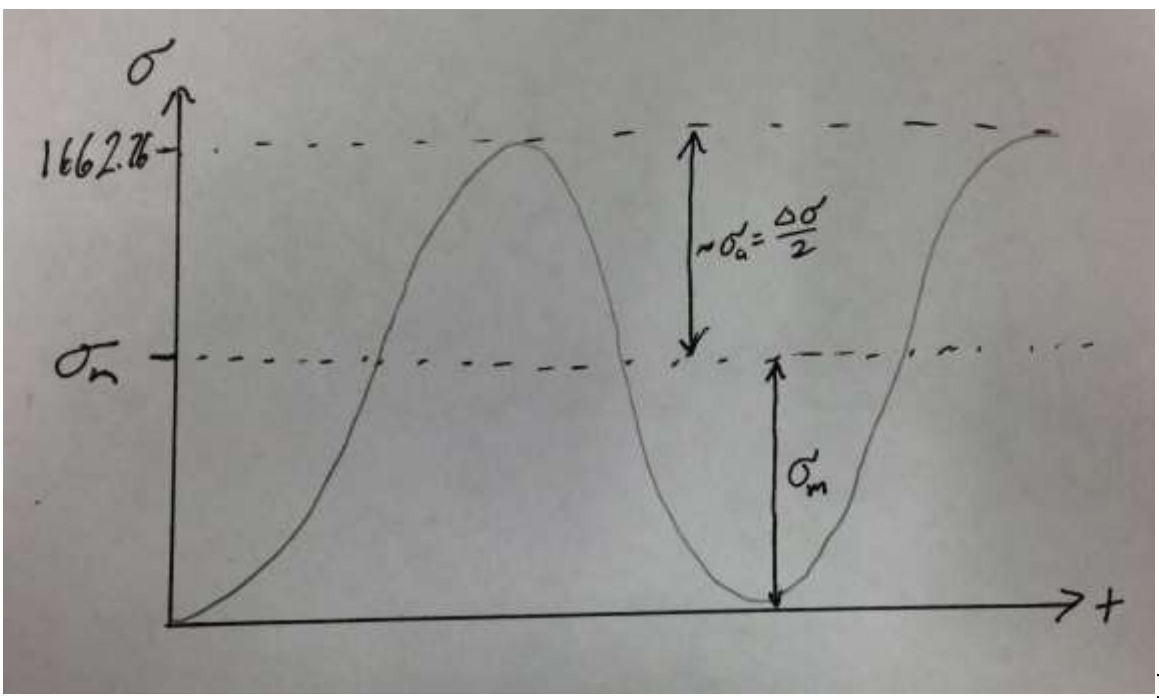


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Fig. 90 – Cyclic loading representation

This graph represents the Von Mises stress in the vessel over the course of it being filled to 120 psi. The mean stress can be found from this graph by finding the average stress it is subjected to. This mean stress is then plugged into the following equation along with the ultimate tensile strength to find σ_a.

$$\frac{\sigma_a}{\sigma_m} + \frac{\sigma_m}{S_{UT}} = 1$$

plugging in the appropriate values the $\sigma_a$is found to be

$$\sigma_a = 712.46\, psi$$

the exponent b must then be found. This is determined through the creation of a S-N graph. This graph gives the strength a material must be stressed to fail after a given number of loads. The linear Y axis is the stress that will cause fracture and the X axis is number of cycles the material experiences. The scale of the X axis is logarithmic. Three points must be plotted to create this graph. The first is the ultimate tensile strength which will cause the material to break after once cycle. The next is the 90% of the ultimate tensile strength which will cause the part to break at 1000 cycles. The last part requires some calculations to determine the strength that will cause the part to break at one million cycles.

The strength that causes a material to break at one million cycles can be found using the following equation

$$S_e = k_a k_b k_c k_d k_e k_f S_e'$$

Where each of the k's is a correction factor. $k_a$is the surface factor, it is only used to correct for shapes when analyzing rotating beams. $k_b$is a correction factor for beams that are bending or experiencing torsion. Therefore this correction factor does not apply. k_c is the correction factor that accounts for the way the load is applied. If the load is applied axially then the correction factor of .85 is used. k_d is the correction factor for temperature. Because the load is applied at room temperature the correction factor is not taken into account. k_e is the reliability factor. It does not take account in this type of loading. Lastly we have k_f which is a correction factor. It accounts for all other variables. It is assumed this is one. Plugging in all these correction factors we find the strength of fracture at one million loads.

$$S_e = (1)(1)(.85)(1)(1)(1)\left(\frac{S_{UT}}{2}\right)$$

$$S_e = (1)(1)(.85)(1)(1)(1)\left(\frac{5812.26\, psi}{2}\right)$$

$$S_e = 2470.21\, psi$$

Using this data the following chart can be generated

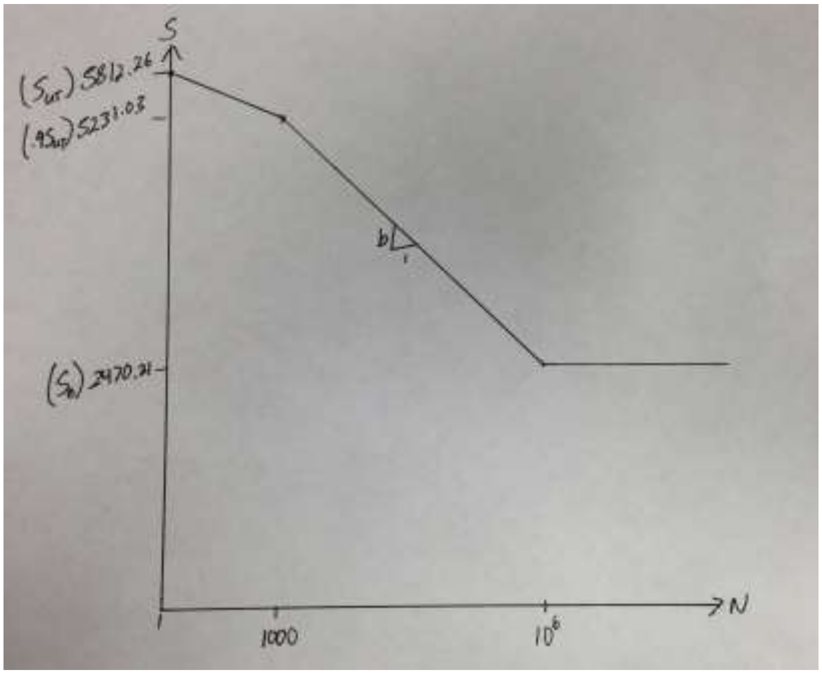


Fig. 91 – S-N diagram

The exponent b is then found using the chart. It is the slope between the fracture stress at 1000 cycles and one million cycles.

The value of b was found to be -.0027

To find the lifespan of the part all of the values must be plugged into the lifecycle equation below

$$\frac{\Delta\sigma}{2} = \sigma_a = \sigma_f'(2N_f)^b$$

$$712.46\,psi = (5812.26\,psi)(2N_f)^{-.0027}$$

The lifespan on the vessel is found to be 2.103×10^{337}. Clearly the life span of this part is sufficient. It would allow for the device to fill four tires a day for 5.257×10^{336} years. That should out survive any user.

Below is a chart generated using the Maximum – Shear – Stress Theory for a Ductile Material. The yield envelope was drawn using the ultimate yield strength. This chart shows what the principal stresses can be before the material will yield. The theory assumes the material is in planar stress. As long as the two non-zero principal stresses stay within the shaded area the material will not fail.

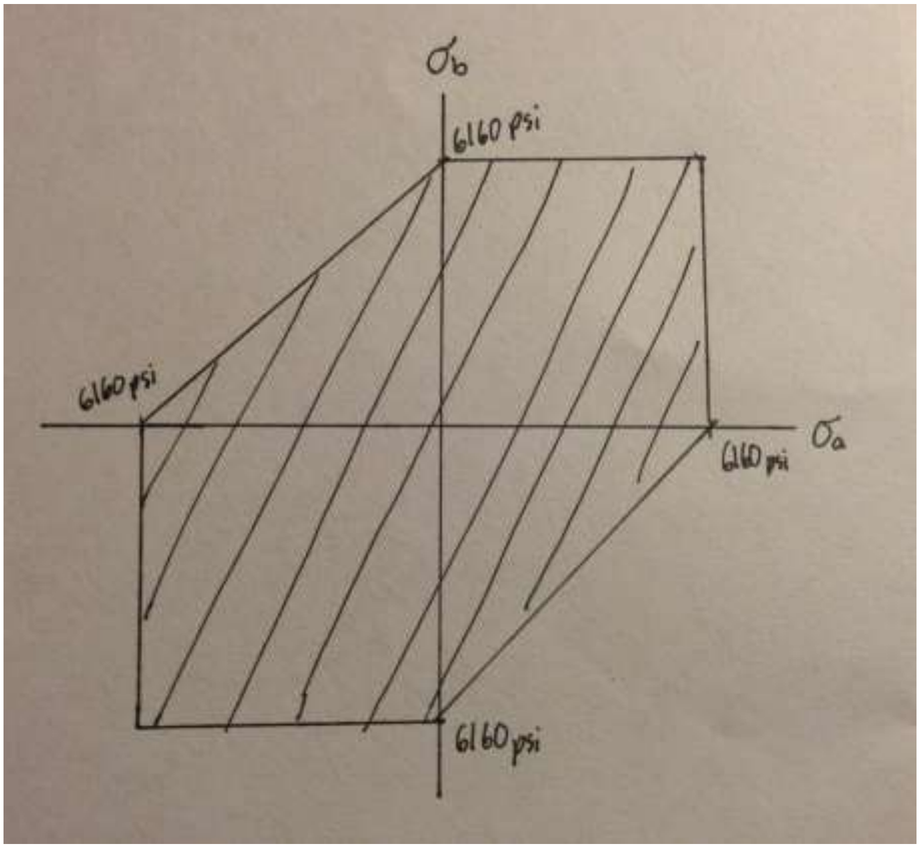


Fig. 92 – Maximum Shear Stress yield envelope

Compressor/Motor Analysis

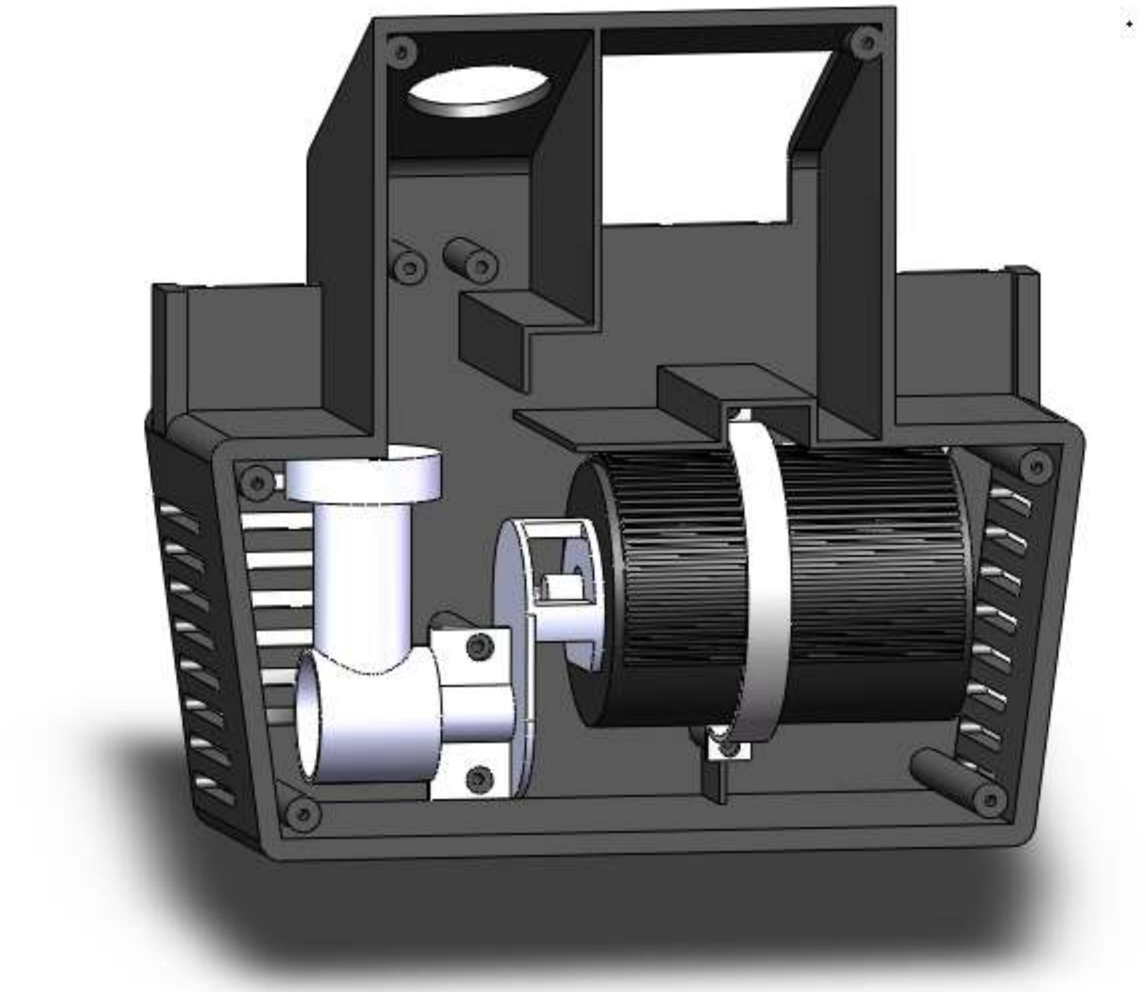


Fig. 93 – CAD model of motor and compressor assembly

Motor Speed

The compressor/motor system must be able to inflate a tire from flat to a pressure of 120 psi within a reasonable amount of time. The fill time for this application was chosen to be 15 minutes for an absolutely worst case scenario where the tire needs to be inflated from flat 120 psi with a tire volume of about 18 L or 5 gal.

First, the mass of air in the fully inflated tire must be calculated assuming an air temperature of 25°C:

$$m_{tire} = \frac{PV}{RT} = \frac{120\cancel{psi} * 6894.757\frac{Pa}{\cancel{psi}} * 5\ \cancel{gal} * 0.003785\frac{\cancel{m^3}}{\cancel{gal}}}{287.058\frac{\cancel{J}}{kg * \cancel{K}} * 298\ \cancel{K}} = 0.1741\ kg$$

Next, the mass flow rate required by the system can be calculated by dividing the total mass by the set desired fill time.

$$\dot{m} = \frac{m}{t} = \frac{0.1741\ kg}{15\ \cancel{min} * 60\frac{sec}{\cancel{min}}} = 0.000193444\frac{kg}{sec}$$

Now that the required mass flow rate has been calculated, the required volume flow rate can be found by dividing out the density of air. Because, the density of air changes as a function of pressure, an average of 1.18 kg/m^3 was chosen.

$$\dot{V}_{actual} = \frac{\dot{m}}{\rho} = \frac{0.000193444\frac{\cancel{kg}}{sec}}{1.18\frac{\cancel{kg}}{m^3}} = 0.000164\frac{m^3}{sec}$$

Because the compressor in not 100% efficient, this number represents the actual volumetric flow rate. In order to find the theoretical, or flow rate before losses, the compressor efficiency must be taken into account using the following correlation.

$$V_{theoretical} = \frac{V_{actual}}{n_c * n_a * n_l}$$

$$clearance\ efficiency = n_c = 1 - c[\left(\frac{P_{exit}}{P_{inlet}}\right)^{\frac{1}{k}} - 1]$$

Assuming c=3% and k=1.4 and an inlet pressure equal to that of the atmosphere, or about 14.7 psi

$$n_c = 1 - 0.03\left[\left(\frac{120\ \cancel{psi}}{14.7\ \cancel{psi}}\right)^{\frac{1}{1.4}} - 1\right] = 0.8956$$

$$heat\ transfer\ efficiency = n_a = 1 - 0.025(\frac{P_{exit}}{P_{inlet}} - 1)$$

$$n_a = 1 - 0.025\left(\frac{120\cancel{psi}}{14.7\cancel{psi}} - 1\right) = 0.821$$

$$leakage\ efficiencyny = n_l \approx 0.98$$

The leakage efficiency of the compressor is assumed to be 98%. Typically, leakage efficiencies rate between 95% and 99% and since this compressor is rather small, it likely has tighter tolerances and leaks less air.

Thus:

$$\dot{V}_{theoretical} = \frac{0.000164\frac{m^3}{sec}}{0.98 * 0.8956 * 0.821} = 0.000227505\frac{m^3}{sec}$$

From this and the input volume per stroke of the compressor, the needed motor rpm can be calculated.

$$V_{compressor} = \frac{\pi D_{piston}^2}{4} * L_{stroke} = \frac{\pi * 0.7\cancel{in}^2}{4} * 0.77\cancel{in} * 0.000016387\frac{m^3}{\cancel{in^3}} = 0.00000485597\ m^3$$

In order to find the rpm of the motor, the gear reduction is also needed. The gear reduction provides information on how many time the motor must rotate in order to achieve 1 full pump of the compressor.

$$gear\ ratio = gr = \frac{N_{large}}{N_{small}} = \frac{52}{11} = 4.73$$

Now the motor speed can be calculated

$$rpm = \frac{\dot{V} * time * gr}{V} = \frac{0.000227505 \frac{\cancel{m^3}}{\cancel{sec}} * \frac{60\ \cancel{sec}}{min} * 4.73\ rot}{0.00000485597\ \cancel{m^3}} = 13296.2\ rpm$$

Thus, the system with the stated parameters must rotate at a speed of 13296.2 rpm in order to fill an 18 L tire to a pressure of 120 psi.

From this same data, the fill time can be calculated based on various starting pressures by first finding the mass needed to fill the tire.

$$m_{required} = m_{total} - m_{starting}$$

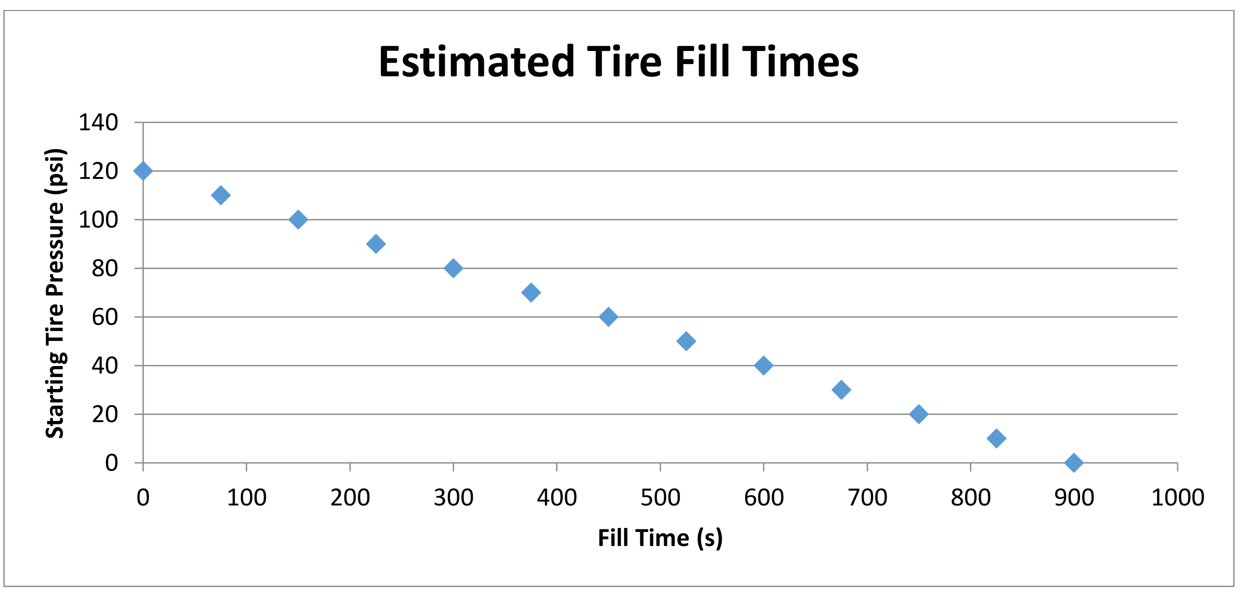
As an example, if the start pressure is 10 psi then

$$m_{required} = 0.1741\ kg - \frac{P_{starting}V}{RT} = 0.1596\ kg$$

Dividing the new mass required by our previously calculated mass flow rate yields the time required.

$$time = \frac{0.1596\ \cancel{kg}}{0.00019344 \frac{\cancel{kg}}{sec}} = 825\ sec$$

Iterating this method for various starting pressures produces the following graph.



Graph 2 – Fill time based on varying starting pressures

Motor Torque

Another very important motor parameter is the required torque necessary to achieve the full 120 psi as desired. In order to calculate to torque required, the system will be model as standard slider-crank mechanism. In this model, the torque required by the crank is equal to the moment on the crank arm where the force is that which is generated by the pressure acting on the piston.

$$F = PA_{piston} = P * \frac{\pi D_{piston}^2}{4}$$

thus,

$$\tau_{cam} = Fr_{cam} sin\alpha$$

Pressure in the compressor varies with the position of the piston in the cylinder. When the piston is all the way at the top of its stroke, the pressure is 120 psi. When the piston is at its lowest point in the cylinder, the pressure equal to that of the atmosphere. For the sake of overdesigning and accounting for the worst case scenario, the pressure will be estimated when the torque is at a maximum. According to the equation above, max torque is experience when the crank angle is perpendicular making the function $sin\alpha$ equal to 1.

Measurements were taken to record the pistons position in the cylinder when the crank angle was at 90°.

$$L_{bottom} = 0.87in$$

$$L_{perp} = 0.53in$$

thus,

$$Stroke\,\% = \frac{0.53\cancel{in}}{0.87\cancel{in}} * 100 = 60.9\%$$

From this, it is assumed that maximum torque occurs at 60.9% of the full stroke, and experiences 60.9% of the maximum pressure.

$$P = 120psi * 60.9\% = 73psi$$

Now the numbers can be plugged in to the previous equations in order to solve for the torque at the cam.

$$F = 73\frac{lb}{\cancel{in^2}} * \frac{\pi * 0.7^2 \cancel{in^2}}{4} = 28.09\ lbf$$

And

$$\tau_{cam} = 28.09\ lbf * 0.36\ in * \sin(90°) = 10.1137\ lbf * in$$

Now, assuming the cam shaft is a rigid rod, the torque at the cam is equal to that at the gear so,

$$\tau_{motor} = \frac{\tau_{gear}}{gear\ reduction} = \frac{10.1137\ lbf * in}{4.73} = 2.138\ lbf * in = 0.242\ N * m$$

Motor Power

Now that the required rpm and torque of the motor have been determined, that motor output power can be calculated.

$$P = \tau\omega = 0.242\ N * m * 13296.2\frac{\cancel{rot}}{\cancel{min}} * \frac{2\pi\ rad * \cancel{min}}{\cancel{rot} * 60\ sec} = 336.376\ W$$

For the purpose of standardization, this number was rounded up to a required motor output of 350W

The motor chosen for the system is a 12V 60ZY with a rated power of 350W made by Dongyang City Dongzheng Motor Co., Ltd. - http://www.alibaba.com/product-gs/297286809/Brush_12V_DC_Motor_60ZY_.html

Thermal Analysis

For purposes of the thermal analysis, some motor specification assumed to be similar to that of another ZY motor with more details from the manufacturer located at http://www.alibaba.com/product-gs/570199131/80ZYT03A_1_25Nm_350W_dc_electric.html. According to the motor specifications, the safe operating temperature is 140°C, therefore when running the motor for continuous periods, it is ideal to keep it below this temperature for as long as possible. In order to find the motor temperature over time, the energy lost due to heat needs to be found. The motor chosen has a rated output of 350W and an assumed efficiency of about 80%. Therefore before losses the motor output is 437.5W for a difference of 87.5W which goes into heating the motor. The heating power can then be converted into energy over time.

$$Energy = \frac{87.5W}{1000} = 0.0875\frac{kJ}{s}$$

Now in order to find the motor heat over time the following equation is used

$$Q = mc_p\Delta T$$

Where

$$Q = Energy * time$$

For this approximation, the motor is modeled as a 75% solid cast iron cylinder where $c_p = 0.46\frac{kJ}{kg*K}$ according to http://www.engineeringtoolbox.com/specific-heat-metals-d_152.html and a $m = 1.2689\ kg$ based on a SolidWorks model of the motor. Thus the heat and any given time interval can be solved using the equation,

$$Q = 0.0875\frac{kJ}{\cancel{s}} * time = 1.2689\cancel{kg} * 0.46\frac{kJ}{\cancel{kg} * K}(T_2 - 25°C)$$

Now assuming the air vents in the shell do not restrict air flow, the cooling effects due to free convection and radiation can be factored in.

$$Energy\ Lost = Q_{free\ convection} + Q_{radiation} = \frac{hA_s\Delta T}{1000} * time + \frac{\varepsilon\sigma A_s(T_2^4 - T_1^4)}{1000} * time$$

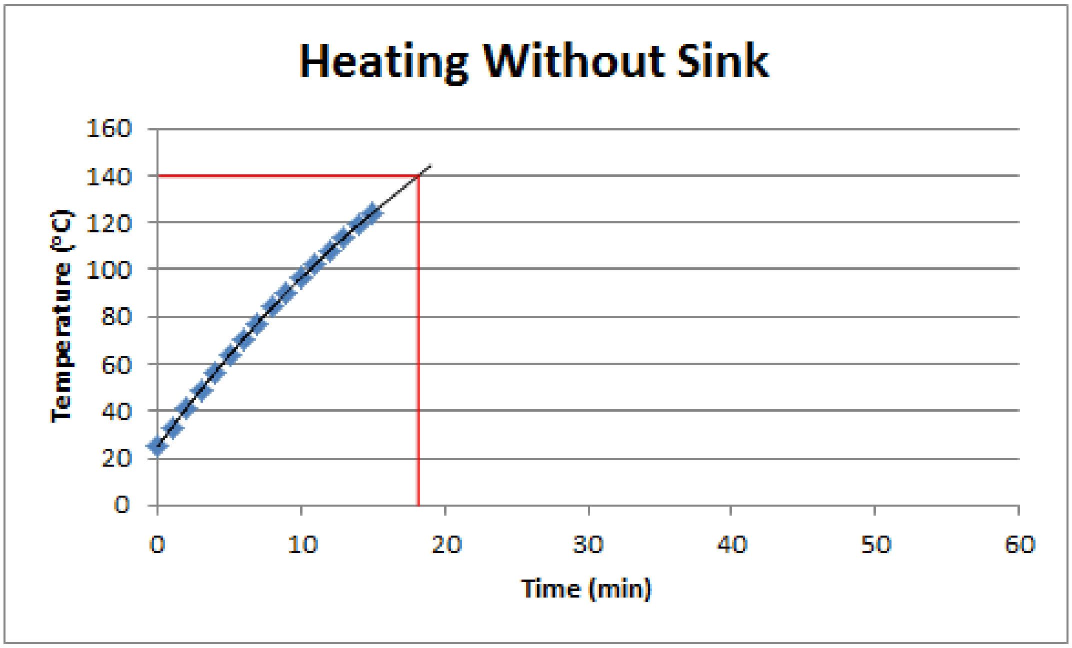
Where A_s, the exposed surface area, is 0.0213 m^2 , h, the overall heat transfer coefficient for the free convection of air over iron, is 5.7 W/m^2 K according to http://www.engineeringtoolbox.com/overall-heat-transfer-coefficients-d_284.html, and $\varepsilon\sigma$, the radiation constant of cast iron is 5.09*10^{-8} $W/m^2°C^4$ according to http://www.engineeringtoolbox.com/radiation-constants-d_150.html.

Once the energy lost is calculated the new overall energy that goes towards heating the motor and new estimated temperate can be calculated

$$Energy_{total} = Energy_{overall} - Energy_{lost}$$

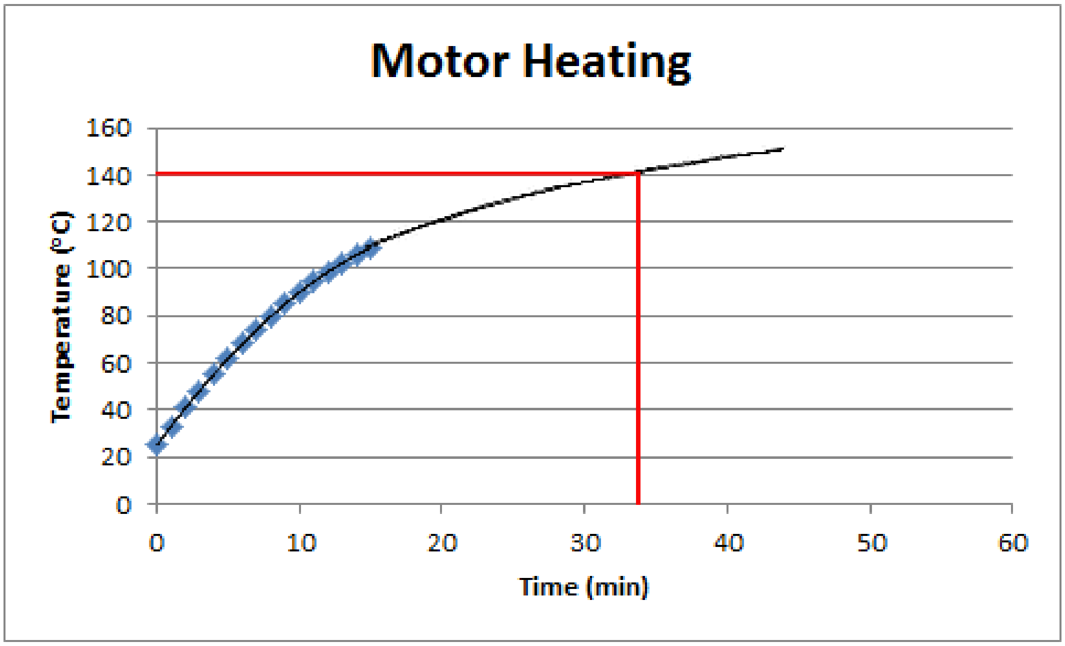
$$Temperature_{adjusted} = \frac{Energy_{total}}{m * c_p} + T_1$$

The outlined method was iterated up to a running time of 15 minutes to produce the following curve.



Graph 3 – Temperature rise of the motor over time

The curve shown above was then project forward to find when it crossed the critical 140°C temperature. From this, the motor is estimated to be able to run for about 18-19 minutes before being shut off by the thermal protector. While this running time is enough to fill a worst case scenario tire, the performance should be greatly increased through the addition of a heat sink. A small 40-fin heat sink was design using SolidWorks, and added on to the motor model. The addition of the heat sink increased the weight of the motor to 1.391 kg and increased the surface area from 0.0213m^2 to 0.03848m^2. Plugging these new parameters into the previous equations yields the following graph.



Graph 4 – Temperature rise in motor over time with heat sink

Again the curve was projected in order to find the estimated time to reach the shutoff point of 140°C. The addition of the very small and simple heat sink increased the possible continuous operating time from 18-19 minutes to 33-34 minutes.

Compressor Work

The work done by the compressor can be calculated using the equation

$$\dot{W}_{comp} = \dot{m}\Delta h$$

In order to find the enthalpy, at point 2, the temperature at point 2 must be estimated using an isentropic relation for an ideal gas assuming k=1.4.

$$T_2 = T_1\left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}} = 298\ K * \left(\frac{120\cancel{psi}}{14.7\cancel{psi}}\right)^{\frac{.4}{1.4}} = 542.936K$$

Using http://www.peacesoftware.de/einigewerte/luft_e.html to calculate the enthalpy of air at the different temperatures and pressures result in

$$\dot{W}_{comp} = 0.000193444\frac{\cancel{kg}}{s} * (298.5969 - 547.997)\frac{kJ}{\cancel{kg}} = 0.048\frac{kJ}{s}$$

Assembly

In order to make the assembly process easier to follow, it is best to break it down into subassemblies. This list will later be used to estimate the assembly time based on this process.

1. Pump Assembly

    A. Valve

    1. Insert the small Schrader value into the valve housing being sure to orient it with the fill stem facing toward the barrel of the housing

Fig. 94 - Inserting the Schrader valve into the housing

    2. Insert the locking lever into the back of the housing and align the hole with the hole in the valve housing
    3. Press fit the small plastic pin through the housing and the level securing the two and allowing the level to rotate up or down

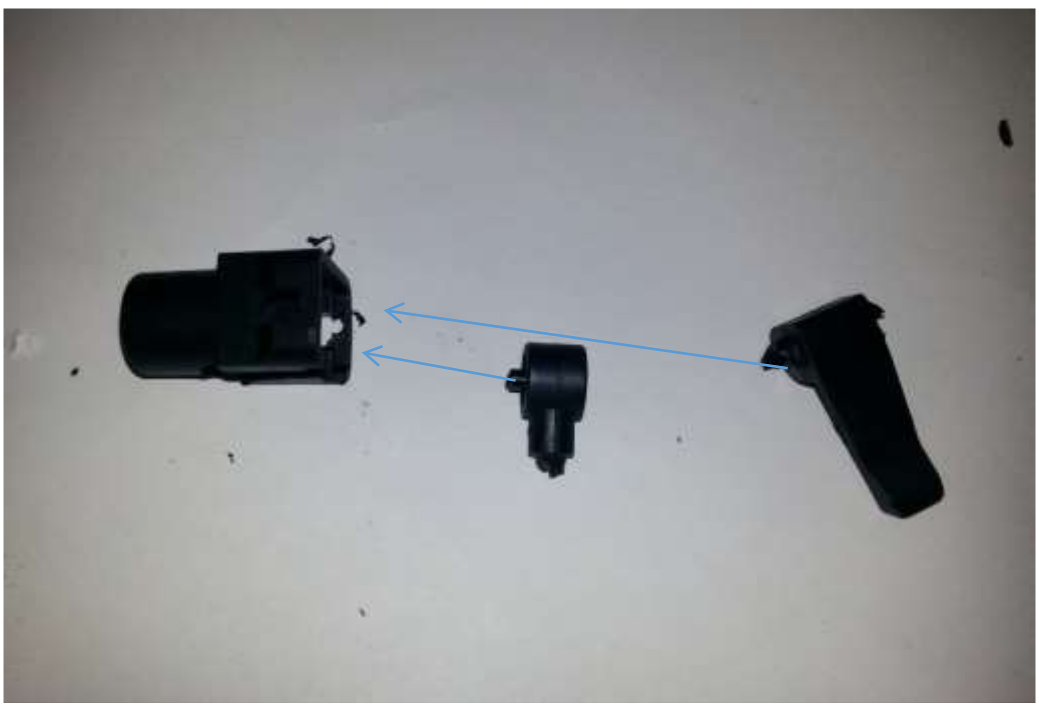


Fig. 95 - Assembly of the pump valve

4. Slide the metal crown piece, flared edge down, over the top of one end of a rubber hose

5. Insert the valve into the hose at the same end where the metal crown was placed

6. Crimp the metal crown to secure the hose to the valve while creating an air-tight seal

Fig. 96 - Attaching the valve to the hose

7. Slide a hose clamping spring onto the side of the hose opposite of the valve

7. Connect the hose from the compressor onto the left hose fitting for the pressure vessel

6 Pressure vessel assembly

A) spring compartment assembly

1- pick up and align vessel

Fig. 97 – Vessel alignment

2- align gasket into spring compartment

Fig. 98 – Gasket alignment

3- Insert gasket into bottom of spring compartment

Fig. 99 – Gasket insertion

4- align bottom plate with spring compartment

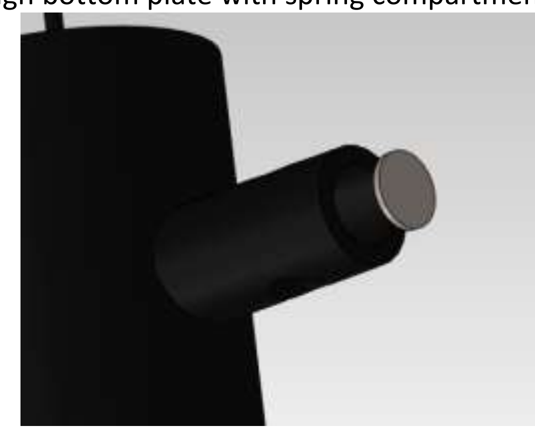


Fig. 100 – Bottom plate alignment

5- Insert bottom plate into bottom of spring compartment flush with the gasket

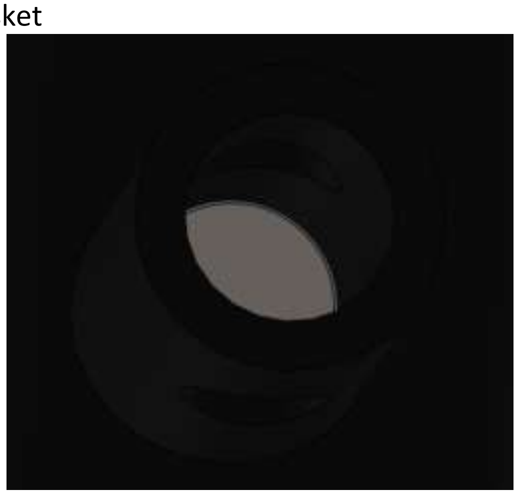


Fig 101 – Bottom plate installation

6- Place the spring in the spring compartment and center it with the bottom plate

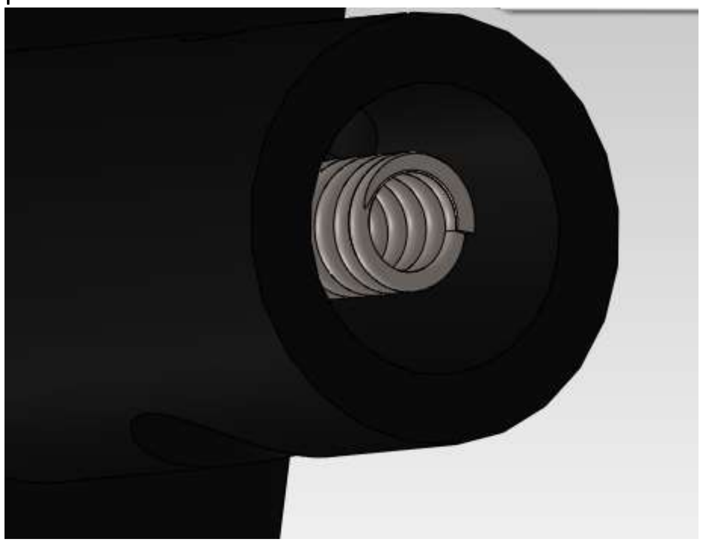


Fig. 102 – Spring installation

7- Align the top plate with the spring compartment

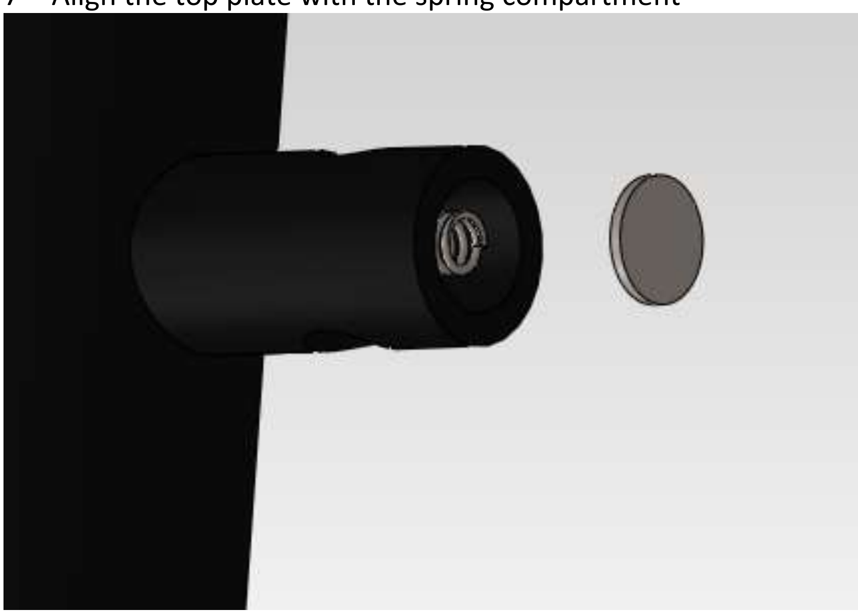


Fig. 103 – Top plate alignment

8- Insert top plate into spring chamber on top of spring

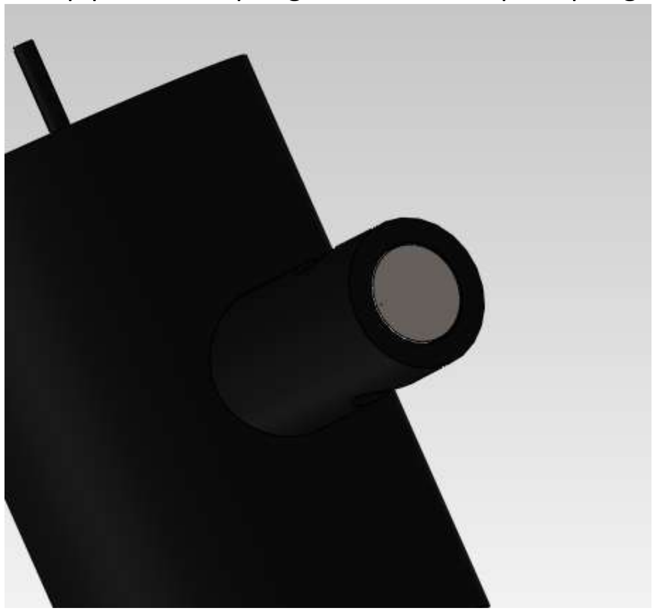


Fig. 104 – Top plate installation

9- Align the end cap with the spring compartment

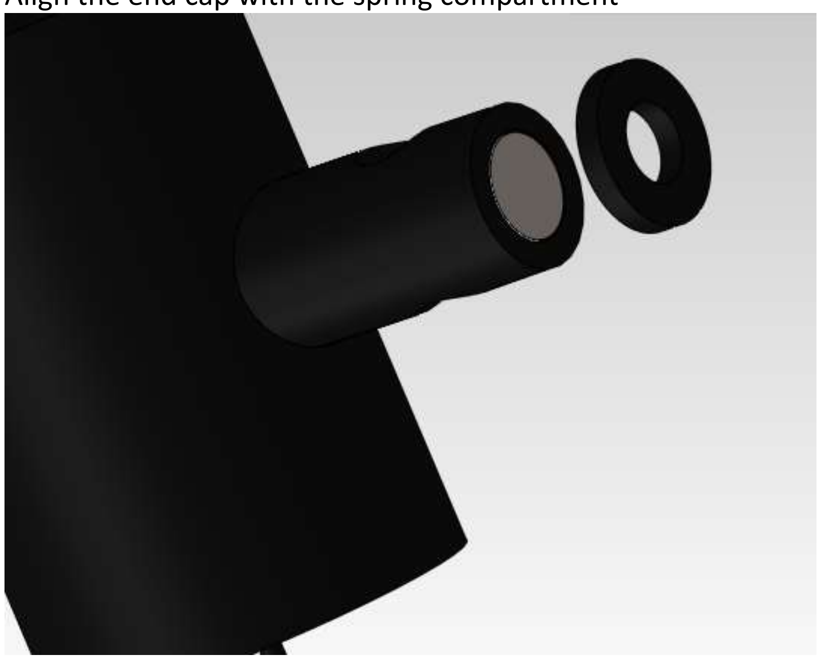


Fig. 105 – End plate alignment

10- Seal spring chamber with end cap

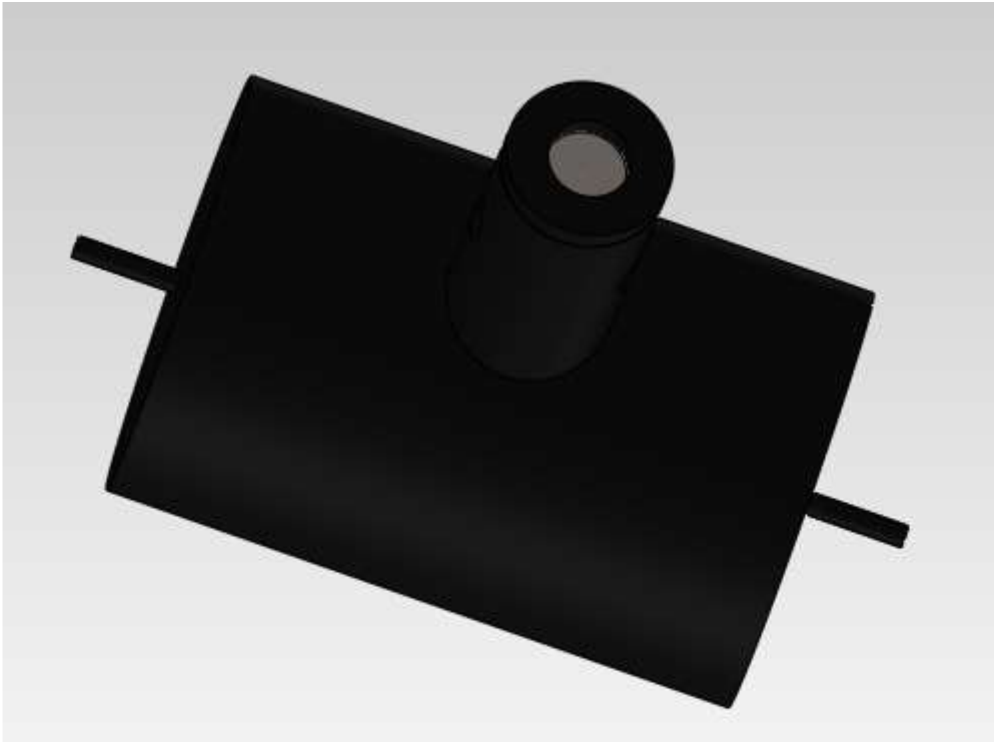


Fig. 106 – End cap installation

11- Thread the fastener though end cap and engage it with top plate

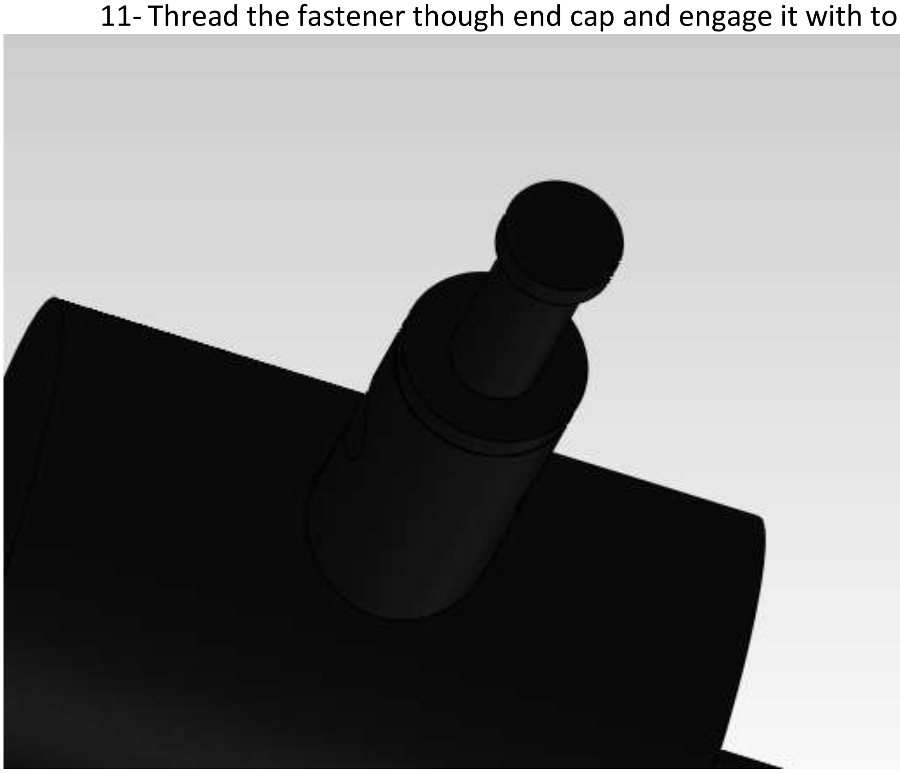


Fig. 107 – Adjustment fastener installation

8. Connect the hose for the valve to the right hose fitting on the pressure vessel

9. Press the open end of the hose over the barb located on the side of the compressor's top piece

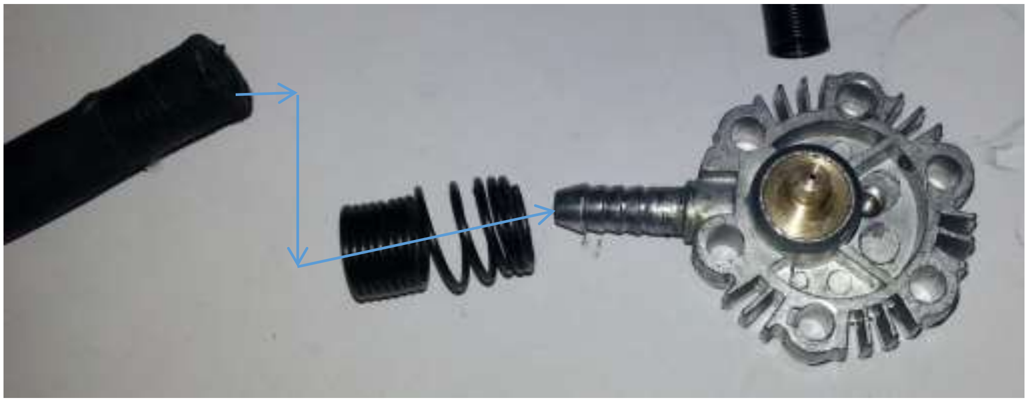


Fig. 108 – Fitting hose on to compressor barb

10. "Screw" the clamping spring towards the edge of the hose to tighten it over the barb

B. Pressure Gauge

1. Insert the mechanical portion of the pressure gauge into the gauge housing aligning it with the readout facing up so that it is visible to the user

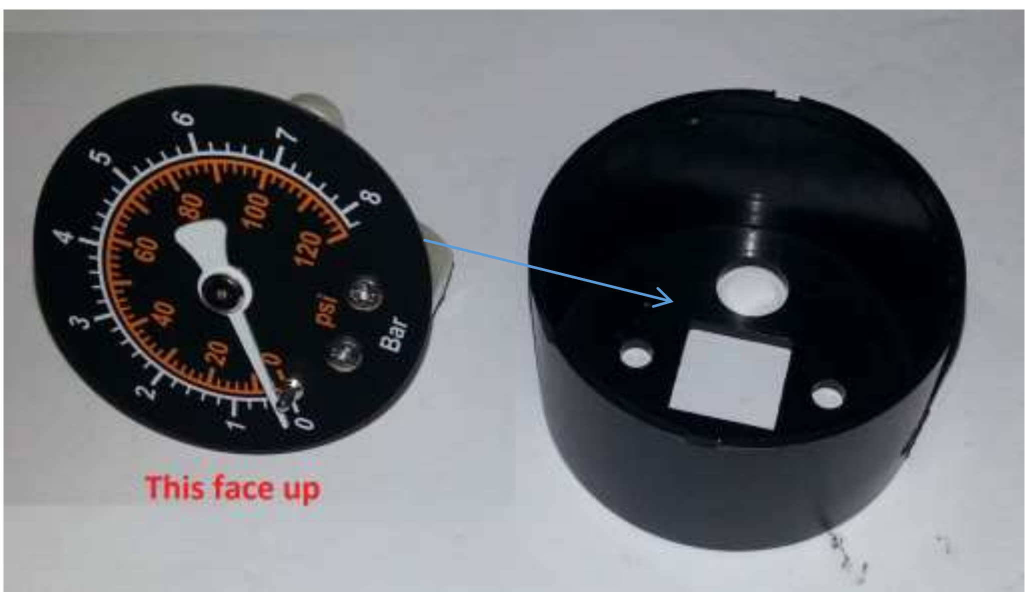


Fig. 109 – Aligning pressure gauge

2. Fasten two screws through the back of the housing and into the pressure gauge, securing it in place

Fig. 110 - Preparing the pressure gauge assembly

3. Snap on the clear front plate onto the gauge housing

Fig. 111 - Assembled pressure gauge

4. Slide a clamping spring onto one end of a rubber hose

5. Press the same side of the hose over the gauge’s barb(brass fitting)

6. Tighten the spring to secure the hose to the barb

Fig. 112 - Attaching the pressure gauge to the hose

7. Slip another clamping spring onto the open side of the hose

8. Press the hose onto the top barb on the top of the compressor’s top piece(brass fitting)

Fig. 113 - Attaching the valve and pressure gauge hoses to the compressor top

9. Tighten the clamping spring

Fig. 114 - After attaching and securing the hoses

C. Compressor

1. Insert the cam/shaft into the compressor housing oriented with the cam closest to the compressor intake

Fig. 115 – Inserting cam shaft into compressor housing

2. Line up the gear and slide it onto the cam shaft where it sticks of the back of the compressor housing

Fig. 116 - Assembling the lower portion of the compressor

3. Snap on a c-clip to the end of the shaft being sure to align points of the “C” with the flat part of the shaft holding it and the gear in place

Fig. 117 – Fixing gear to the shaft

4. Place the piston head onto the thinner end of the conrod and align the holes

Fig. 118 – Align piston head

5. Press the small metal pin through the piston head and crank arm to fasten the two together while still allowing the arm to rotate

Fig. 119 - Attaching the piston to the crank arm

6. Insert the piston arm into the top of the compressor housing in order to place it onto the small end of the cam shaft

Fig. 120 - Attaching the piston to the cam

7. Place the compressor cylinder over the piston and onto the cylinder housing

Fig. 121 – Placing the cylinder over the piston

8. Place the compressor top piece with the attached pressure gauge and pump valve onto the compressor cylinder

Fig. 122 - Attaching the top piece to the compressor

9. Fasten two screws through the top piece and into the housing in order to hold the assembly together

Fig. 123 - Fully assembled compressor

10. Fasten two screws through the compressor housing into the motor ensuring that the motor and compressor gears are in constant contact

Fig. 124 - Preparing to attach the motor

11. Press the motor cooling fan onto the end of the shaft coming out of the back of the motor

Fig. 125 - Full pump/compressor assembly

2. Front Panel Assembly

A. On/Off Mechanism

1. Snap the on/off turn knob onto the plastic back piece

Fig. 126 - Attaching the on/off knob to the back piece

2. Insert the plastic back piece into the right most hole (from operator perspective) of the front panel

Fig 127 – Inserting the switch into front panel

3. Fit the smaller of the two on/off body pieces to the back of the knob back piece

4. Insert the small jagged edged piece into the back of the body, flat side down that that it sits flat in the cutout

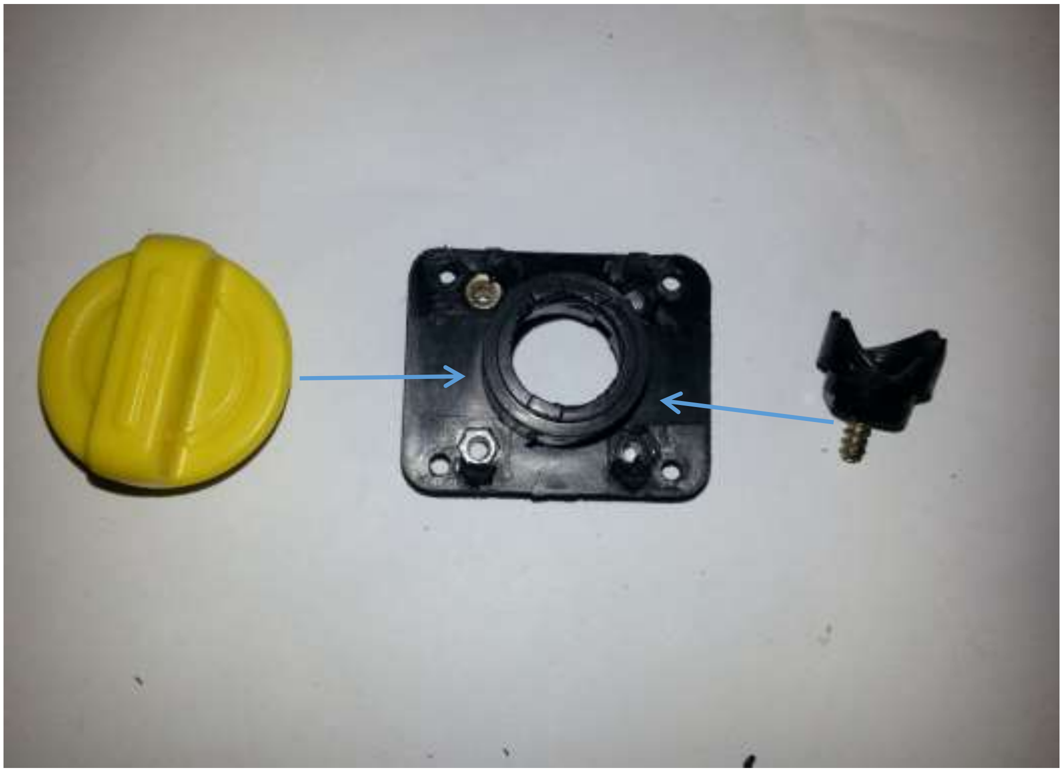


Fig. 128 - Assembling the front part of the on/off mechanism

5. Fasten a screw through the previously inserted piece and into the knob to secure it to the front panel while allowing the knob to turn

Fig. 129 - Front portion of the mechanism attached to the front panel

6. Fasten the small top hat shaped piece to the metal shaft with the larger radius section against the shaft

Fig. 130 – Attaching to the shaft

7. Slide the large spring over the shaft

Fig. 131 - Preparing to assembly the middle portion of the on/off mechanism

Fig. 132 – Inner switch assembly

8. Insert the shaft into the large on/off body part, ensuring that the large spring fit neatly around the extrusion on the body

Fig. 133 - Inserting the spring and shaft into the housing

9. Slide the small spring over the shaft coming through the back of the body

10. Place the small rectangular metal piece onto the shaft

Fig. 134 – Attaching C-clip to shaft

11. Snap a c-clip onto the end of the shaft to hold the metal piece and spring in place

Fig. 135 - Securing the metal plate in place using a c-clip

12. Set the two spacers in place on the back of the main body

13. Set the two metal brackets on top of each spacer that was previously set in place

Fig. 136 - Inserting the space and metal brackets

14. Fasten four screws, two for each bracket, in order to secure the mechanism together

15. Place to back plate onto the mechanism

Fig. 137 - Attaching the back piece

16. Fasten the back plate to the rest of the assembly using two screws

B. Circuitry

1. Solder a ground wire to the metal cylinder used for the DC power outlet

Fig. 138 – Solder wire to the DC cylinder

2. Insert the metal DC outlet cylinder into the left most hole (operator's perspective) of the front panel

Fig. 139 – Where to insert cylinder on front panel

3. Place the DC outlet back plate onto the front panel behind where the cylinder was previously inserted

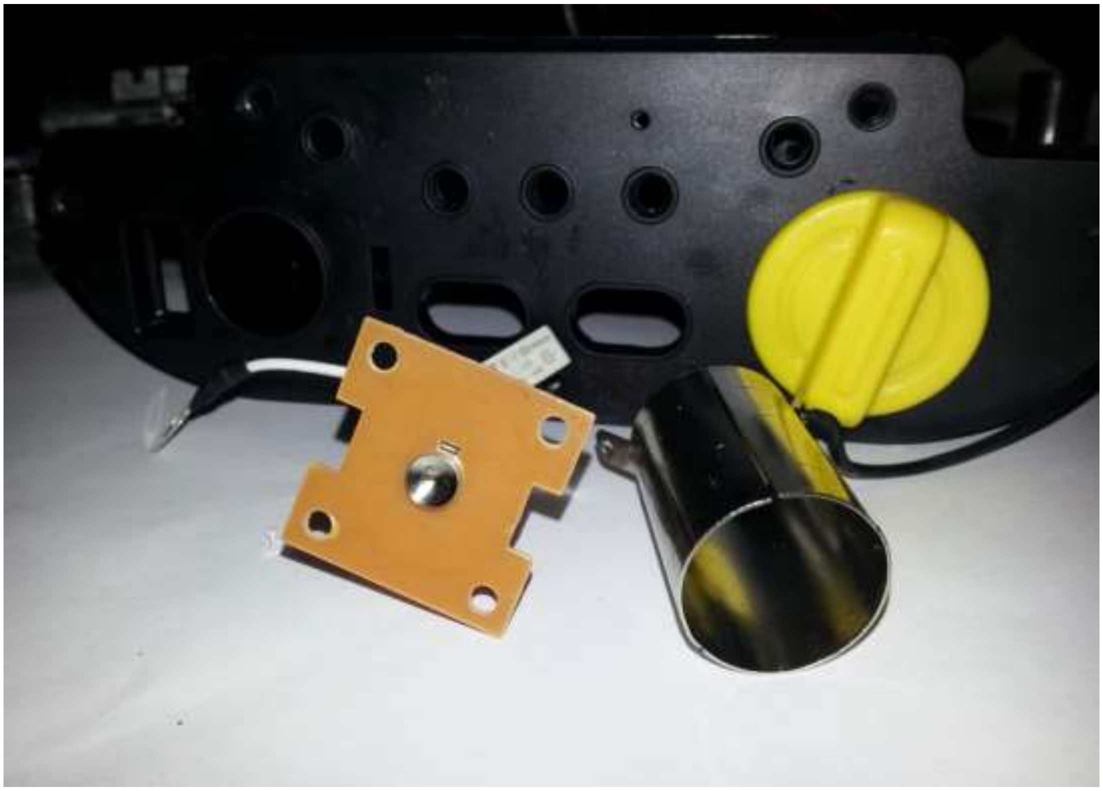


Fig. 140 - Preparing to assembly the DC outlet

4. Fasten the back piece in place using four small screws

5. Solder both a ground and a power wire to the back plate

Fig. 141 – Attaching the backplate

6. Thread the tab of the USB/DC outlet cover piece through the front panel in order to align the hole with the screw post

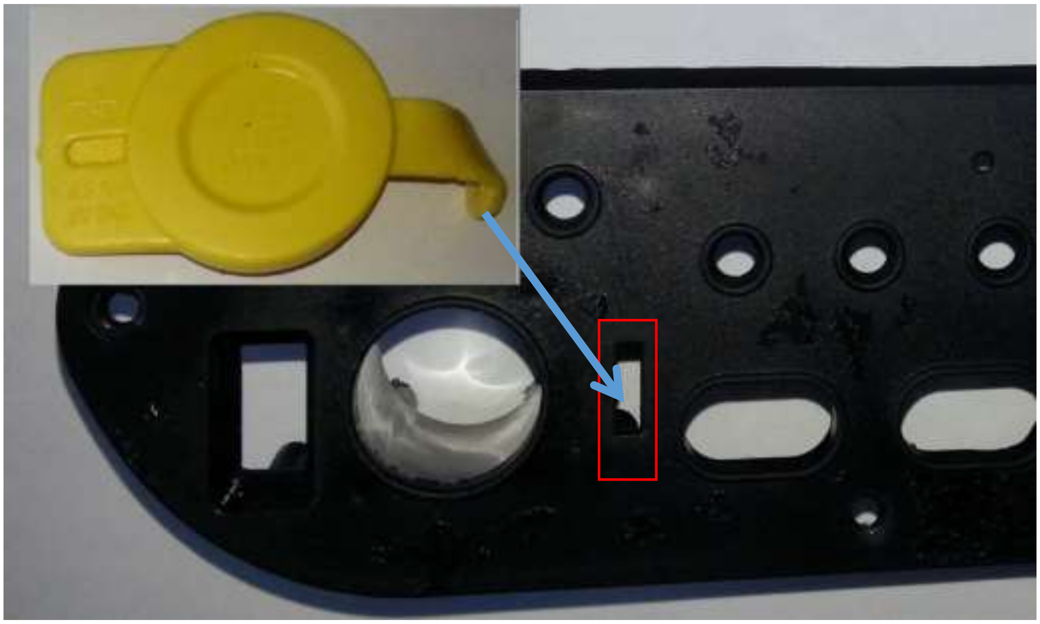


Fig. 142 – Inserting outlet cover

7. Fasten the USB/DC outlet cover to the front panel using one small screw

Fig. 143 - Fastening the DC outlet and outlet cover to the front panel

8. Solder the USB circuit to the main circuit board using three wires

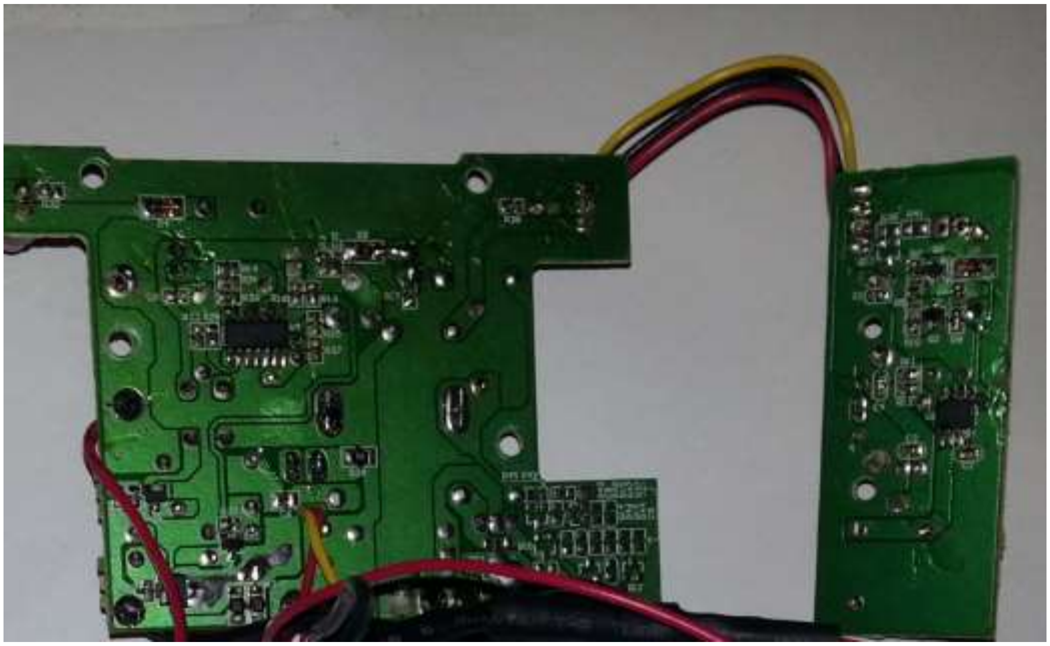


Fig. 144 – Attaching the two circuits

9. Solder the all other wires to the circuit board, including the AC adapter wires, flashlight wires, wires for the compressor on/off switch etc. In all there are 10 wires that need to be attached to the board

Fig. 145 - Soldering wires to the circuit board

10. Insert the left button into the front panel

11. Set the small button spring on the back of the button

12. Insert the other button

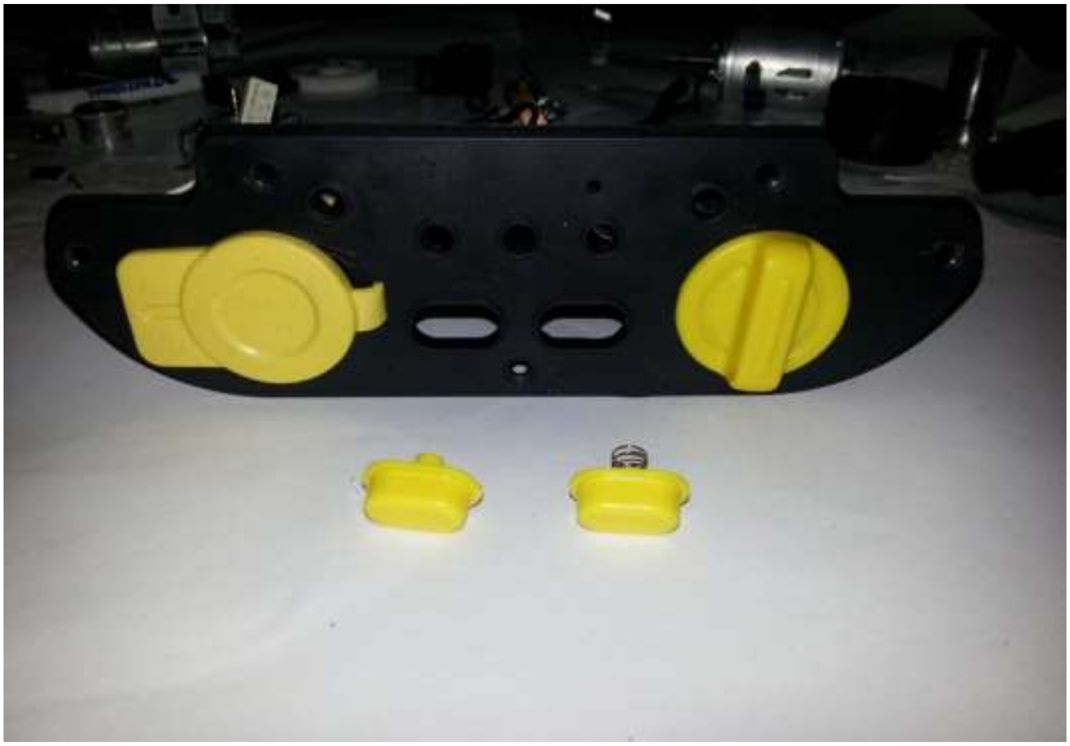


Fig. 146 - Inserting the buttons into the front panel

13. Set the circuitry in place

14. Secure the circuit to the front panel using six screws

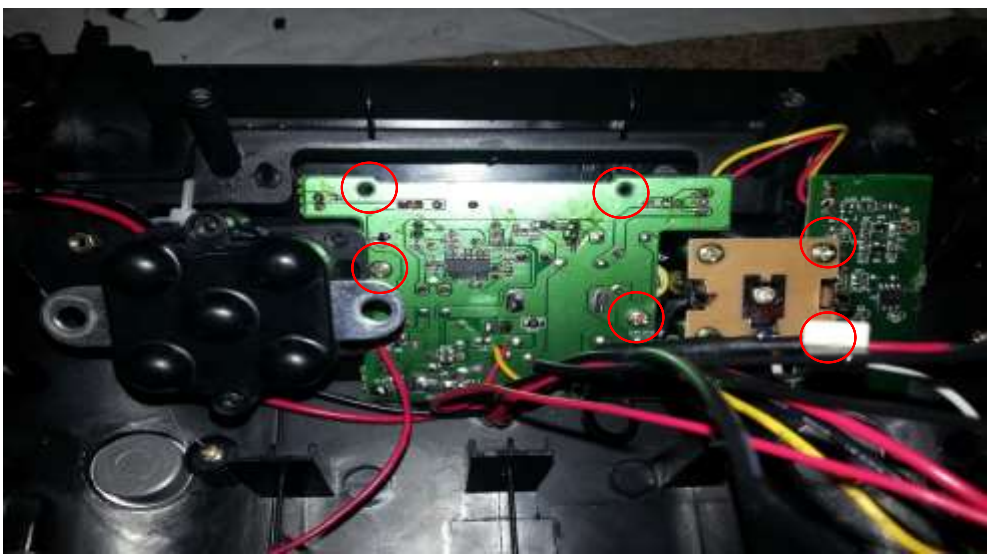


Fig. 147 - Securing the circuitry to the front panel

C. Flashlight

1. Solder the flashlight circuit to the two designated flashlight wires
2. Solder two more wires to the flashlight circuit
3. Solder the two open wires to the led light
4. Set the circuit inside of the flashlight shell

Fig. 148 – Attaching flashlight circuit board

5. Using two screws, secure the circuit to the shell
6. Set the led light in the shell
7. Set the light diffuser in the front of the shell piece

Fig. 149 – Inserting light diffuser

8. Press the other half of the shell on top of the half previously being used

9. Press in the two plastic locking pieces to help hold the shell together

10. Fasten a screw into the bottom of the shell to ensure the assembly stays together

Fig. 150 – Fully assembled flashlight

3. Inside Assembly

A. Main Housing

1. Attach the two front aesthetic panels to the front of the main housing

Fig. 151 – Attaching front panels

2. Secure the front panels by fastening five screws to each

Fig. 152 - Securing the two front panels to the housing

3. Insert the entire front panel assembly and fasten it to the front of the main housing using five screws

Fig. 153 - Attaching the front panel to the housing

4. Insert a screw into the left bracket of the on/off mechanism (if looking at the back side of the mechanism)

Fig. 154 - Preparing to attach the wires

5. Slide one power wire loop onto the screw

6. Slide one of the clamp cables onto the screw

7. Fasten a nut to the screw to ensure the two cables make a constant connection

8. Insert a screw into the right bracket of the on/off mechanism

9. Slide on the short main power cable

10. Fasten the cable into place using a nut

Fig. 155 - Attaching wires to the on/off control mechanism

11. Insert the battery into the main housing
12. Insert a screw through the left (ground) terminal of the battery
13. Slide two ground wire loops onto the screw
14. Slide a clamp cable onto the screw
15. Slide ground wire for the modular battery onto the screw

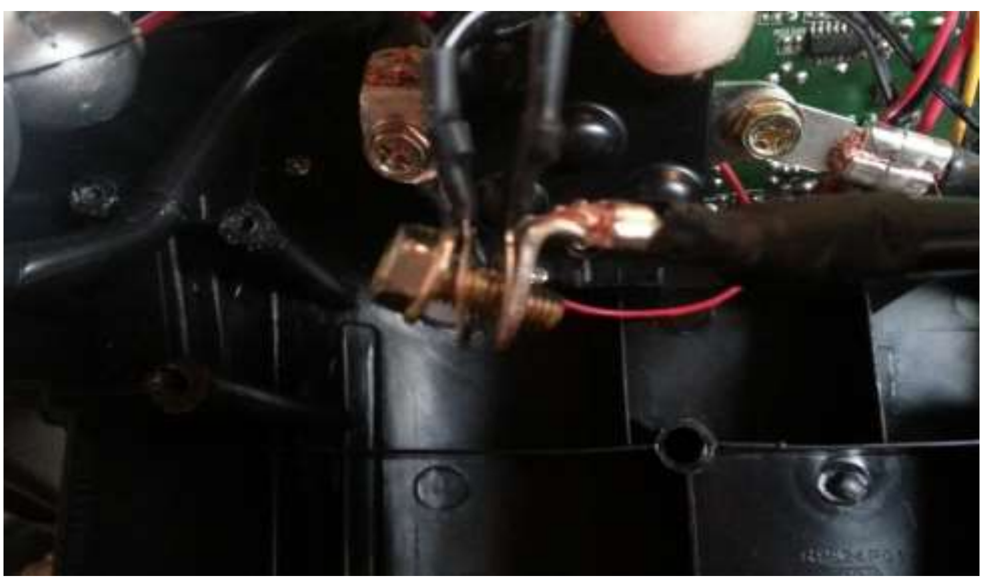


Fig. 156 - Attaching wires to the screw

16. Secure all the wires to the terminal by fastening a nut onto the screw

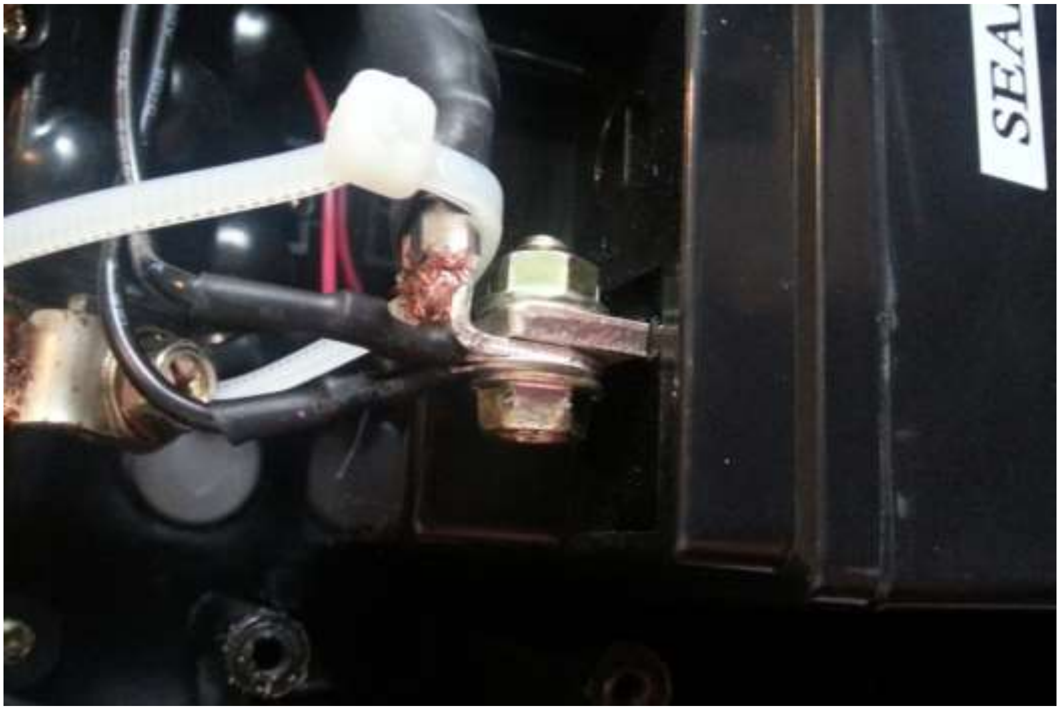


Fig. 157 - Attaching the wires to the ground terminal

17. Insert a screw into the right (hot) terminal of the battery

18. Slide on one hot wire loops

19. Slide on the short main power wire coming from the on/off mechanism

20. Slide the positive wire for the modular battery unit onto the bolt

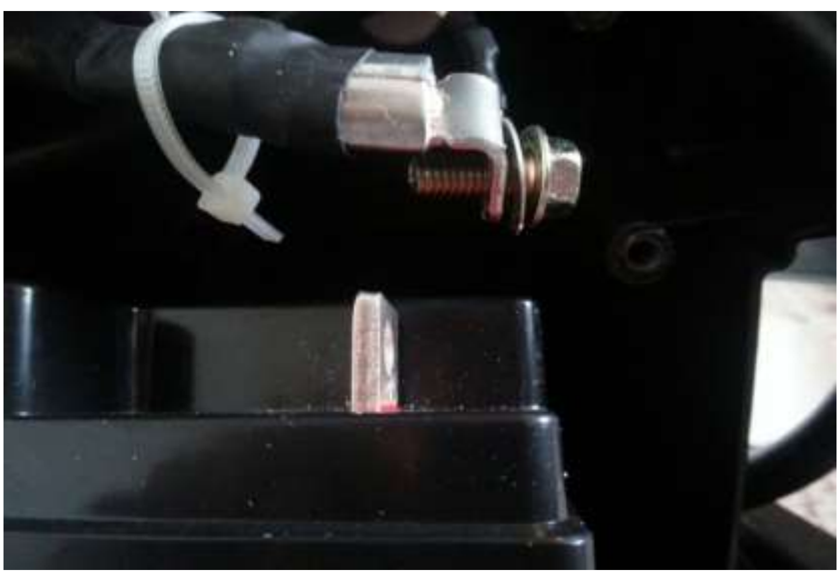


Fig. 158 - Preparing to attach the hot wires

21. Secure the wire to the terminal using a nut

Fig. 159 - Securing the wire to the hot terminal of the battery

22. Arrange the left (ground) wire to sit between the two posts on the right side of the housing
23. Place a yellow plastic wire tie down over the cable and sitting on the two posts
24. Secure the wire tie down with two screws

Fig. 160 – Arranging wire clamp # 1

25. Arrange the clamp wire attached to the left side of the on/off mechanism so that it sits between the two posts on the left side of the housing
26. Place the other yellow wire tide down on top of the two posts
27. Fasten the tie down with two screws

Fig. 161 – Arrange clamp wire # 2

Fig. 162 - After securing the wire tie downs

28. Insert the rubber AC adapter cover into the slot on the back piece of the main housing

29. Secure the cover to the housing using a small screw

Fig. 163 - Attaching the AC adaptor cover

30. Insert the AC adapter into the slot on the back piece of the main housing

Fig. 164 - Inserting the AC adaptor

31. Place the square bracket over the adapter

32. Fasten the bracket using two screws ensuring that the AC adapter stays in place

Fig. 165 - Securing the AC adaptor

33. Slide the metal handle onto the two posts at the top of the housing

34. Insert the two metal posts into each side of the metal handle previously inserted

Fig. 166 - Attaching the metal handle to the housing

35. Set the flashlight into the grove on the side of the housing
36. Pull the clamp wire pinned down on the left through the left arm hole in the main body back piece
37. Pull the motor wire and compressor on/off switch wires through the hole near the middle of the back piece

Fig. 167 - Pulling the wires through the housing

38. Pull the clamp wire pinned down on the right through the right arm hole in the main body back piece

Fig. 168 – Connecting front and back pieces

39. Fit the back piece onto the front piece

40. Secure the main body together by fastening 16 screws

B. Back Compartment

1. Place the on/off switch spacer onto the switch cutout

Fig. 169 – Solder wires on to switch

2. Solder four wires to the on/off switch

3. Insert the on/off switch into the switch cutout

4. Fasten the switch the housing using two screws

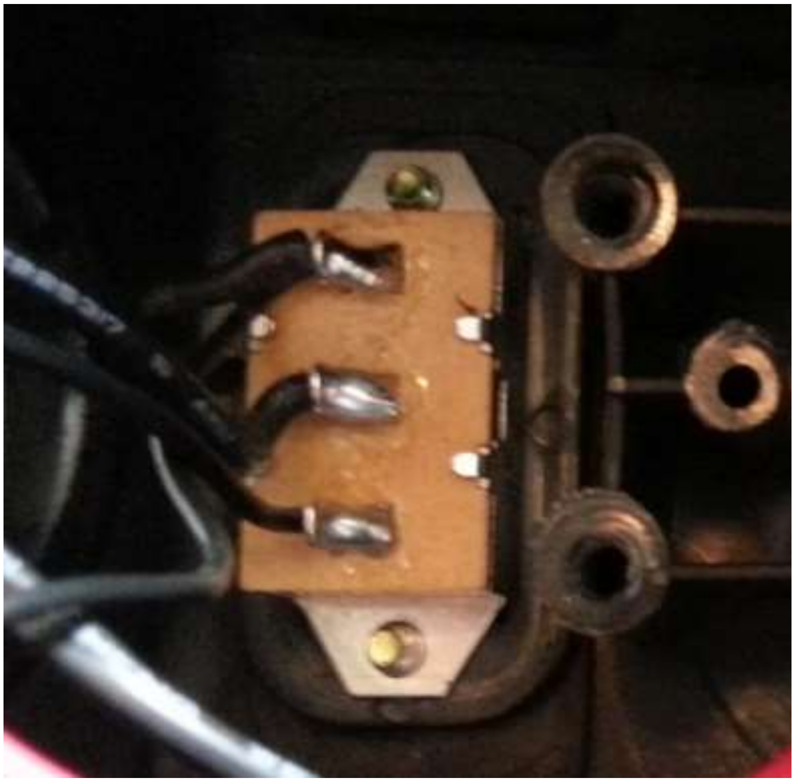


Fig. 170 – Arrange wires for on/off switch

5. Arrange the wires to be in between the two small posts

6. Place the small wire tie down onto the two posts

7. Secure the wire tie down using two small screws

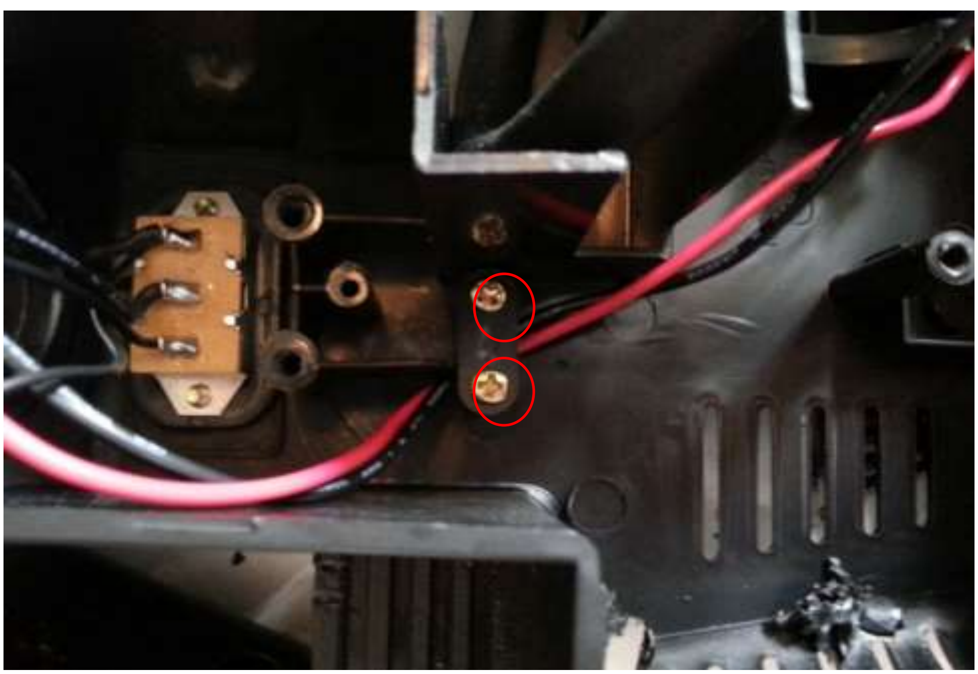


Fig. 171 - Securing the wire tie down

8. Solder the two motor wires to the two terminals on the back of the motor

Fig. 172 – Soldering two wires to motor

9. Crimp the thermal protector onto the positive motor wire and another power wire crimped into the other end

10. Insert the rubber motor space into the housing

11. Set the motor/compressor assembly into the housing

12. Place two rubber spacers into the screw holes on the compressor housing

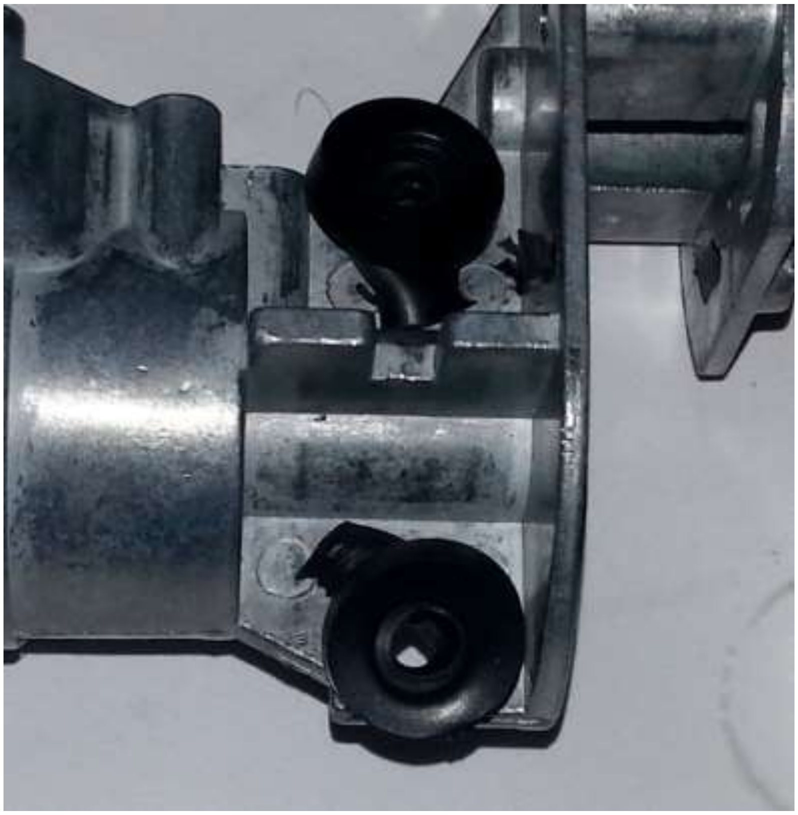


Fig. 173 – Inserting the rubber washers

13. Secure the motor/compressor assembly to the housing using two screws

14. Place the rounded metal bracket over the motor

15. Secure the bracket to the housing using two screws

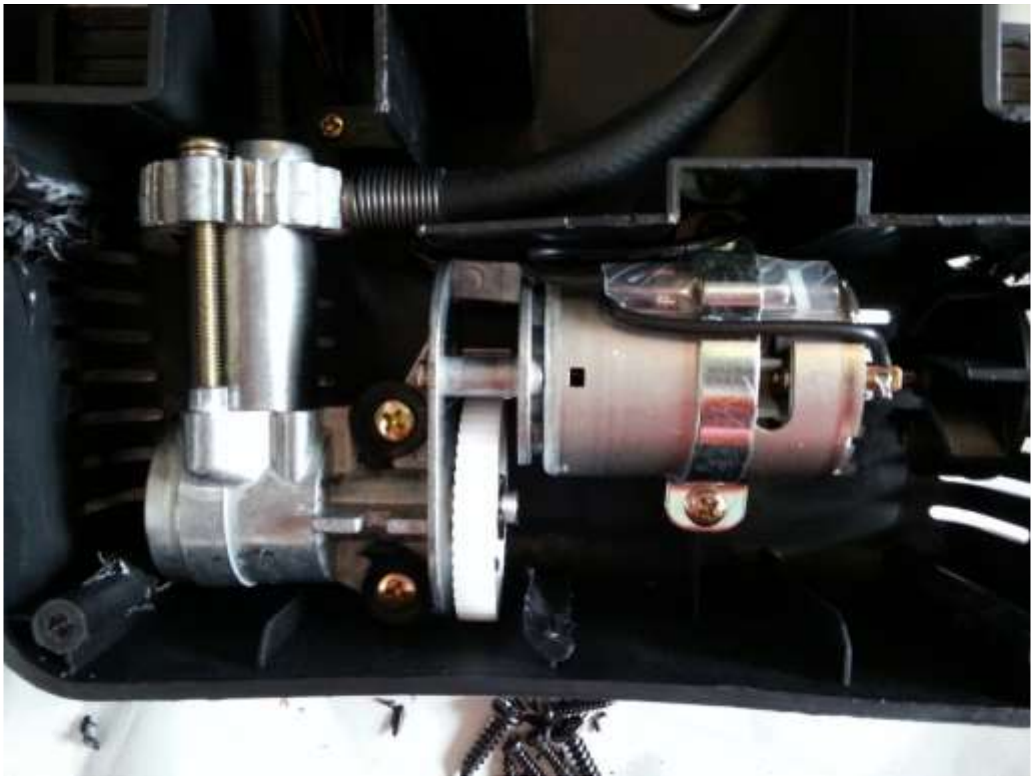


Fig. 174 – Inserting the motor/compressor assembly into housing

16. Fit the pressure gauge assembly into the hole in the back of the housing
17. Place the angled metal bracket against the pressure gauge and on top of the two screw posts
18. Fasten the bracket to the housing using two screws

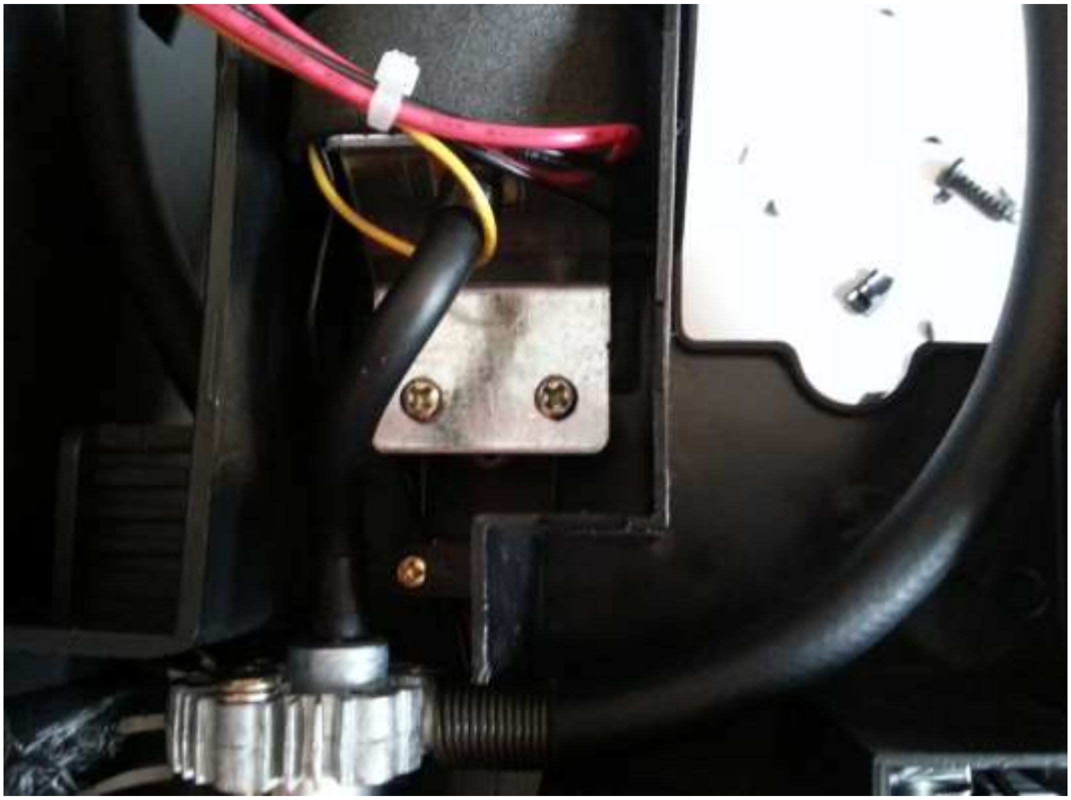


Fig. 175 - Attaching the bracket to hold the pressure gauge in place

19. Pull the pump valve through the square hole in the top of the housing

20. Place the back housing compartment onto the main housing

21. Fasten the two bodies together using six screws

4. External Components

A. Body

1. Insert a plastic corner bumper into the metal handle

2. Insert the other half of the bumper into the handle

3. Secure the two halves around the handle using one screw

4. Repeat steps 1, 2, and 3 for the bumper on the other side of the handle

Fig. 176- Attaching the corner bumpers

5. Place the rubber grip onto the handle

Fig. 177 - Inserting one half of the rubber grip

6. Sandwich the other half of the rubber grip onto the handle

7. Fasten the rubber grip around the handle using two screws

Fig. 178 – Finished handle assembly

B. Clamps

One should note that the assembly process is identical for both clamps.

1. Place exposed copper wire onto the end of the copper jaws
2. Crimp the copper jaws around the wire to secure the two together

Fig. 179 - Attaching the main wire to the copper jaw

3. Place a plastic spacer onto the bottom half of the clamp
4. Place the copper jaw with attached wire onto of the spacer

5. Rivet the three components together

6. Place a plastic space onto the other half of the clamp

7. Place the other copper jaw on top of the spacer

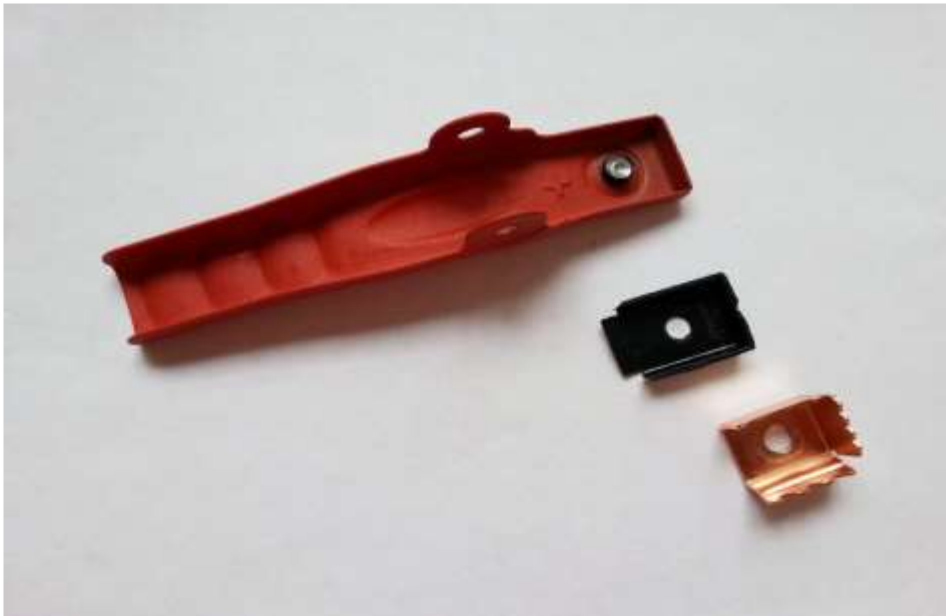


Fig. 180 – Assembling one half of the clamp

8. Rivet the three components together

Fig. 181 - Assembled half of the clamp

9. Align the spring in between the two clamp halves

Fig. 182 – Aligning the spring between the two clamp halves

10. Compress the two halves together in order to get a rivet through both sides and the spring

Fig. 183 - Fully assembled clamp

The following assembly charts are based directly off of the steps previously outlined. The step number corresponds to the specific subsection step of each subassembly. The final chart displays the overall time it take to assembly the product from start to finish.

5. Modular Assembly

A) Baseplate installation

1. Place two buttons in button slots located in the baseplate

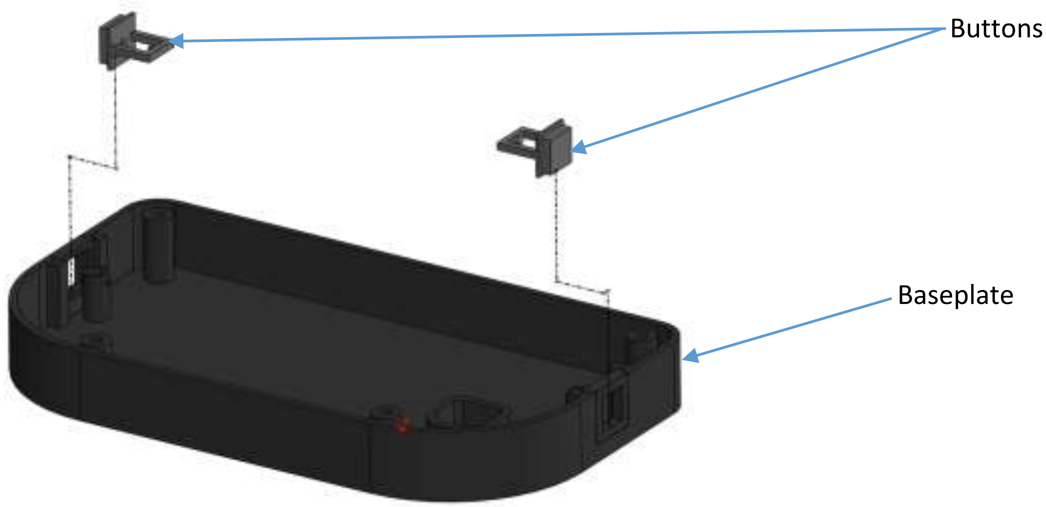


Fig. 184 – Aligning buttons on the baseplate

2. Place one spring in between each button and battery peg cylinder

3. Solder wires connecting new baseplate power plug to the original units power supply

4. Place baseplate with buttons installed up against the bottom of the completed original unit

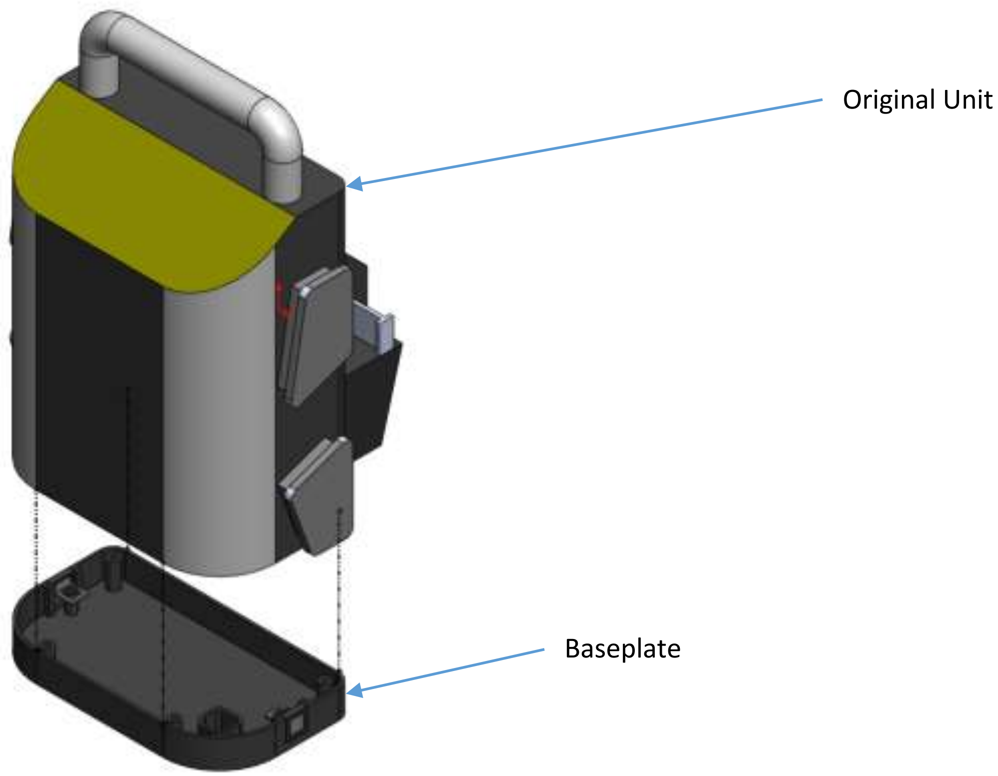


Fig. 185 – Aligning baseplate to the main unit

5. Fasten baseplate to the original unit using four 10-24 fasteners that are 1.5” long

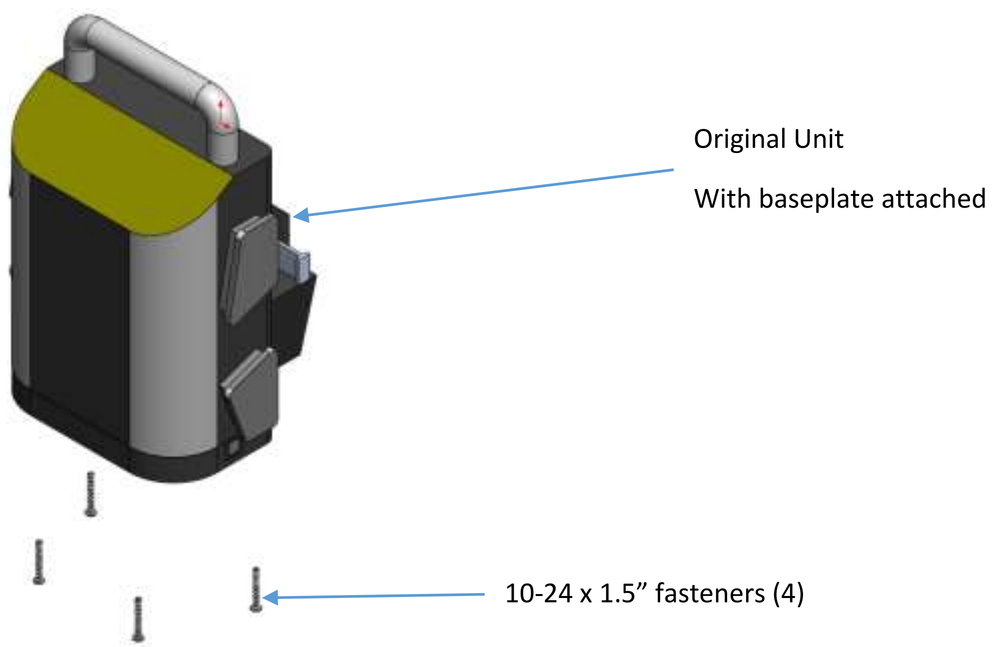


Fig. 186 – Fasten baseplate to the main unit

6. The original unit is now upgraded and ready to receive the optional modular unit

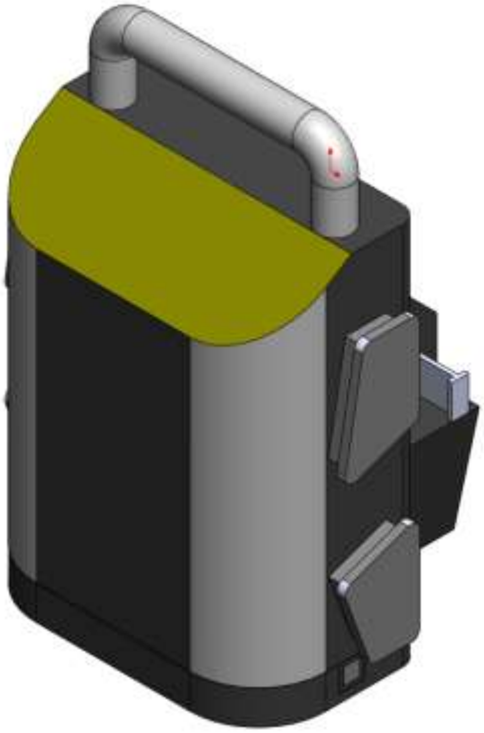


Fig. 187 – Finished baseplate and main unit assembly

B) Modular Unit Assembly

1. Grab modular unit top

Fig. 188 – Aligning 12 to 24 volt switch

2. Install 12-24 V switch into front hole of the modular unit top

Fig. 189 – Aligning 12 to 24 volt switch

3. Install the 12-24 V switch backplate

Fig. 190 – 12 to 24 V switch backplate installation

The backplate clasps the 12-24 V switch onto the modular unit, as well as provides the circuit board that is necessary to alternate between 12V jump start capability and 24V. When utilizing the 12V jump start capability, the circuit board aligns the two 12 V batteries in a parallel connection. When utilizing the 24V jump start capability, the circuit board aligns the two 12 V batteries in a series connection.

4. Solder one end of the new power wires to the 12-24V switch backplate and the other end to the 12 V battery connection posts

5. Solder another set of power wires from the 12-24V switch backplate to the power plug located at the top of the modular unit

6. Insert 12 V battery in the modular top

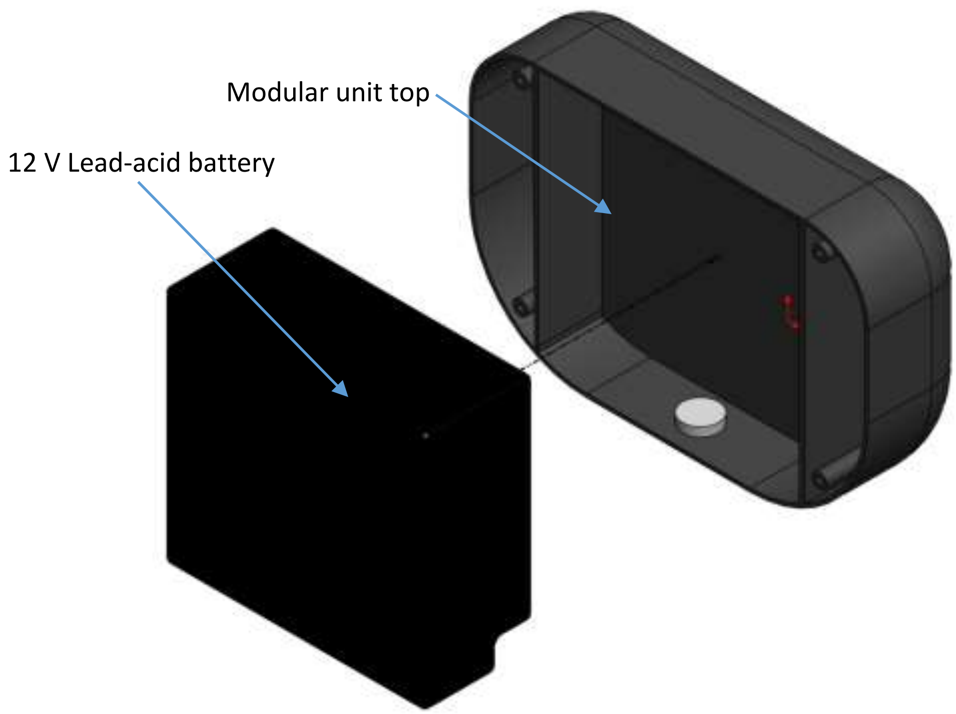


Fig. 191 – 12 V battery installation

7. Position modular unit bottom over the bottom side of the 12 V battery

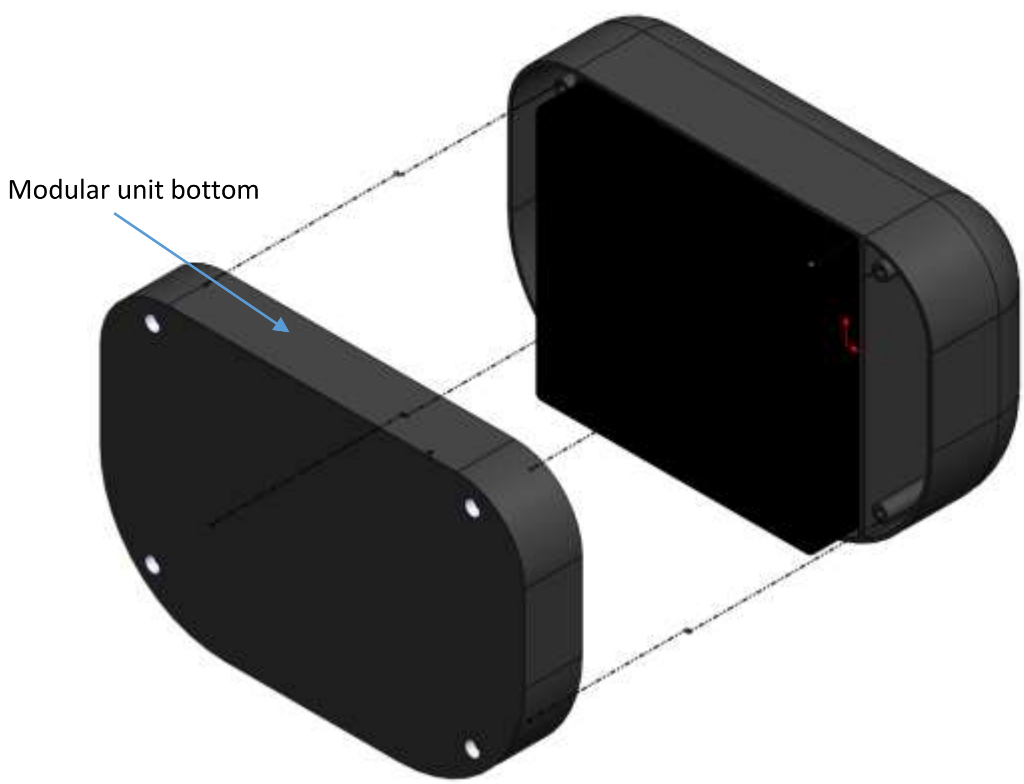


Fig. 192 – Aligning the modular unit bottom

8. Fasten the bottom of the modular unit to the top of the modular unit using four 10-24 x 1.5” fasteners

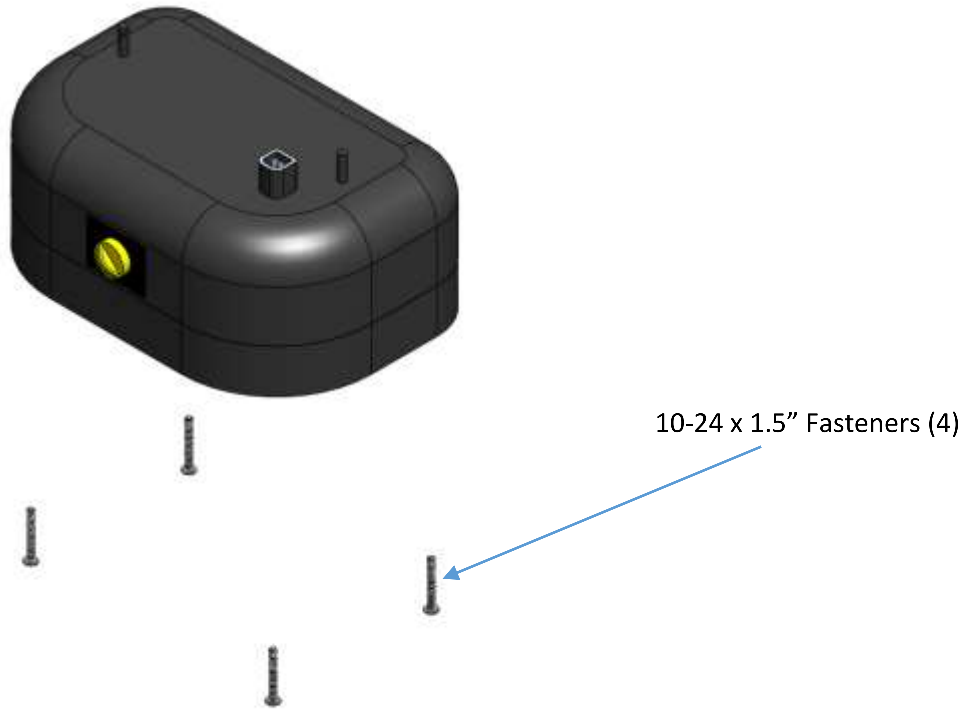


Fig. 193 – Fastening modular unit bottom to the unit top

9. You now have a completed modular assembly

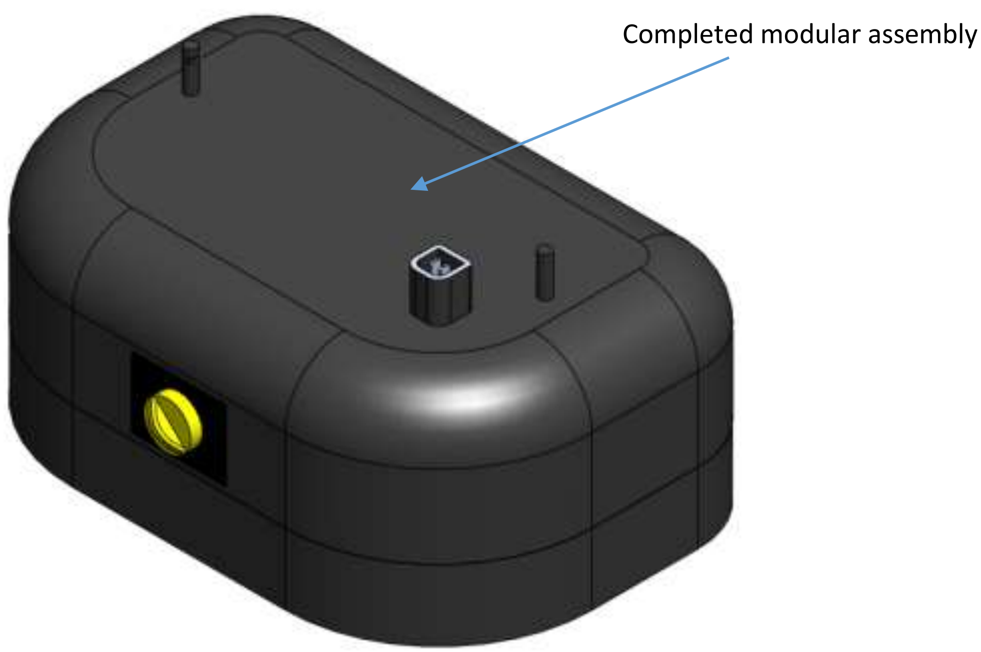


Fig. 194 – Completed modular unit assembly

Cost Analysis

In order to determine the cost of this device multiple sources of cost were taken into account. The three major categories of cost were material cost, manufacturing cost, and assembly cost.

Material Cost – To determine the raw material cost of the device the amount of material necessary to produce each part was determined. The mass of each part had to be found. Each part used from the original device was massed with a scale. Any parts that were custom created had their masses approximated using Solidworks. Material cost in grams per US dollars were found from various retailers on the internet. Using these costs along with the mass of the material necessary for each part the cost to purchase the raw materials could be found. Below is a sample calculation.

First the mass of the material is found, along with its bulk material cost

Mass of pressure vessel = 417.3 grams

Unit cost of ABS = $0.0025 per gram

Using these two values the raw material cost of the pressure vessel can be found as shown below

$$Raw\ materal\ cost = 417.3\ grams * \frac{0.0025\ dollars}{1\ gram\ ABS} = \$1.04$$

This was then computed for each part of the device. The material costs for each part can be seen in the table below.

Modular Unit Materials					
Part Name	**Material**	**Unit**	**Cost/Unit**	**Amount**	**Cost**
Modular Top	ABS	grams	$0.0025	848.2	$2.1205
Modular Bottom	ABS	grams	$0.0025	421.8	$1.0545
12-24V Switch	ABS	grams	$0.0025	4.5	$0.0113
Switch Backplate	ABS	grams	$0.0025	4.5	$0.0113
Circuit Board	N/A	each	$3.0000	1	$3.0000
10-24 x 1.5" Phillips Head Pan Screws	Stainless Steel	each		8	$0.0000
Wiring	N/A	in	$0.0050	12	$0.0600
Power Plug	N/A	each	$0.0600	1	$0.0600
12 V Battery	N/A	each	$11.7500	1	$11.7500
				Total Material Cost	**$18.0675**

Original Unit materials								
Component	**QTY**	**material**	**mass (g)**	**density (kg/m^3)**	**volume (m^3)**	**$/m^3**	**$/unit**	**Total Cost**
Control Panel	1	PP	31.8	855	3.7193E-05	7862.397229	N/A	0.29
DC Cylinder	1	abs	12	1040	1.15385E-05	7687.303871	N/A	0.09
Jump Starter Power Knob	1	abs	3.2	1040	3.07692E-06	7687.303871	N/A	0.02
USB Button	1	abs	1	1040	9.61538E-07	7687.303871	N/A	0.01
Battery Status Button	1	abs	0.9	1040	8.65385E-07	7687.303871	N/A	0.01
USB/DC Casing	1	abs	5.2	1040	0.000005	7687.303871	N/A	0.04
On/Off switch	1	PP	72.5	855	8.47953E-05	7862.397229	N/A	0.67
AC Adapter Bracket	1	abs	8.6	1040	8.26923E-06	7687.303871	N/A	0.06
Compressor Switch Bracket	10	abs	1.1	1040	1.05769E-06	7687.303871	N/A	0.08
4 x 40 x 1/4" Phillips Flat Head	5	N/A	-	N/A	N/A	N/A	0.0375	0.19
4 x 40 x 3/8" Phillips pan Head	25	N/A	-	N/A	N/A	N/A	0.043	1.08
4 x 40 x 7/16" Phillips Pan Head	4	N/A	-	N/A	N/A	N/A	0.0436	0.17
4 x 40 x 5/16" Phillips Pan Head	6	N/A	-	N/A	N/A	N/A	0.042	0.25

4 x 40 x 1/2" Phillips Pan Head	16	N/A	-	N/A	N/A	N/A	0.0445	0.71
8 x 32 x 5/8 " Phillips Pan Head	4	N/A	-	N/A	N/A	N/A	0.0833	0.33
4 x 40 x 3/8 " Phillips Truss Head	1	N/A	-	N/A	N/A	N/A	0.0435	0.04
4 x 40 x 5/8 " Phillips Pan Head	6	N/A	-	N/A	N/A	N/A	0.0432	0.26
6 x 32 x 1/2" Phillips Pan Head	2	N/A	-	N/A	N/A	N/A	0.0514	0.10
8 x 32 x 1/2 " Phillips Pan Head	4	N/A	-	N/A	N/A	N/A	0.0754	0.30
Compressor Rear Panel	1	PP	191	855	0.000223392	7862.397229	N/A	1.76
AC Charger Covering	1	abs	15.8	1040	1.51923E-05	7687.303871	N/A	0.12
Motor Cradle	1	abs	1.3	1040	0.00000125	7687.303871	N/A	0.01
Foam Connectors	2	abs	10	1040	9.61538E-06	7687.303871	N/A	0.15
Motor Bracket	1	abs	7.7	1040	7.40385E-06	7687.303871	N/A	0.06
Pressure Gage Trim Ring	1	abs	5.2	1040	0.000005	7687.303871	N/A	0.04
Air Pressure Gage	1	abs	29.4	855	3.4386E-05	7862.397229	N/A	0.27
Compressor Washers	2	abs	1.6	1040	1.53846E-06	7687.303871	N/A	0.02
Nozzle	1	N/A	-	N/A	N/A	N/A	0.93	0.93
Air Hose	1	N/A	-	N/A	N/A	N/A	0.47	0.47

Pressure Gage Bracket	1	abs	0.4	855	4.67836E-07	7862.397229	N/A	0.00
Compressor Wire Connector	1	N/A	-	N/A	N/A	N/A	0.32	0.32
Center Housing	1	PP	337.3	855	0.000394503	7862.397229	N/A	3.10
Front Panel	1	PP	507.8	1040	0.000488269	7687.303871	N/A	3.75
Right Panel	1	PP	38.3	1040	3.68269E-05	7687.303871	N/A	0.28
Left Panel	1	PP	38.3	1040	3.68269E-05	7687.303871	N/A	0.28
Handle Bumper Front	2	abs	4.3	1040	4.13462E-06	7687.303871	N/A	0.06
Handle Bumper Back	2	abs	4.3	1040	4.13462E-06	7687.303871	N/A	0.06
Front Grip	1	abs	18.1	855	2.11696E-05	7862.397229	N/A	0.17
Back Grip	1	abs	16.5	1040	1.58654E-05	7687.303871	N/A	0.12
Handle	1	N/A	-	N/A	N/A	N/A	0.97	0.97
1/4"-1-1/4" Bright Finish Alloy Dowel Pin	2	N/A	-	N/A	N/A	N/A	0.11	0.22
12 V Lead Acid Battery	1	N/A	-	N/A	N/A	N/A	15.46	15.46
Positive Clamp	1	N/A	-	N/A	N/A	N/A	3.73	3.73
Negative Clamp	1	N/A	-	N/A	N/A	N/A	3.73	3.73
Clamp Connector	2	N/A	-	N/A	N/A	N/A		0.00
Zipties	5	N/A	-	N/A	N/A	N/A		0.00
Adapter Nozzles	3	N/A	-	N/A	N/A	N/A		0.00
Charging Adapter	1	N/A	-	N/A	N/A	N/A		0.00
Flashlight Housing	1	abs	12.1	855	1.4152E-05	7862.397229	N/A	0.11
Misc. Wiring	-	-	-	-	-	-	-	5.00

Misc. Circuit Boards	-	-	-	-	-	-	-	7.00
60 ZY DC Motor	1	N/A	N/A	N/A	N/A	N/A	20	20.00
							Total Material Cost	72.91

Pressure Vessel Materials					
Part	Material	Unit	Cost/Unit	Amount	Cost
Vessel	ABS	Grams	0.0025	417.3	1.04325
End Cap	ABS	Grams	0.0025	4.53	0.011325
Gasket	N/A	Each	0.04	1	0.04
Top Plate	Stainless Steel	grams	0.0007	9.07	0.006349
Bottom Plate	Stainless Steel	Grams	0.0007	9.07	0.006349
Adjustment Fastener	ABS	Grams	0.0025	18.14	0.04535
Spring	N/A	Each	1.38	1	1.38
Electrical contact	N/A	each	0.1	1	0.1
				Total Material Cost	2.632623

Charts 2 through 4 – Total material costs for each subassembly

Assembly Cost- To estimate the assembly cost the assembly procedure had to be used. Using the handling and insertion time charts times for each step could be estimated. Based on the size and grip of the parts being assembled a time for each step was selected. Once a time was selected it was then multiplied by the wage to employ a US worker. This was done for each assembly step to find the total cost to assemble the entire device.

Below is an example of an estimate to assemble part of the pressure regulator. It is for assembling the bottom plate into the pressure regulator. First the two angles of orientation were determined to properly orient the plate with the pressure vessel. Alpha was determined to be 180 degrees. This means the plate can be oriented properly every time it is rotated 180 degrees about the alpha axis. The beta angle is 0 degrees. This means no matter what the orientation about the beta axis it will be oriented correctly. This is because it is a disk and has symmetry about the beta axis. To find the time the chart is then used with the angles. The size of the part must be taken into account. The sum of alpha and beta is less than 360 so the value will be in row 0. The part has a thickness greater than 2 mm so it will be in either column 1, 2, or 3. The size is greater than 15 millimeter therefore the time to perform this action is 1.13 seconds. Next, the time to insert the plate into the chamber is found. For this time the insertion chart must be used. This analysis is not as objective as the handling time. The first row was selected because the part can be considered easy to reach and no tools are required. The first column is then selected because the piece is easy to align and there is no resistance to the part being inserted. This gives an insertion time of 1.5 seconds.

The times are then added together and multiplied by the wage of a US worker as shown below.

$$Assembly\ cost = 2.63\ seconds * \frac{1\ minute}{60\ seconds} * \frac{1\ hour}{60\ minutes} * \frac{20\ dollars}{1\ hour} = 0.01\ dollars$$

This is then summed for each step in the assembly. The times and cost are shown in the tables below. The tables are divided by subsections of the assembly.

Pump Assembly							
Step	**α (degrees)**	**β (degrees)**	**α+β (degrees)**	**Chart Cell**	**Handling Time (s)**	**Chart Cell2**	**Insertion Time (s)**
A1	360	360	720	3,1	2.25	0,0	1.5
A2	360	360	720	3,0	1.95	0,0	1.5
A3	180	0	180	0,4	2.18	3,1	5
A4	360	0	360	1,1	1.8	0,0	1.5
A5	360	0	360	1,0	1.5	3,0	2
A6	N/A	N/A	N/A	N/A	0	9,3	3.5
A7	180	0	180	0,1	1.43	0,1	2.5
A8	360	0	360	1,0	1.5	3,1	5
A9	360	0	360	1,1	1.8	9,2	5
B1	360	360	720	3,0	1.95	0,0	1.5
B2	360	0	360	1,1*2	3.6	3,8*2	12
B3	360	0	360	1,3	2.06	3,0	2
B4	180	0	180	0,1	1.43	0,1	2.5
B5	360	0	360	1,1	1.8	3,1	5
B6	360	0	360	1,1	1.8	9,2	5
B7	180	0	180	0,1	1.43	0,1	2.5
B8	360	0	360	1,0	1.5	3,1	5
B9	360	0	360	1,1	1.8	9,2	5
C1	360	0	360	1,0	1.5	0,0	1.5
C2	180	180	360	1,0	1.5	0,2	2.5
C3	180	180	360	1,4	2.55	3,1	5
C4	360	180	540	2,1	2.1	0,0	1.5
C5	180	0	180	0,3	1.69	3,1	5
C6	360	180	540	2,0	1.8	1,0	4
C7	180	0	180	0,0	1.13	0,0	1.5
C8	360	360	720	3,0	1.95	0,0	1.5
C9	360	0	360	1,0*2	3	3,8*2	12
C10	360	180	540	2,0*2	3.6	4,8*2	17
C11	360	0	360	1,0	1.5	3,1	5
				Total:	54.1	**Total:**	124.5
						Overall Time:	178.6

Front Panel Assembly

Step	α (degrees)	β (degrees)	α+β (degrees)	Chart Cell	Handling Time (s)	Chart Cell2	Insertion Time (s)
A1	360	180	540	2,0	1.8	3,1	5
A2	360	0	360	1,0	1.5	0,0	1.5
A3	360	180	540	2,0	1.8	0,0	1.5
A4	360	0	360	1,1	1.8	0,0	1.5
A5	360	0	360	1,1	1.8	4,8	8.5
A6	360	0	360	1,1	1.8	3,8	6
A7	180	0	180	0,0	1.13	0,0	1.5
A8	360	0	360	1,0	1.5	0,0	1.5
A9	180	0	180	0,0	1.13	0,0	1.5
A10	180	180	360	1,3	2.06	0,0	1.5
A11	180	0	180	1,4	2.55	4,1	7.5
A12	180	360	540	2,3*2	4.72	0,0*2	3
A13	180	360	540	2,3*2	4.72	0,0*2	3
A14	360	0	360	1,1*4	3.6	3,8*4	24
A15	360	180	540	2,0	1.8	0,0	1.5
A16	360	0	360	1,1*2	3.6	3,8*2	12
B1	360	0	360	1,3	2.06	9,5	8
B2	360	0	360	1,0	1.5	0,0	1.5
B3	360	90	450	1,3	2.06	0,0	1.5
B4	360	0	360	1,1*4	7.2	3,8*4	24
B5	360	0	360	1,3*3	4.12	9,5*2	16
B6	360	360	720	3,1	2.25	0,2	2.5
B7	360	0	360	1,1	1.8	3,8	6
B8	360	0	360	1,3*6	7.2	9,5*6	48
B9	360	0	360	1,3*10	20.6	9,5*10	80
B10	360	180	540	2,1	2.1	0,0	1.5
B11	180	0	180	0,1	1.43	0,0	1.5
B12	360	180	540	2,1	2.1	0,0	1.5
B13	360	360	720	3,3	2.51	0,1	2.5
B14	360	0	360	3,1*6	13.5	3,8*6	36
C1	360	0	360	1,3*2	4.12	9,5*2	16
C2	360	0	360	1,3*2	4.12	9,5*2	16
C3	360	0	360	1,3*2	4.12	9,5*2	16
C4	360	360	720	3,3	2.51	0,1	2.5
C5	360	0	360	1,4*2	5.1	3,8*2	12
C6	360	360	720	2,1	2.25	0,1	2.5
C7	180	0	180	0,1	1.43	0,0	1.5
C8	360	360	720	3,0	1.95	0,0	1.5
C9	360	0	360	1,1*2	3.6	3,1*2	10
C10	360	0	360	1,4	2.55	3,8	6
				Total:	139.49	**Total:**	395.5
						Overall Time:	534.99

Inside Assembly							
Step	α (degrees)	β (degrees)	α+β (degrees)	Chart Cell	Handling Time (s)	Chart Cell2	Insertion Time (s)
A1	360	360	720	3,0*2	3.9	0,2*2	5
A2	360	0	360	1,1*10	18	3,8*10	60
A3	360	360	720	3,0+1,1*5	19.95	0,0+3,8*5	31.5
A4	360	0	360	1,1	1.8	0,0	1.5
A5	180	0	180	0,3	1.69	0,0	1.5
A6	180	0	180	0,3	1.69	0,0	1.5
A7	360	0	360	1,1	1.8	3,8	6
A8	360	0	360	1,1	1.8	0,0	1.5
A9	180	0	180	0,3	1.69	0,0	1.5
A10	360	0	360	1,1	1.8	3,8	6
A11	360	360	720	3,0	1.95	0,0	1.5
A12	360	0	360	1,1	1.8	0,0	1.5
A13	180	0	180	0,3*2	3.38	0,0*2	3
A14	180	0	180	0,3	1.69	0,0	1.5
A15	180	0	180	0,3	1.69	0,0	1.5
A16	360	0	360	1,1	1.8	3,8	6
A17	360	0	360	1,1	1.8	0,0	1.5
A18	180	0	180	0,3	1.69	0,0	1.5
A19	360	0	360	0,3	1.69	0,0	1.5
A20	180	0	180	0,3	1.69	0,0	1.5
A21	360	0	360	1,1	1.8	3,8	6
A22	360	360	720	3,0	1.95	0,0	1.5
A23	360	180	540	2,0	1.8	0,6	5.5
A24	360	0	360	1,1*2	3.6	3,8*2	12
A25	360	360	720	3,0	1.95	0,0	1.5
A26	360	180	540	2,0	1.8	0,6	5.5
A27	360	0	360	1,1*2	3.6	3,8*2	12
A28	360	360	720	3,0	1.95	0,0	1.5
A29	360	0	360	1,1	1.8	3,8	6
A30	360	360	720	3,0	1.95	0,0	1.5
A31	360	180	540	2,0	1.8	0,2	2.5
A32	360	0	360	1,1*2	3.6	3,8*2	12
A33	360	180	540	2,0	1.8	0,0	1.5
A34	180	0	180	0,0*2	2.26	0,0*2	3
A35	360	0	360	1,1	1.8	0,0	1.5
A36	360	0	360	1,0	1.5	0,3	3.5
A37	360	0	360	1,3	2.06	0,3	3.5
A38	360	0	360	1,0	1.5	0,3	3.5
A39	360	360	720	3,0	1.95	0,2	2.5
A40	360	0	360	1,1*16	28.8	3,8*16	96
B1	180	180	360	1,0	1.5	0,0	1.5

B2	360	0	360	1,3*4	8.24	9,5	32
B3	360	180	540	2,0	1.8	0,0	1.5
B4	360	0	360	1,4*2	5.1	3,8*2	12
B5	360	0	360	1,3	2.06	0,0	1.5
B6	360	180	540	2,2	2.55	0,6	5.5
B7	360	0	360	1,4*2	5.1	3,8*2	12
B8	360	0	360	1,3*2	4.16	9,5*2	16
B9	N/A	N/A	N/A	N/A	N/A	9,0*2	8
B10	360	180	540	2,0	1.8	0,0	1.5
B11	360	360	720	3,0	1.95	0,0	1.5
B12	360	0	360	1,1*2	3.6	0,1*2	5
B13	360	0	360	1,1*2	3.6	3,8*2	12
B14	360	360	720	3,0	1.95	0,2	2.5
B15	360	0	360	1,1*2	3.6	3,8*2	12
B16	360	0	360	1,0	1.5	0,2	2.5
B17	360	360	720	3,0	1.95	0,2	2.5
B18	360	0	360	1,1*2	3.6	3,8*2	12
B19	360	0	360	1,0	1.5	0,0	1.5
B20	360	360	720	3,0	1.95	0,2	2.5
B21	360	0	360	1,1*6	10.8	3,8*6	36
				Total:	210.88	**Total:**	501
						Overall Time:	711.88

External Components							
Step	**α (degrees)**	**β (degrees)**	**α+β (degrees)**	**Chart Cell**	**Handling Time (s)**	**Chart Cell2**	**Insertion Time (s)**
A1	360	360	720	3,0	1.95	0,0	1.5
A2	360	360	720	3,0	1.95	0,0	1.5
A3	360	0	360	1,1	1.8	3,8	6
A4	N/A	N/A	N/A	A1+A2+A3	5.7	A1+A2+A3	9
A5	360	180	540	2,0	1.8	0,0	1.5
A6	360	180	540	2,0	1.8	0,0	1.5
A7	360	0	360	1,1*2	3.6	3,8*2	12
B1	360	0	360	1,1	1.8	0,0	1.5
B2	N/A	N/A	N/A	N/A	N/A	9,0	4
B3	360	360	720	3,3	2.51	0,0	1.5
B4	360	360	720	3,0	1.95	0,0	1.5
B5	360	0	360	1,1	1.8	9,1	7
B6	360	360	720	3,3	2.51	0,0	1.5
B7	360	360	720	3,0	1.95	0,0	1.5
B8	360	0	360	1,1	1.8	9,1	7
B9	360	360	720	3,0	1.95	0,9	7.5
B10	360	0	360	1,0	1.5	9,1	7
				Total:	36.37	**Total*2:**	146

Overall Time:	182.37

Modular Unit							
Step	**α (degrees)**	**β (degrees)**	**α+β (degrees)**	**Chart Cell**	**Handling Time (s)**	**Chart Cell2**	**Insertion Time (s)**
A1	180	360	540	2,1*2	4.2	0,0*2	3
A2	180	0	180	0,3*2	3.38	0,1*2	5
A3	360	0	360	1,3*2	4.12	9,5*2	16
A4	360	360	720	3,0	1.95	0,0	1.5
A5	360	0	360	1,1*4	7.2	9,2*4	20
B1	360	360	720	3,0	1.95	0,0	1.5
B2	360	360	720	3,2	2.7	0,6	5.5
B3	360	360	720	3,2	2.7	3,4	6
B4	360	0	360	1,3*2	4.12	9,5*2	16
B5	360	0	360	1,3*2	4.12	9,5*2	16
B6	360	360	720	3,0	1.95	0,0	1.5
B7	360	360	720	3,0	1.95	0,0	1.5
B8	360	0	360	1,1*4	7.2	9,2*4	20
				Total:	47.54	**Total:**	113.5
						Overall Time:	161.04

Pressure Regulator							
Step	**α (degrees)**	**β (degrees)**	**α+β (degrees)**	**Chart Cell**	**Handling Time (s)**	**Chart Cell2**	**Insertion Time (s)**
A1	0	0	0	0,0	1.13	N/A	0
A2	180	0	180	0,0	1.13	N/A	0
A3	N/A	N/A	N/A	N/A	0	3,0	3.5
A4	180	0	180	0,0	1.13	N/A	0
A5	N/A	N/A	N/A	N/A	0	0,0	1.5
A6	180	0	180	0,0	1.13	N/A	0
A7	180	0	180	3,2	2.7	N/A	0
A8	N/A	N/A	N/A	N/A	0	6,0	5.5
A9	180	0	180	0,0	1.13	N/A	0
A10	N/A	N/A	N/A	N/A	0	6,5	12
A11	360	0	360	3,0	1.95	N/A	0
B1	180	0	180	0,0	1.13	1,0	2.5
B2	360	0	360	0,0	1.13	1,0	2.5
				Total:	12.56	**Total:**	27.5
						Overall Time:	40.06

Chart 5 – Assembly time for each step of full assembly

The total times is then added up and multiplied by the wage for a US worker below

$$Cost\ for\ assembly = 1808.94\ seconds * \frac{1\ minute}{60\ seconds} * \frac{1\ hour}{60\ minutes} * \frac{20.00\ dollars}{1\ hour} = \$10.04$$

Manufacturing cost- To estimate the cost for parts that required manufacturing the following approach was taken. First the types of manufacturing techniques necessary for the part to be made were determined. Once the necessary techniques were determined videos of the processes were studied on the internet in order to determine the time each process would require. The time to run each machine was then multiplied by the wage for a US worker. This gave the cost to employ a person to run the machines during the production of the device. A sample calculation is shown below.

To produce the pressure vessel the only manufacturing technique required is injection molding. It is estimated that it would take 120 seconds for the injection mold to be filled and then cooled. We take this time and multiply it by the US wage below.

$$Manufactuing\ cost = 120\ seconds * \frac{1\ minute}{60\ seconds} * \frac{1\ hour}{60\ minutes} * \frac{20\ dollars}{1\ hour} = 0.66\ dollars$$

This was then done for every part that required manufacturing. The total manufacturing cost was then added up. The values can be seen in the table below.

Modular Unit Manufacturing Cost			
Part Name	**Manufacturing Process**	**Manufacturing Time (s)**	**Manufacturing Cost**
Modular Top	Injection mold	11	$0.061
Modular Bottom	Injection mold	11	$0.061
12-24V Switch	Injection mold	3	$0.017
Switch Backplate	Injection mold	3	$0.017
Circuit Board	N/A	N/A	N/A
10-24 x 1.5" Phillips Head Pan Screws	N/A	N/A	N/A
Wiring	N/A	N/A	N/A
Power Plug	N/A	N/A	N/A
12 V Battery	N/A	N/A	N/A
		Total Cost	**$0.156**

Chart 6 – Modular unit manufacturing cost

Motor/Compressor Manufacturing Cost			
Part Name	Manufacturing Process	Manufacturing Times (s)	Manufacturing Cost ($)
Heat sync	casted	6	0.033
shell	Injection molding	15	0.0825
		Total Cost	0.1155

Chart 7 – Motor/compressor manufacturing cost

Pressure Vessel Manufacturing Cost			
Part	Manufacturing Techniques	Time required (s)	Labor cost
Pressure Vessel	Injection molding	120	0.67
End cap	Injection molding	20	0.11
top plate	stamped	2	0.01
bottom plate	stamped	2	0.01
adjustment fastener	injection molding, rolled	30	0.17
			0.97

Chart 8 – Pressure vessel manufacturing cost

Original Unit Manufacturing Cost			
Part	**Manufacturing Method**	**Manufacturing Time (s)**	**Total cost ($)**
On/Off Knob	Injection mold	8	0.01
On/off Backpiece	Injection mold	4	0.07
Main Body 1	Injection mold	15	0.61
Main Body 2	Injection mold	15	0.79
Main Body Back Plate	Injection mold	15	0.56

Switch Shaft	Lathe	10	0.02
Small Spring	Drawn	4	0
Large Spring	Drawn	4	0
Metal Plate	Stamped	2	0
Hold in Knob	Injection mold	5	0
C - Clip (on/off knob)	Stamped	2	0
On-Off Knob Back Plates	Injection mold	4	0.49
Back Plate Spacer	Compression molding	10	0.01
Front Plate	Injection mold	5	0.08
DC Outlet Shaft	Stamped	4	0.01
DC/USB cover	Injection mold	3	0.01
Button	Injection mold	6	0
Button Spring	Drawn	4	0
USB Button	Injection mold	3	0
Pressure Gauge Housing	Injection mold	5	0.02
Gauge Front Plate	Injection mold	3	0.05
Compressor Top	Cast	45	0.05
Piston Shaft	Cast	30	0.02
Piston	Cast	30	0.03
Piston Pin	Lathe	15	0.01
Rubber Spacers	Injection mold	4	0.01
Compressor Shaft	Lathe	10	0.03

Compressor Cam	Cast	30	0.06
Compressor Housing	Cast	60	0.82
Comrpessor Shell	Injection mold	8	0.4
Motor Gear	Injection mold	4	0.01
C-Clip (motor)	Stamped	2	0
Motor Fan	Injection mold	4	0.02
Motor Spacer	Injection mold	4	0.02
Grip	Injection mold	4	0.1
Corner Bumpers	Injection mold	4	0.05
Handle Brackets	Stamped	4	0.01
AC Outlet Cover	Injection mold	5	0.04
On/Off Spacer	Injection mold	2	0.03
Main Wire Tie Downs	Injection mold	4	0.01
On/Off wire Tie downs	Injection mold	3	0
Pressure Gauge Bracket	Stamped	4	0.03
Motor Bracket	Stamped	4	0.01
AC Module Bracket	Stamped	4	0.01
Valve	Injection mold	2	0
Valve Housing	Injection mold	5	0.01
Valve Lever	Injection mold	3	0.01
Hose Clamping Springs	Drawn	4	0.01
Clamp Handle	Stamped	4	0.04

Clamp Insulator	Injection mold	4	0.01
Clamp Jaw	Stamped	19	0.82
Metal Handle	Mandrel-bent	15	0.13
External Housing	Injection mold	26	0.27
		Total Cost	5.8

Chart 9 – Original unit manufacturing cost

Once the cost for the materials, assembling, and manufacturing were determined the total cost to produce the device could be found.

$$\boldsymbol{Total\ Cost\ to\ Produce} = \$\mathbf{110.68}$$

Circuits

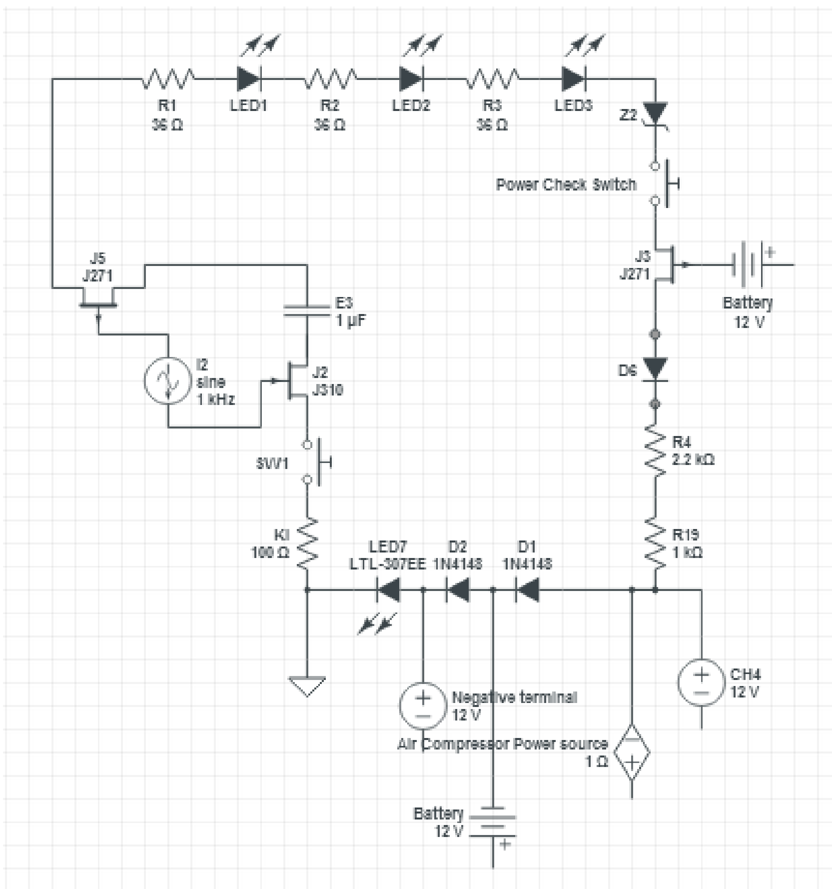


Fig. 195 – Main circuit board

Circuit Board

This device is comprised of multiple circuit systems that are all interconnected to the main circuit board. The main board, as represented by the larger tan shape, has all wires leading to and from it. It currently has five LED lights that are connected directly to the board, two switches, and thirteen individual wires. It also houses multiple resistors and capacitors to ensure operation with the right amount of power. The wires each play an important role to make each component to work together and still allow the system complete a closed circuit. The red wires are all positive and are connected to the positive terminal on the battery and other mechanisms. The black wires do the same as the red, the only difference is that they all lead and are connected to the negative terminal of the battery or grounded. The yellow wire transmits a signal when the circuit loop is closed and transmits for things such as on/off switched and the presence of a connecting device.

There are four switches: two on the main board and two that operate off the board. The two on the board are connected directly to the board, the large switch controls the USB on/off position. Once the switch is on the USB can be used as a charging device, and therefore will trigger the LED light to signal a closed circuit. The smaller one is used to check the batteries level of power, which is connected to the three LED lights that indicate the level of power in the battery. Each LED will light up once the necessary power is able to pass through the resistor; the same occurs for each level of fullness. Hence the more power the battery has the more likely for it to power the highest level of resistor. The off board switches are used for the main on/off switch and the flashlight switch. This switch is also directly grounded to the air compressor and pressure gauge LED. The flashlight switch is connected to a mini circuit board that holds the LED that acts as a flashlight and once the switch is closed power is allowed to pass through and completes the circuit, hence turning on the flashlight.

Two of the LED lights not discussed yet are the pressure gauge LED and the polarity LED. The pressure gauge LED light is used to show that the air compressor is on and fully functional. The polarity LED light is used as a safety feature and is used in the event that the jumper cables are incorrectly positioned. For instance if the user accidentally were to place the red jumper cable claw and connect it to the negative terminal the light would shine to warn you that the system will not work under these conditions.

There are six diodes that are a two-terminal electronic component that has an asymmetric transfer characteristic. It also uses one zener diode which is a diode which allows current to pass in the forward direction just like an ideal diode. There were three electrical impedances that measured the opposition that a circuit presents to the path of a current when voltage is applied. There are also two switches that are in the open position and are closed to allow the voltage to pass through. There are multiple resistors and one capacitor to charge amperage ready to be released whenever necessary. There are two positive sources that are connected to the battery and one cable that is grounded as seen in the figure above. The power wires leading away from the system are the ones that are powering the other controls for this system ie. flashlight, on / off switch, and USB port.

Safety

The system is designed with several safety features to ensure the user is not injured during proper operation. The compressor motor is equipped with a thermal relay that turns the motor off when the temperature reaches 140°C to prevent damage to the motor as well as a burn injury. Rubber caps are included to seal the holes in the bottom of the main unit when the modular battery pack is not utilized. This prevents accidental contact with the electrical circuit inside the unit, which could result in electrical shock. The connection on the modular battery pack is designed so that the electrical contacts are surrounded by plastic to prevent an accidental short circuit.

The device manual provides strict instructions to maximize your understanding and safety with the device. The device should not be used in a manner inconsistent with the instructions. Avoid extreme temperatures and do not allow the unit to freeze or get wet. Specific safety precautions are given below.

Shock Hazard

To prevent electric shock, ensure the jumper cables are attached securely to the battery terminals before switching the unit on. Always attach the positive cable first and ground the negative cable to the chassis to prevent arcing. When charging the unit, do not use frayed or damaged extension cords. Do not insert foreign objects into the charging ports.

Burn Hazard

When operating the compressor, make sure the unit is in a well-ventilated area and be careful of hot surfaces. The motor gets very hot during operation. Never use the unit around an open flame or smoke around the unit, as the batteries contain flammable acid.

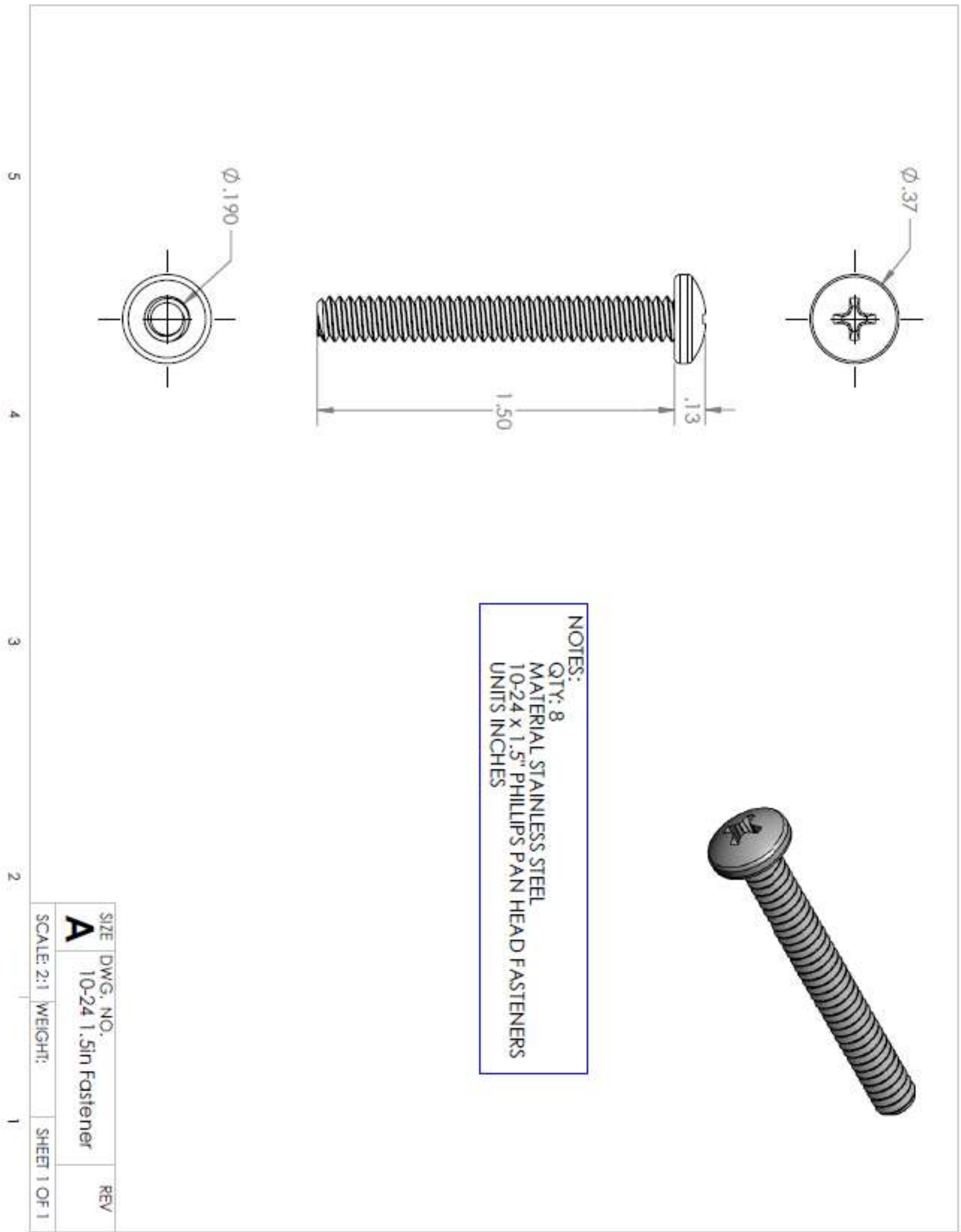
Burst Hazard

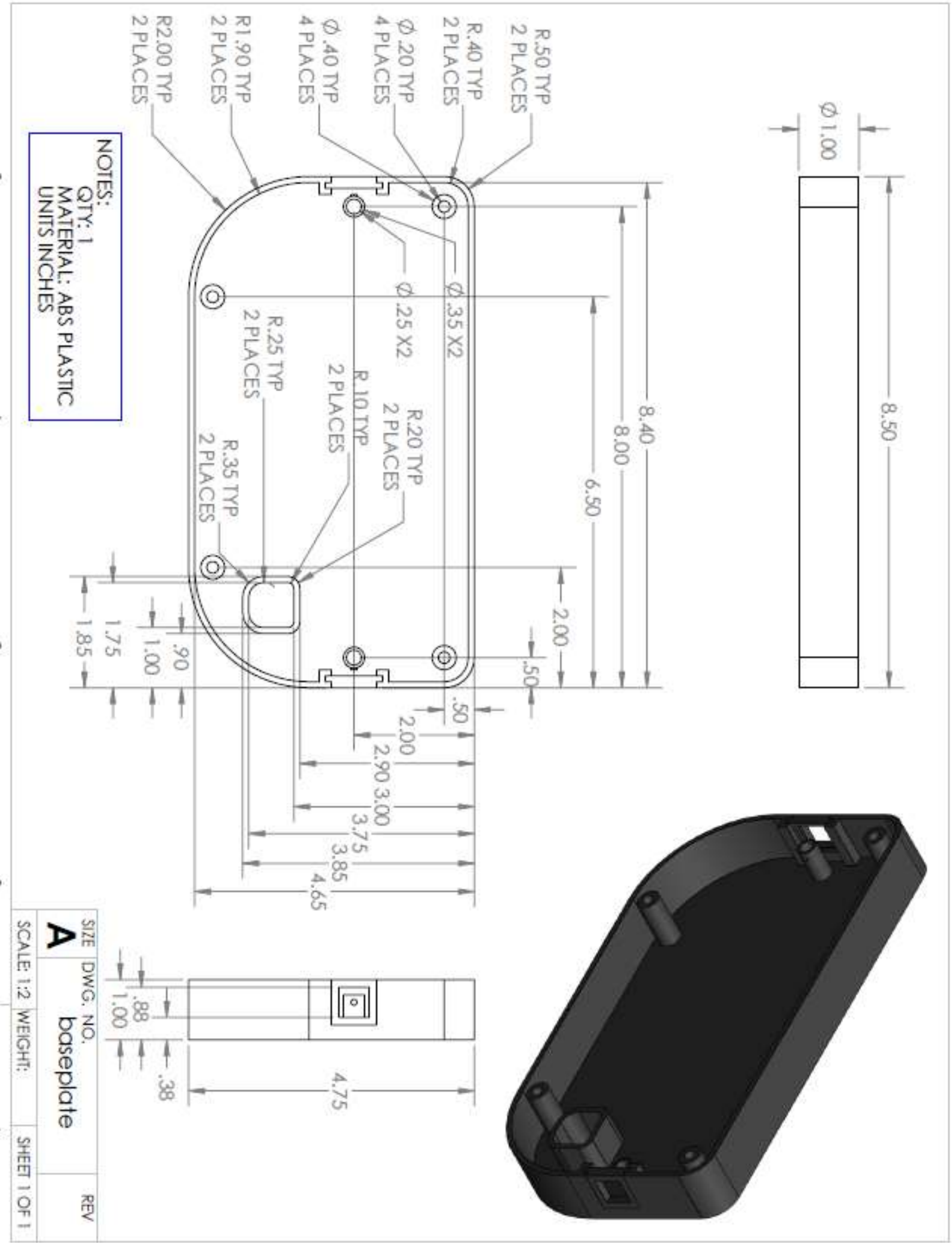
Do not overinflate vehicle tires using the compressor. Always read the tire sidewall to determine fill pressure, and set the regulator accordingly. Never leave unit running unattended, as the regulator could fail and over-inflation could occur, possibly bursting the tire.

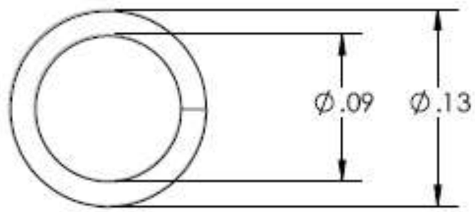
Conclusion

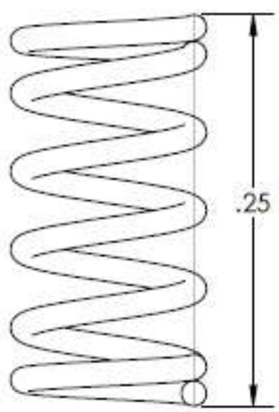
The changes made to the Stanley car jump starter make it a significantly better product. The Car jumper 2000 now has the ability to be used with a tractor trailer. With the new modular system the device can either jump tractor trailers or a standard car with the turn of a knob. The new pressure regulator system allows for any tire up to 18 liters to be filled from 0 psi to 120 psi within 12 minutes. With the built-in contact switch the compressor turns off automatically to save power. A new 350 watt motor was added to allow the system to be used with tractor trailer tires. The motor coupled with a cast iron heat sink allows the motor to run continuously for 33 minutes without overheating. All of these upgrades along with minor modifications like longer hoses make the new design a superior product. Within the allotted budget everything was improved to meet the necessary specifications. Other potential upgrades to the device include stronger batteries and an improved flashlight. If the batteries were to be upgraded it would allow for even larger engines to be jump started. More capabilities could also be added to the flashlight. A strobe effect could be added to send out a SOS signal. If the flashlight were to be made detachable it would also greatly improve the functionality. With a larger budget these ideas could be implemented.

Appendix A – Part Drawings




R.50 TYP
2 PLACES
R.40 TYP
2 PLACES
Ø.20 TYP
4 PLACES
Ø.40 TYP
4 PLACES
R1.90 TYP
2 PLACES
R2.00 TYP
2 PLACES
Ø1.00
8.50
8.40
8.00
6.50
2.00
.50
Ø.35 X2
Ø.25 X2
R.25 TYP
2 PLACES
R.10 TYP
2 PLACES
R.20 TYP
2 PLACES
R.35 TYP
2 PLACES
.90
1.00
1.75
1.85
.50
2.00
2.90
3.00
3.75
3.85
4.65
.88
1.00
.38
4.75
NOTES:
QTY: 1
MATERIAL: ABS PLASTIC
UNITS INCHES
SIZE
A
DWG. NO.
baseplate
REV
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1

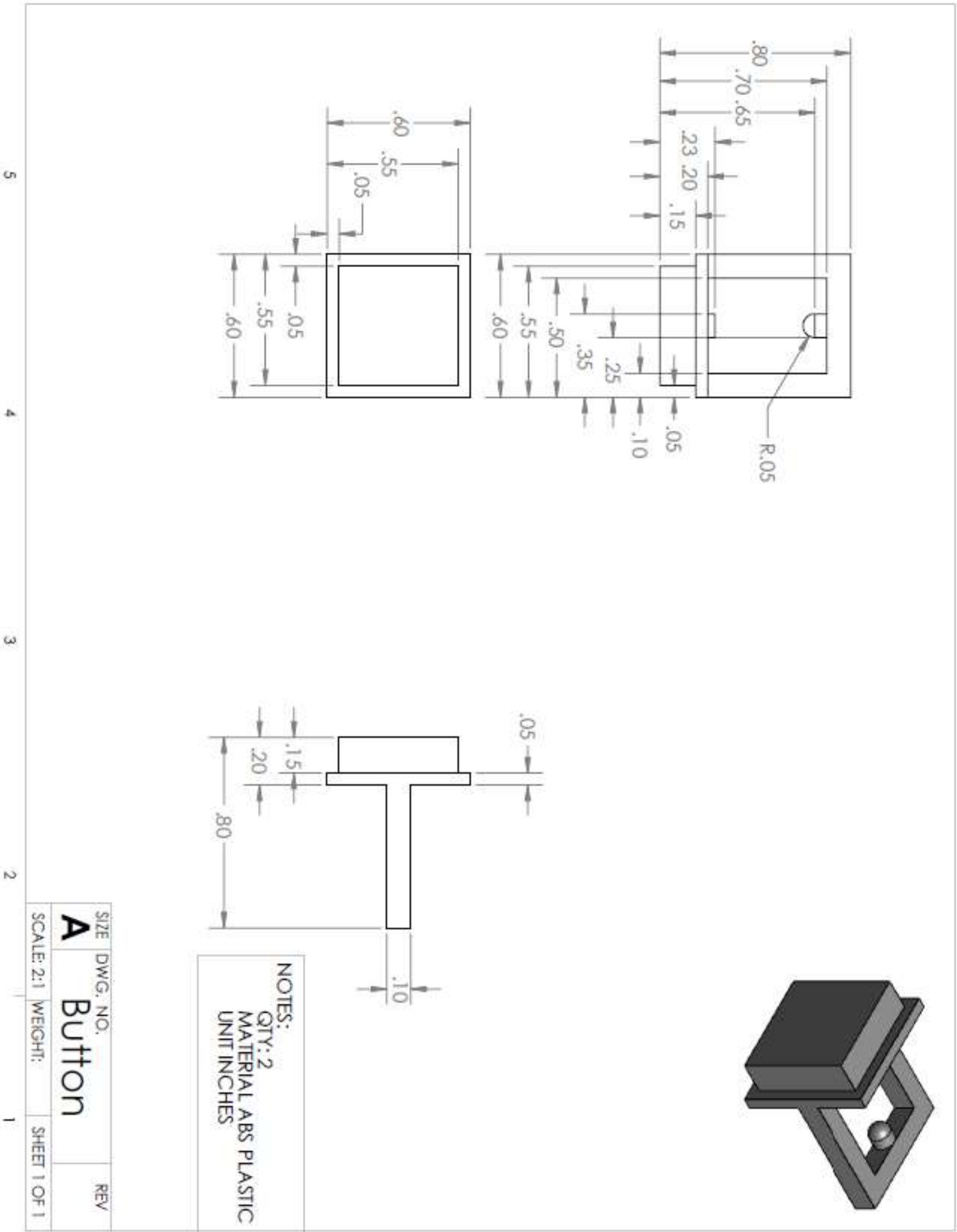


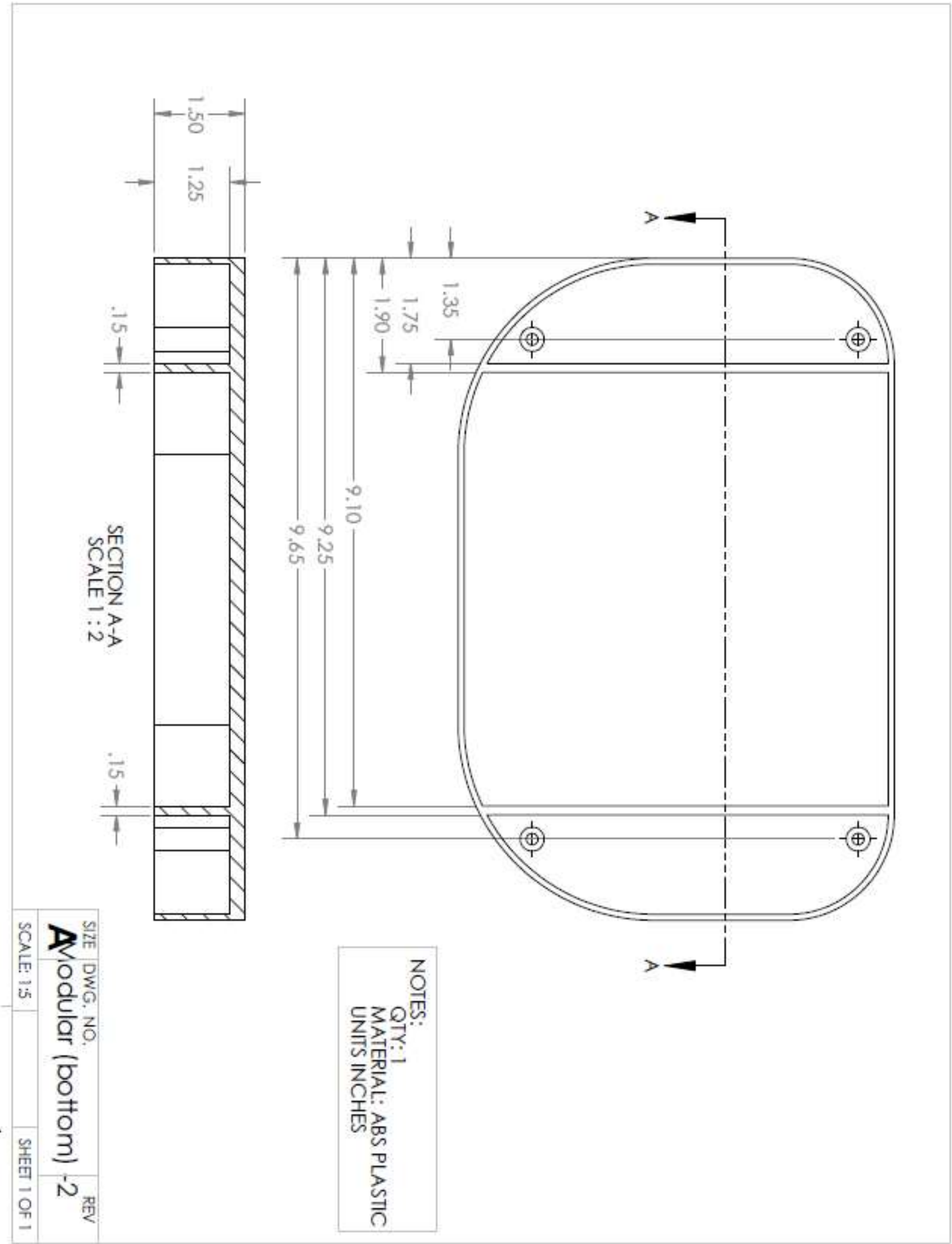


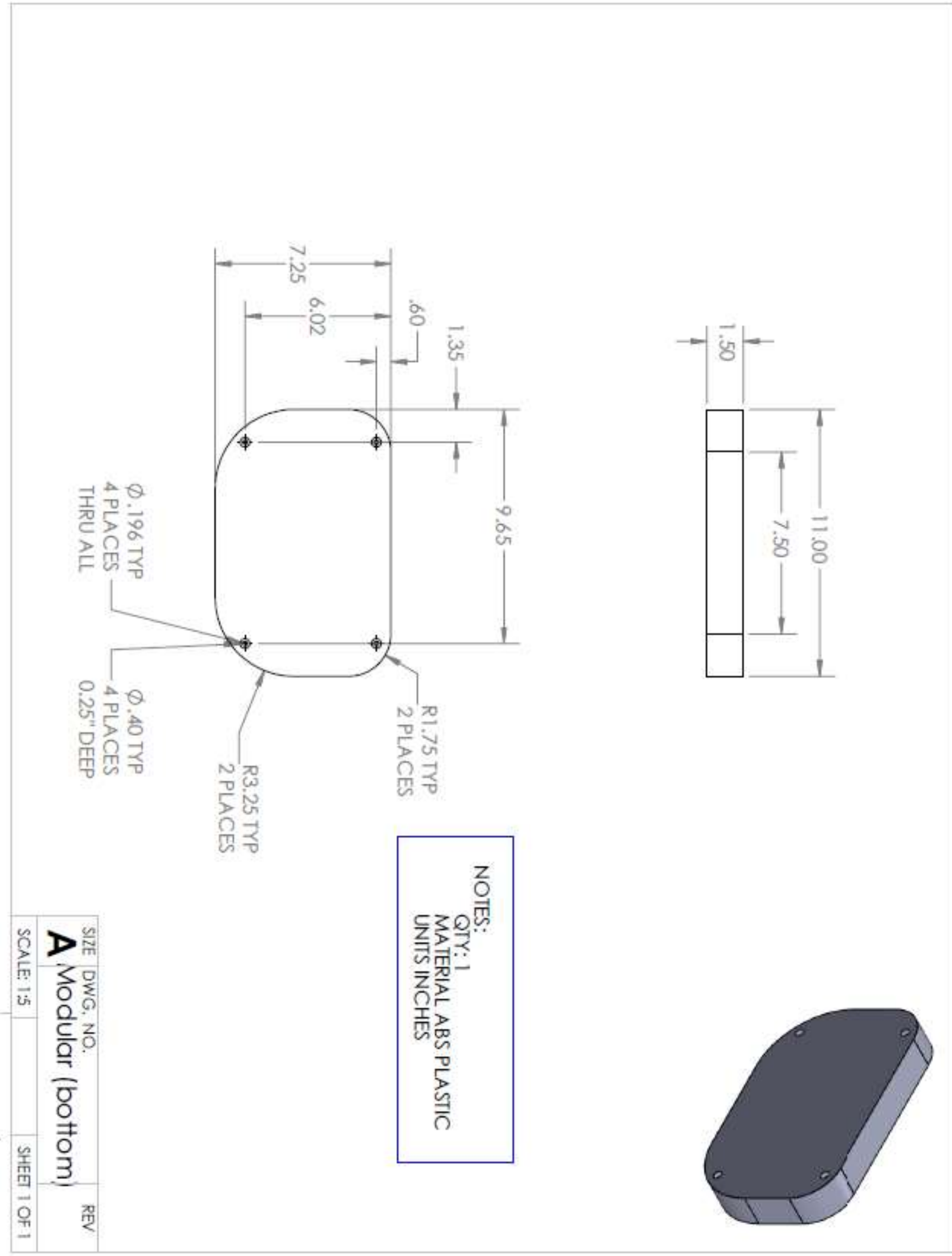
NOTES:
QTY: 2
MATERIAL STEEL
STIFF SPRING
UNITS INCHES

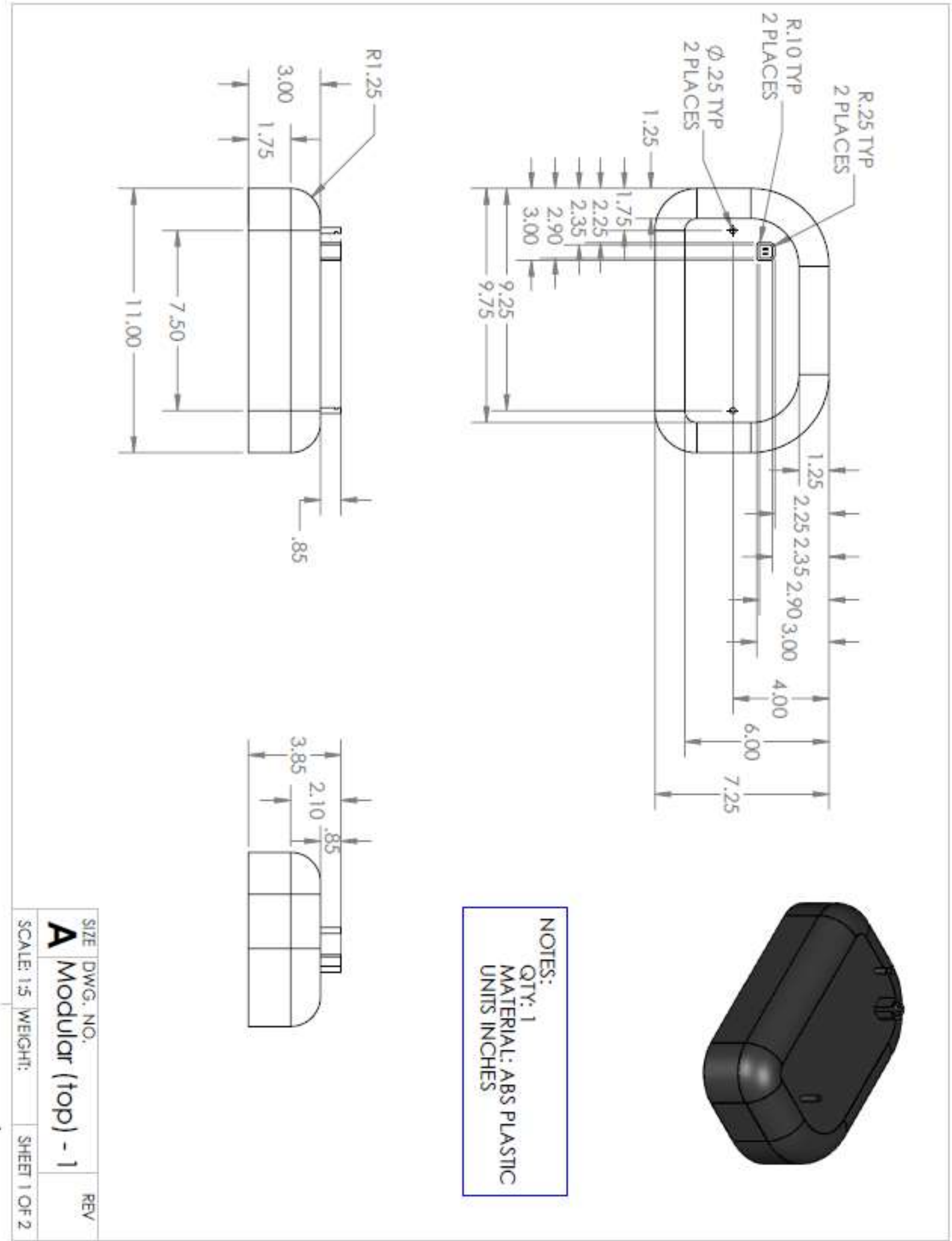
SIZE	DWG. NO.	REV
A	Button Spring	
SCALE: 10:1	WEIGHT:	SHEET 1 OF 1

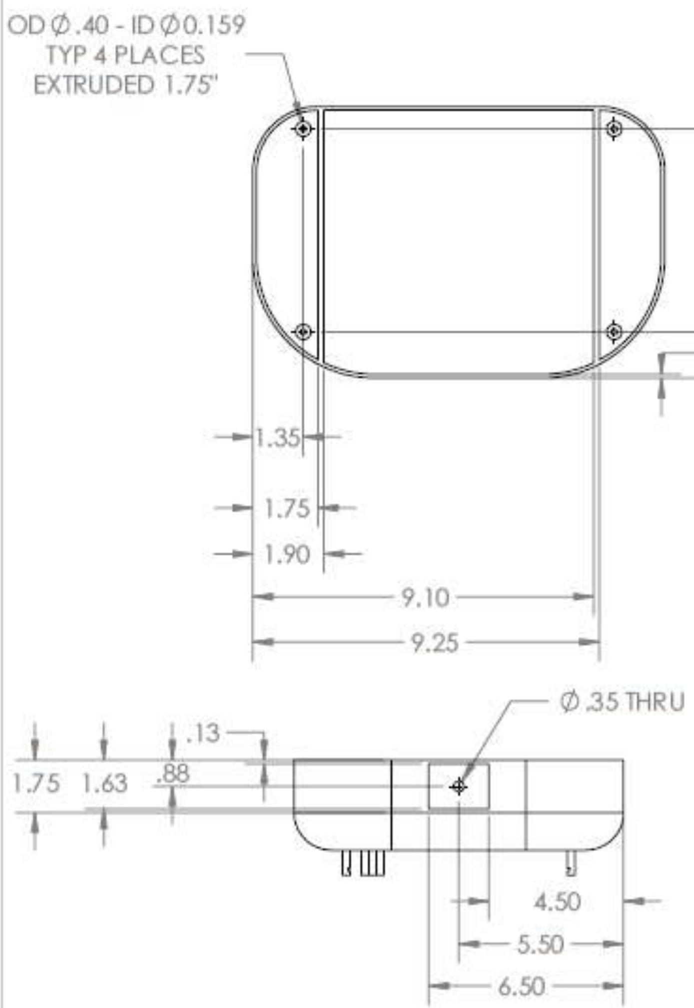
1


NOTES:
QTY: 2
MATERIAL ABS PLASTIC
UNIT INCHES
SIZE
A
DWG. NO.
Button
REV
SCALE: 2:1
WEIGHT:
SHEET 1 OF 1
R.05


1.50
1.25
.15
.15
SECTION A-A
SCALE 1 : 2
1.35
1.75
1.90
9.10
9.25
9.65
A
A
NOTES:
QTY: 1
MATERIAL: ABS PLASTIC
UNITS INCHES
SIZE
A
DWG. NO.
Modular (bottom)
REV
-2
SCALE: 1:5
SHEET 1 OF 1


7.25
6.02
.60
1.35
9.65
1.50
11.00
7.50
Ø.196 TYP
4 PLACES
THRU ALL
Ø.40 TYP
4 PLACES
0.25" DEEP
R3.25 TYP
2 PLACES
R1.75 TYP
2 PLACES
NOTES:
QTY: 1
MATERIAL ABS PLASTIC
UNITS INCHES
SIZE
A
DWG. NO.
Modular (bottom)
REV
SCALE: 1:5
SHEET 1 OF 1

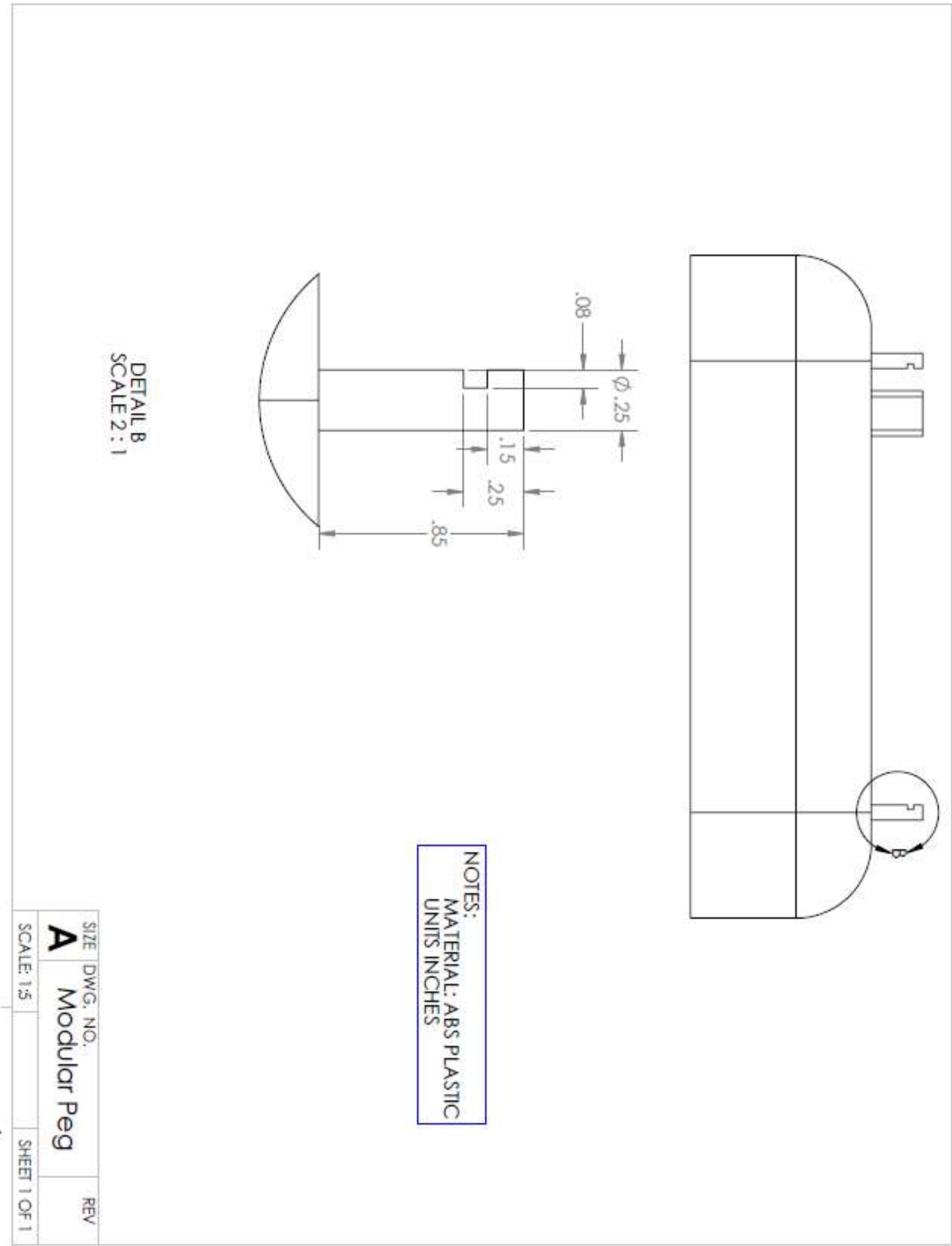

R.25 TYP
2 PLACES
R.10 TYP
2 PLACES
Ø.25 TYP
2 PLACES
1.25
1.75
2.25
2.35
2.90
3.00
9.25
9.75
1.25
2.25
2.35
2.90
3.00
4.00
6.00
7.25
R1.25
3.00
1.75
7.50
11.00
.85
3.85
2.10
.85
NOTES:
QTY: 1
MATERIAL: ABS PLASTIC
UNITS INCHES
SIZE
A
DWG. NO.
Modular (top) - 1
REV
SCALE: 1:5
WEIGHT:
SHEET 1 OF 2

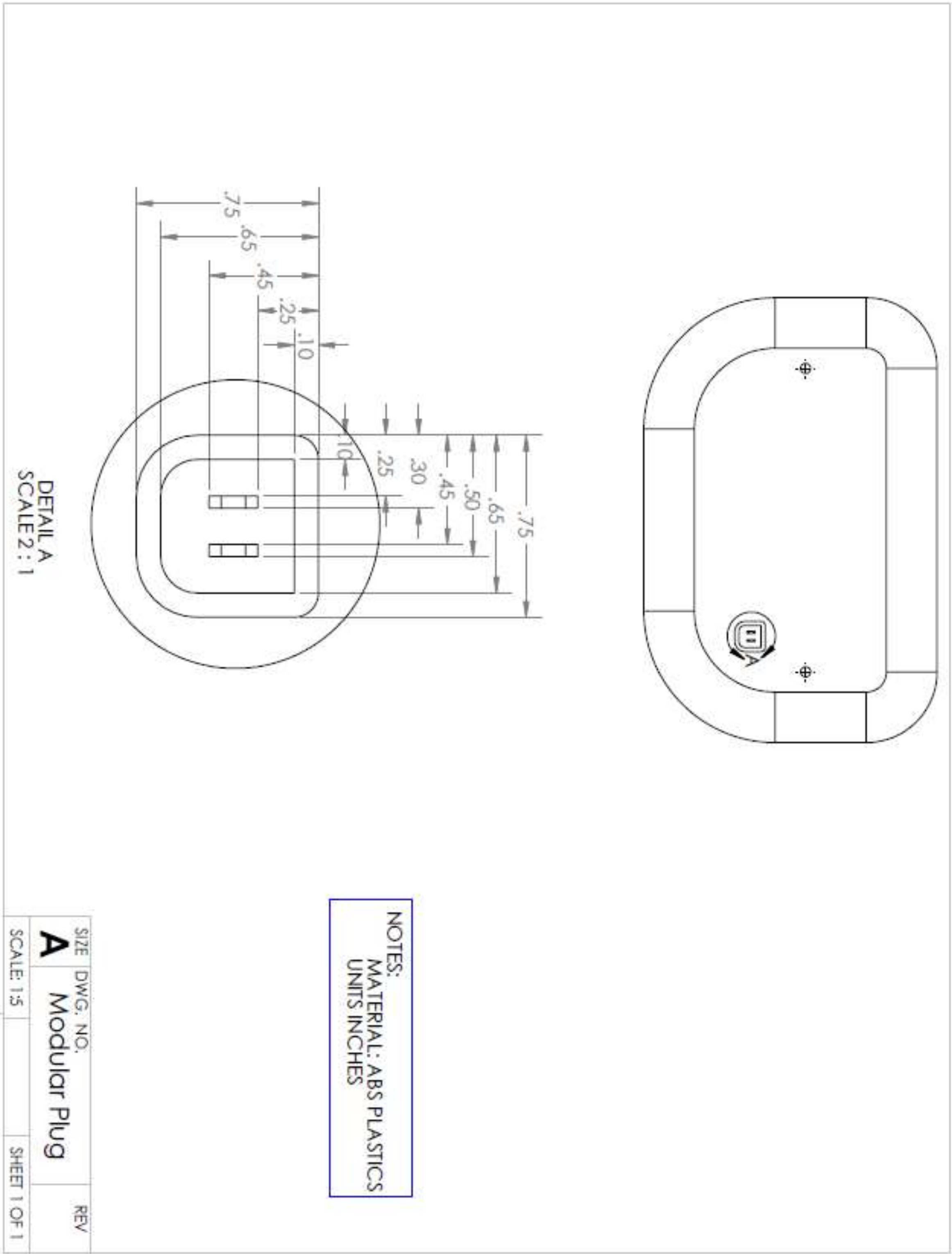


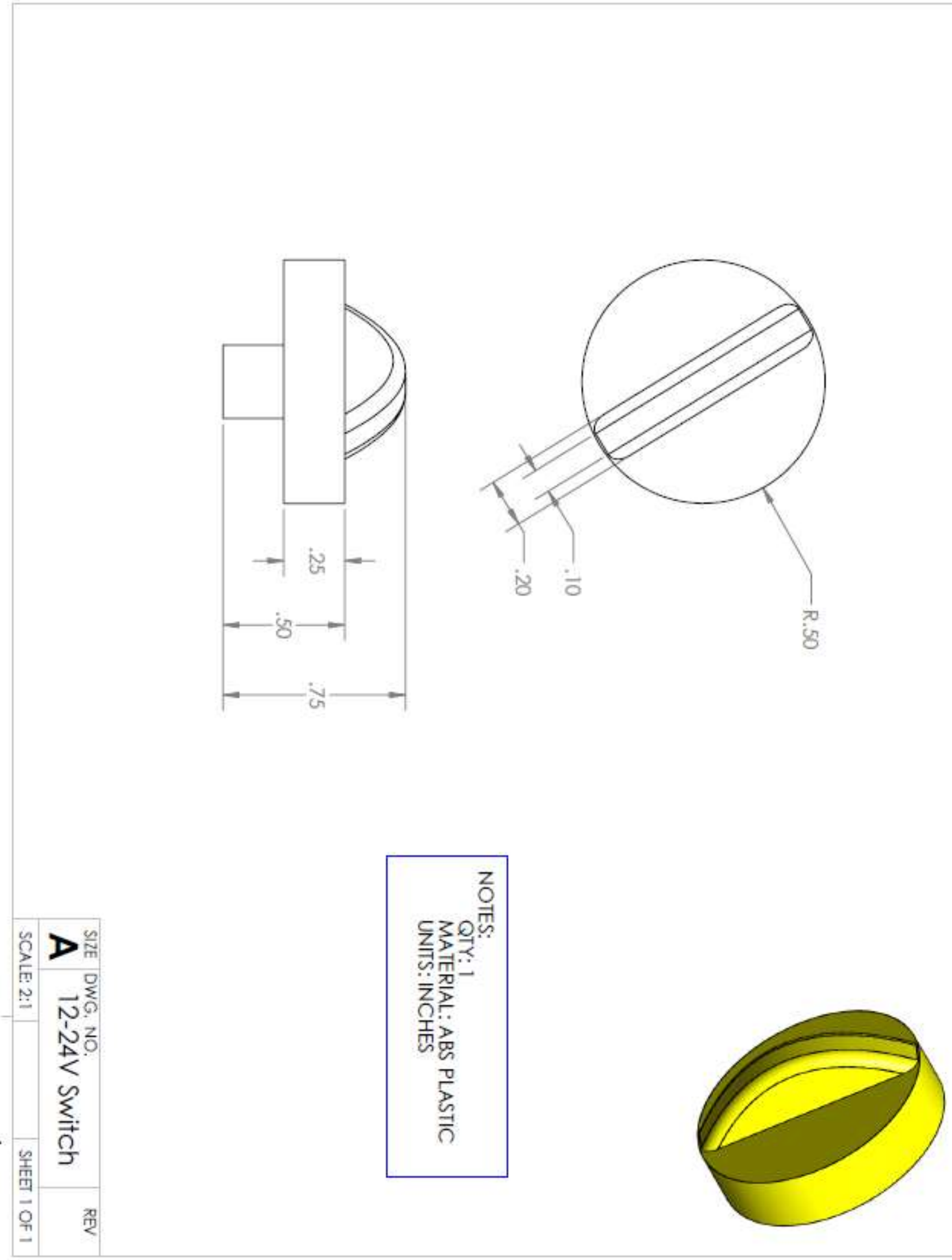
NOTES:
QTY: 1
MATERIAL: ABS PLASTIC
UNITS INCHES

SIZE	DWG. NO.	REV
A	Modular (top) - 2	
SCALE: 1:5		SHEET 2 OF 2

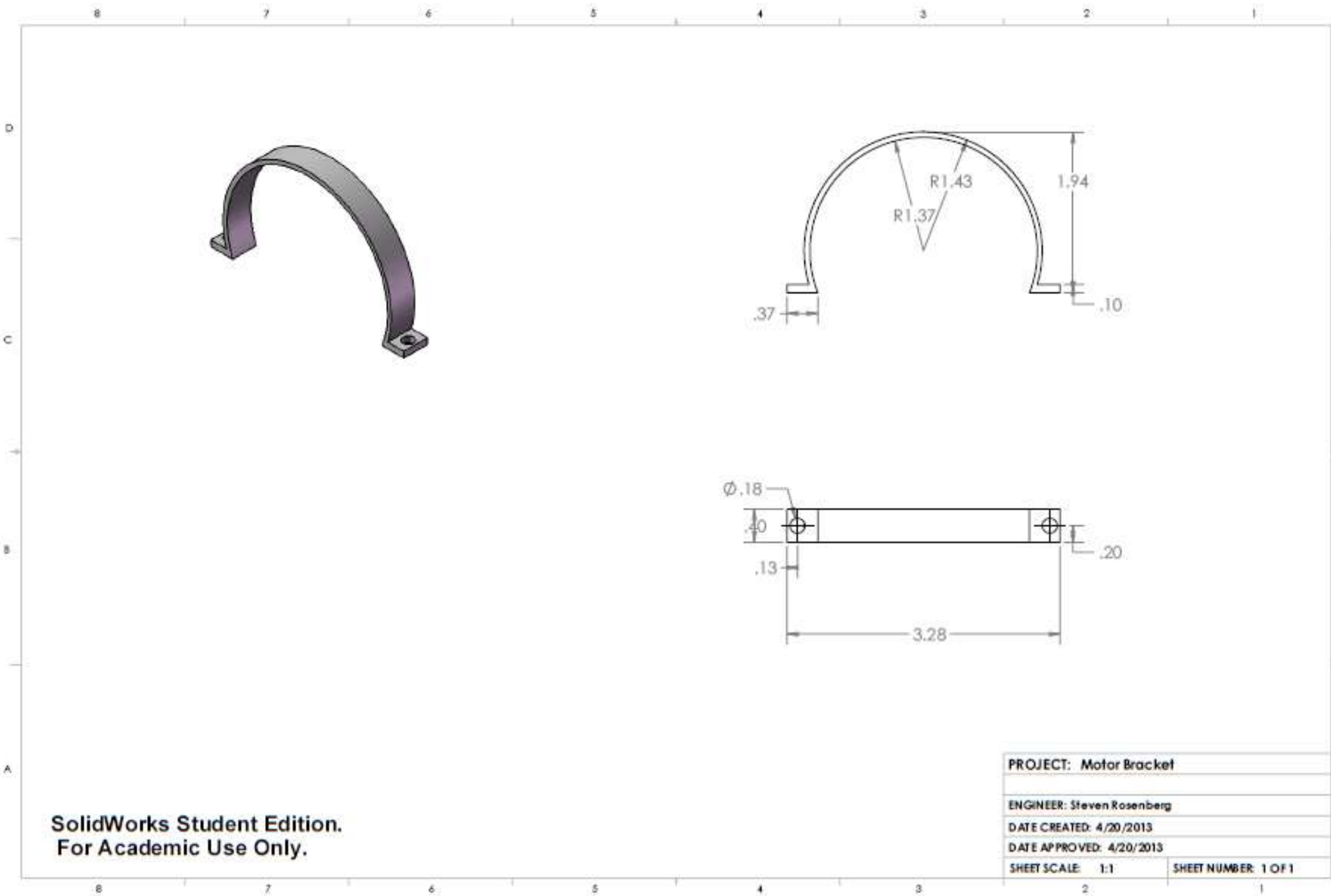
1

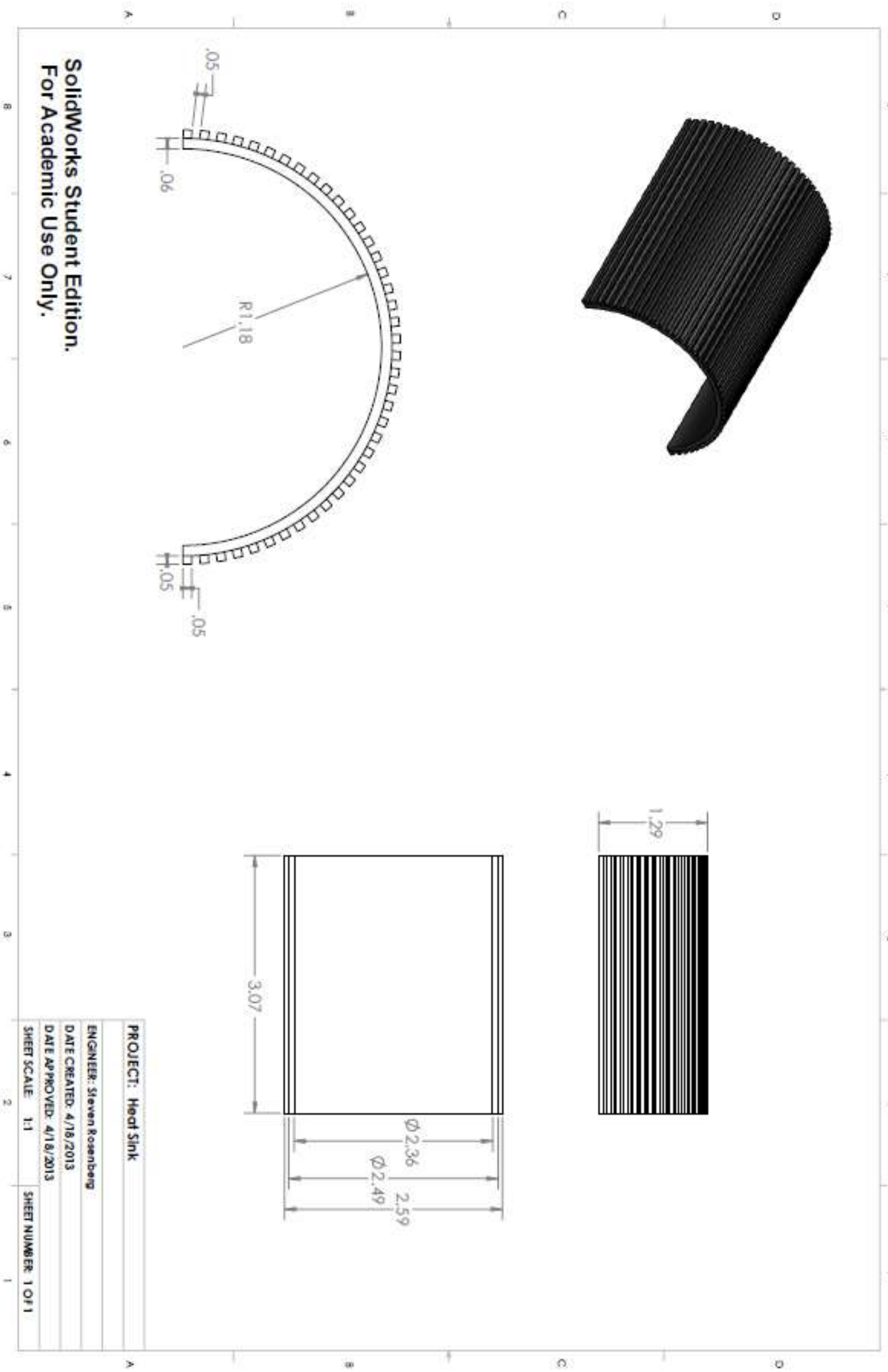

.08
Ø.25
.15
.25
.85
DETAIL B
SCALE 2 : 1
B
NOTES:
MATERIAL: ABS PLASTIC
UNITS INCHES
SIZE
A
DWG. NO.
Modular Peg
REV
SCALE: 1:5
SHEET 1 OF 1

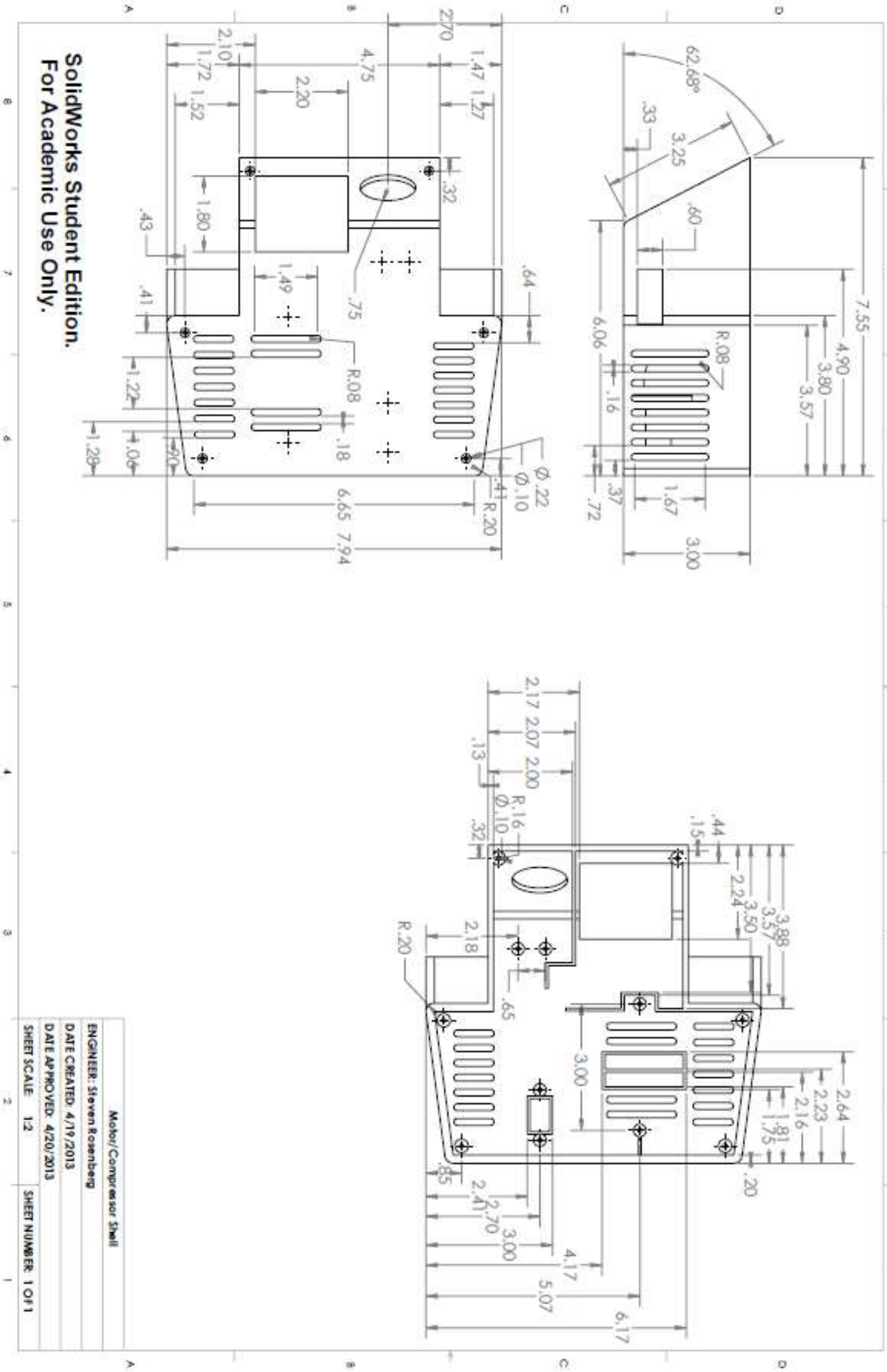

.75
.65
.45
.25
.10
.10
.25
.30
.45
.50
.65
.75
DETAIL A
SCALE 2 : 1
A
NOTES:
MATERIAL: ABS PLASTICS
UNITS INCHES
SIZE
A
DWG. NO.
Modular Plug
REV
SCALE: 1:5
SHEET 1 OF 1

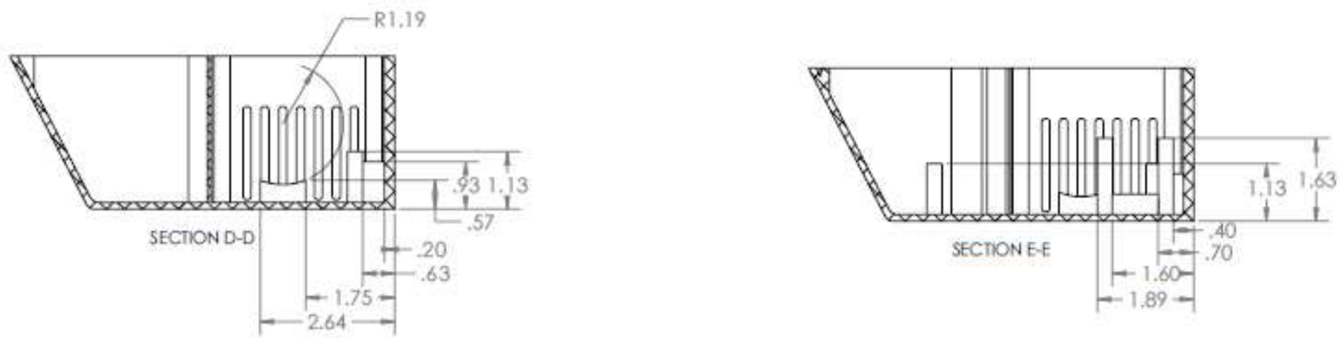


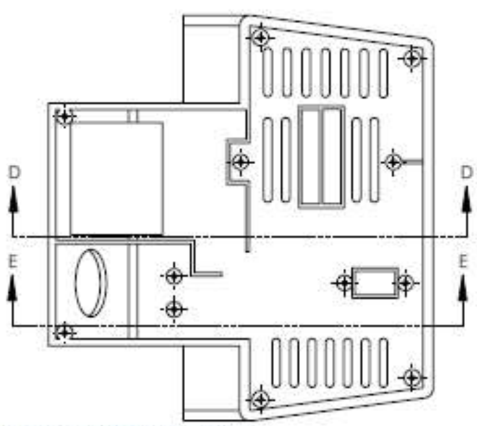
.25
.50
.75
.20
.10
R.50
NOTES:
QTY: 1
MATERIAL: ABS PLASTIC
UNITS: INCHES
SIZE
A
DWG. NO.
12-24V Switch
REV
SCALE: 2:1
SHEET 1 OF 1


R1.43
R1.37
1.94
.37
.10
Ø.18
.40
.13
.20
3.28
SolidWorks Student Edition.
For Academic Use Only.
PROJECT: Motor Bracket
ENGINEER: Steven Rosenberg
DATE CREATED: 4/20/2013
DATE APPROVED: 4/20/2013
SHEET SCALE: 1:1
SHEET NUMBER: 1 OF 1

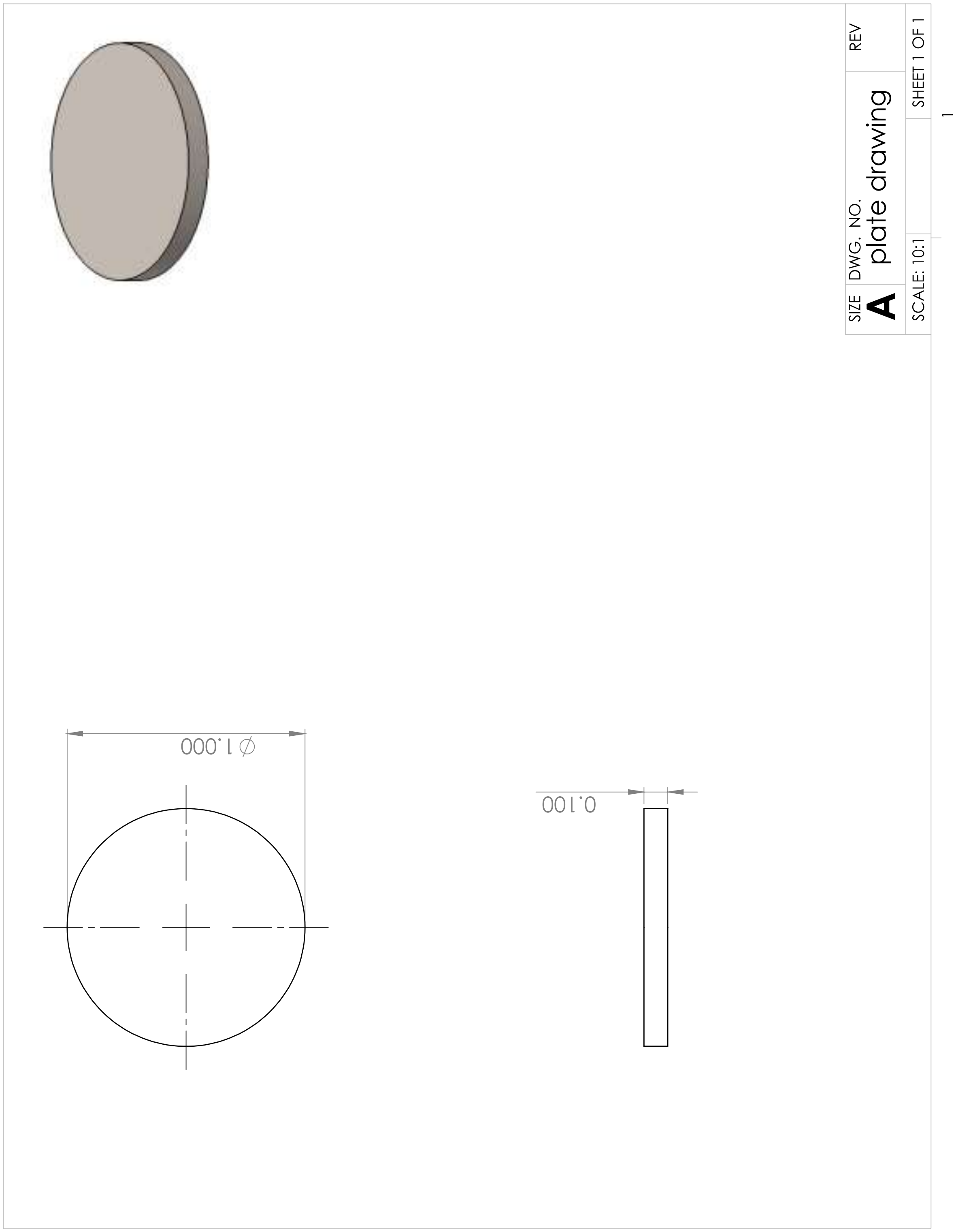

SolidWorks Student Edition.
For Academic Use Only.
.05
.06
R1.18
.05
.05
1.29
3.07
Ø2.36
Ø2.49
2.59
PROJECT: Heat Sink
ENGINEER: Steven Rosenberg
DATE CREATED: 4/18/2013
DATE APPROVED: 4/18/2013
SHEET SCALE 1:1
SHEET NUMBER 1 OF 1

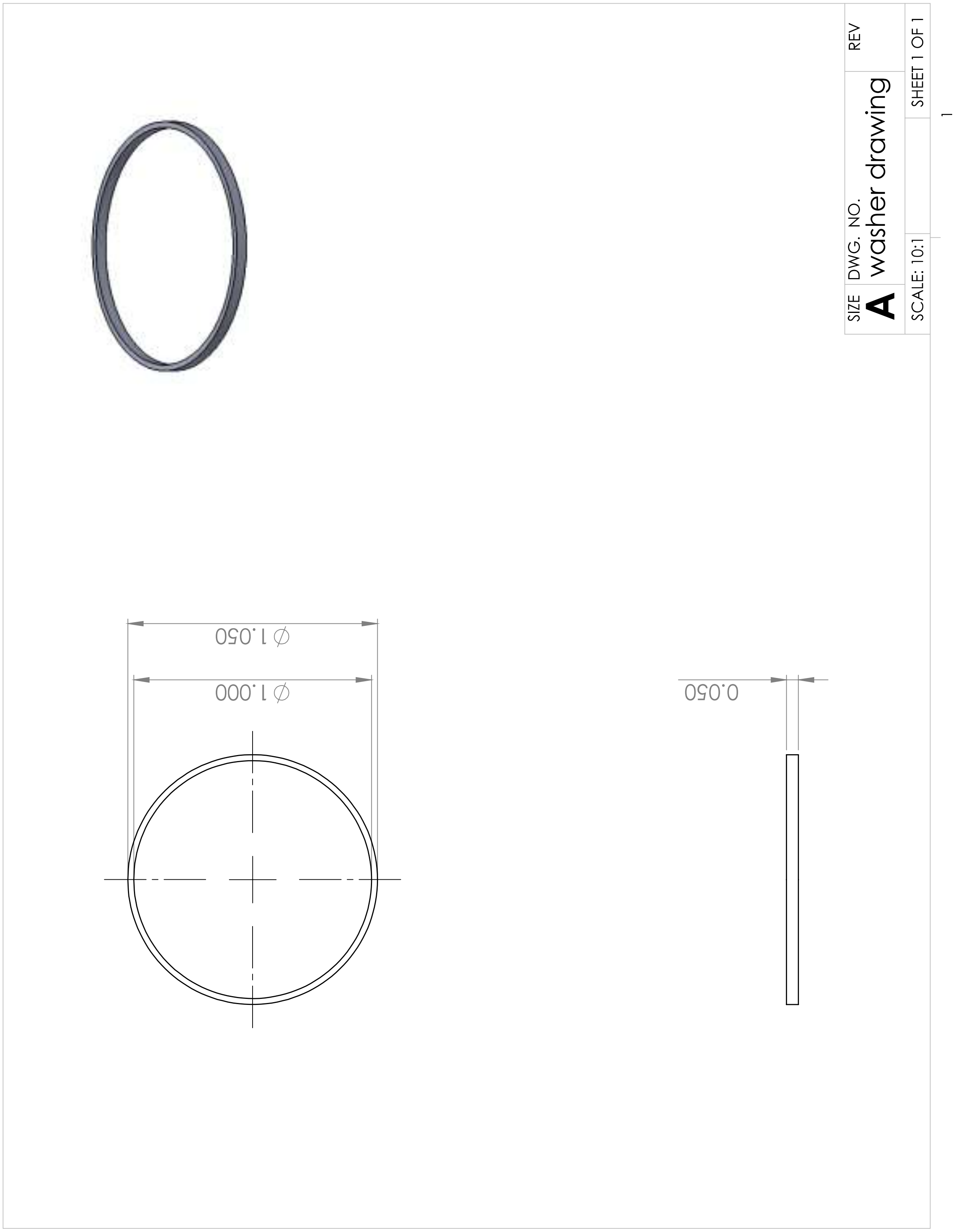

SolidWorks Student Edition.
For Academic Use Only.
Motor/Compressor Shell
ENGINEER: Steven Rosenberg
DATE CREATED: 4/19/2013
DATE APPROVED: 4/20/2013
SHEET SCALE 1:2
SHEET NUMBER 1 OF 1

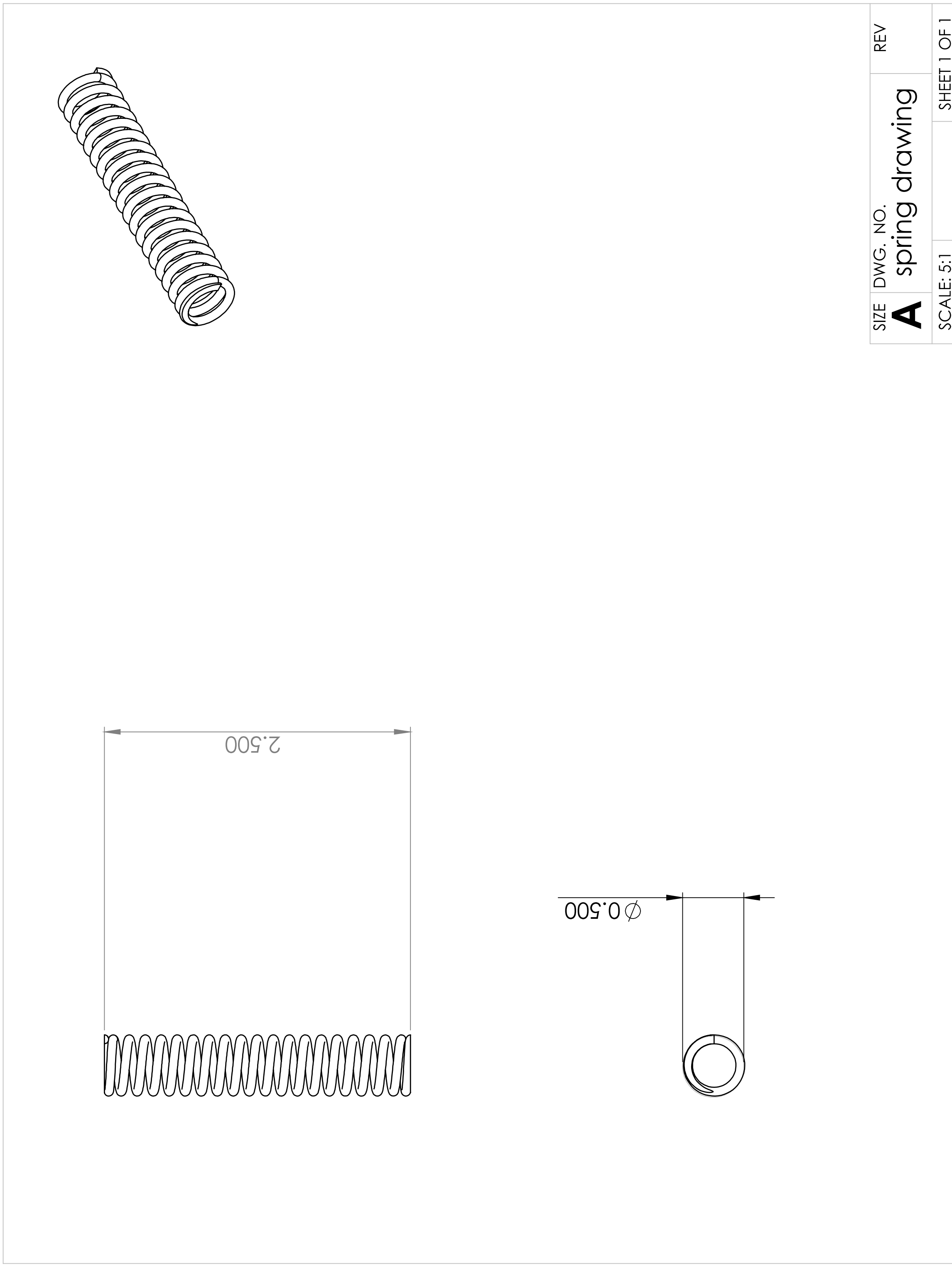


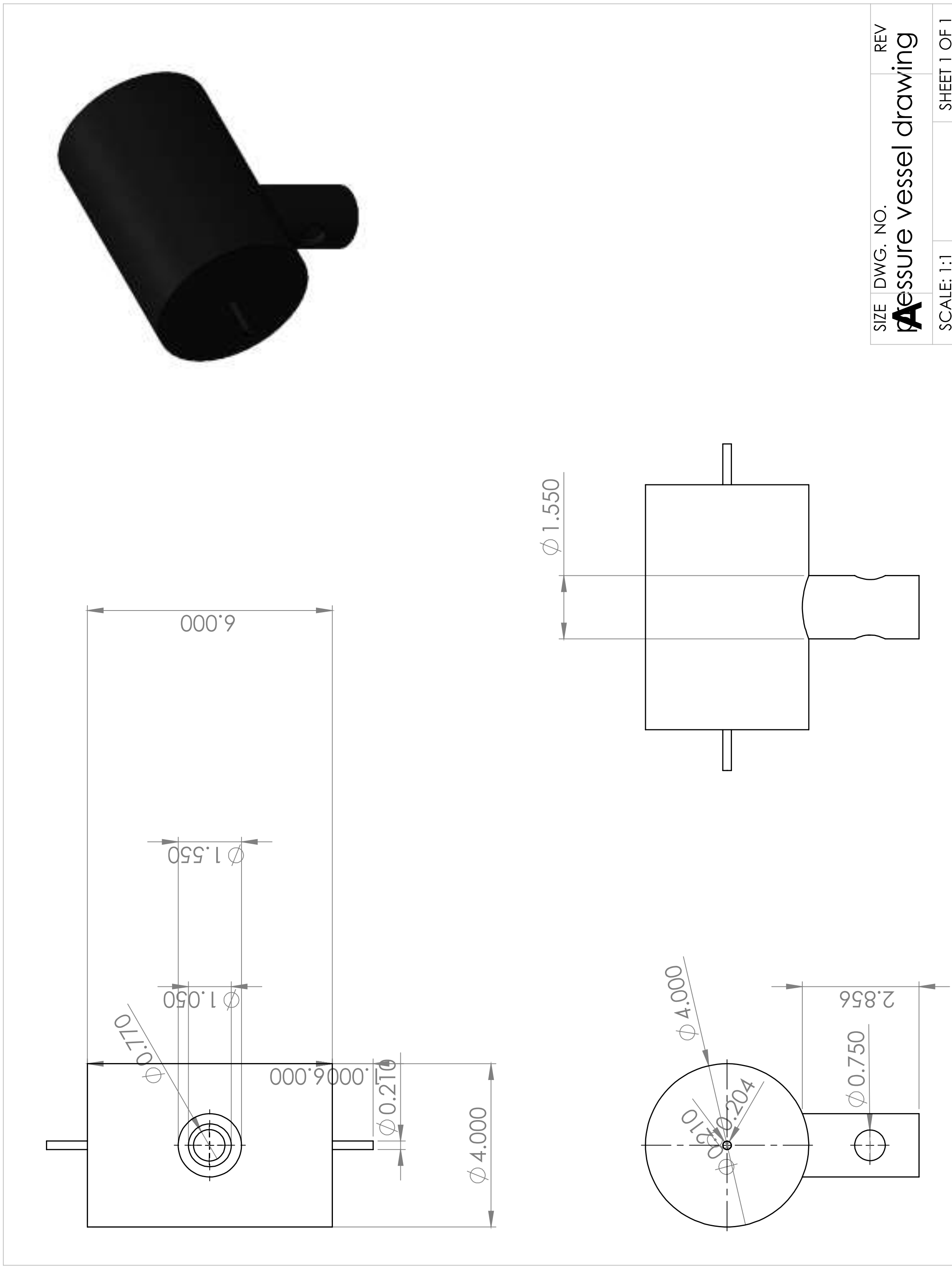


PROJECT: Motor/Compressor Shell	
ENGINEER: Steven Rosenberg	
DATE CREATED: 4/19/2013	
DATE APPROVED: 4/20/2013	
SHEET SCALE: 1:2	SHEET NUMBER: 1 OF 1

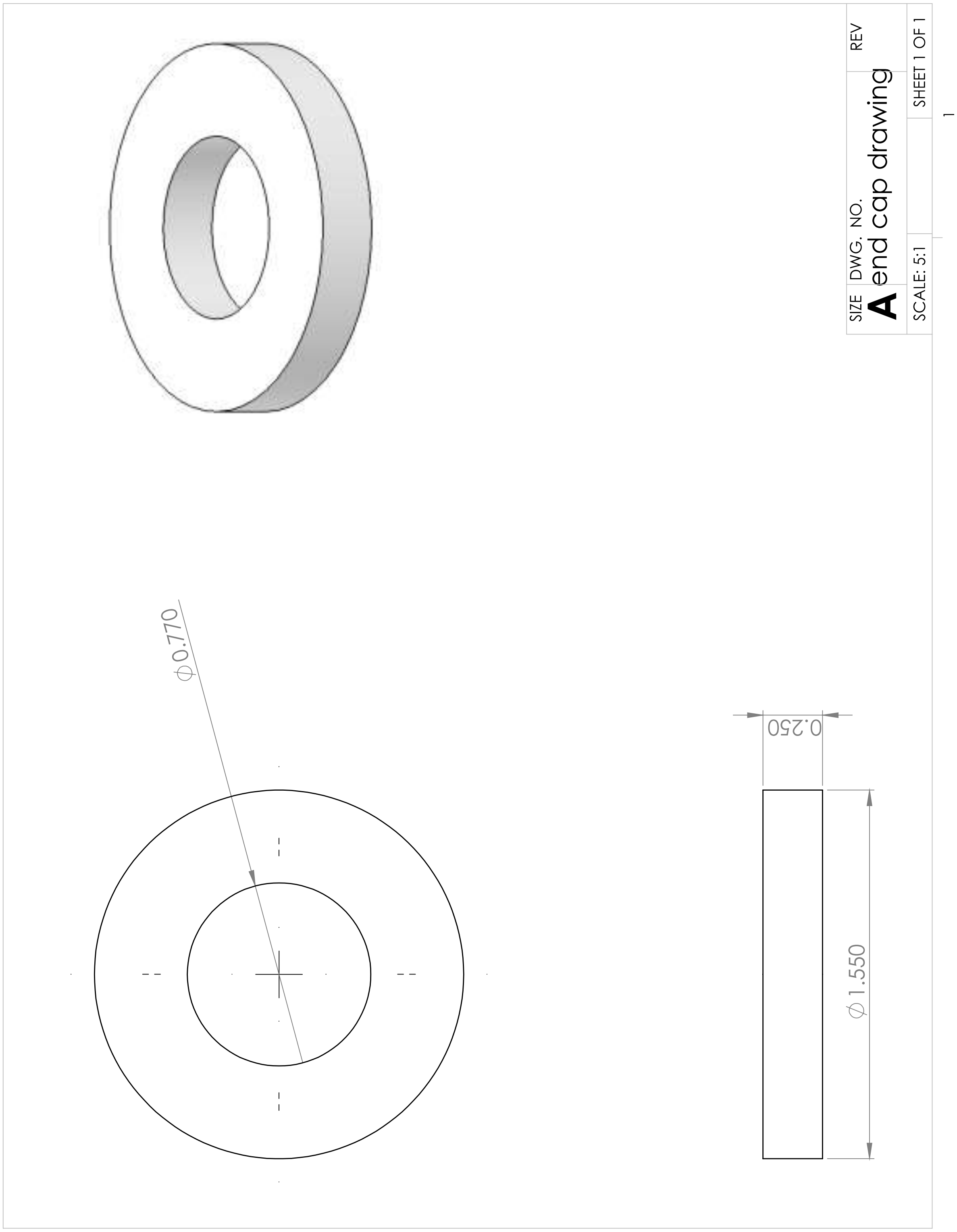

SIZE
A
DWG. NO.
plate drawing
REV
SCALE: 10:1
SHEET 1 OF 1
⌀ 1.000
0.100


SIZE
A
DWG. NO.
washer drawing
REV
SCALE: 10:1
SHEET 1 OF 1
⌀ 1.050
⌀ 1.000
0.050

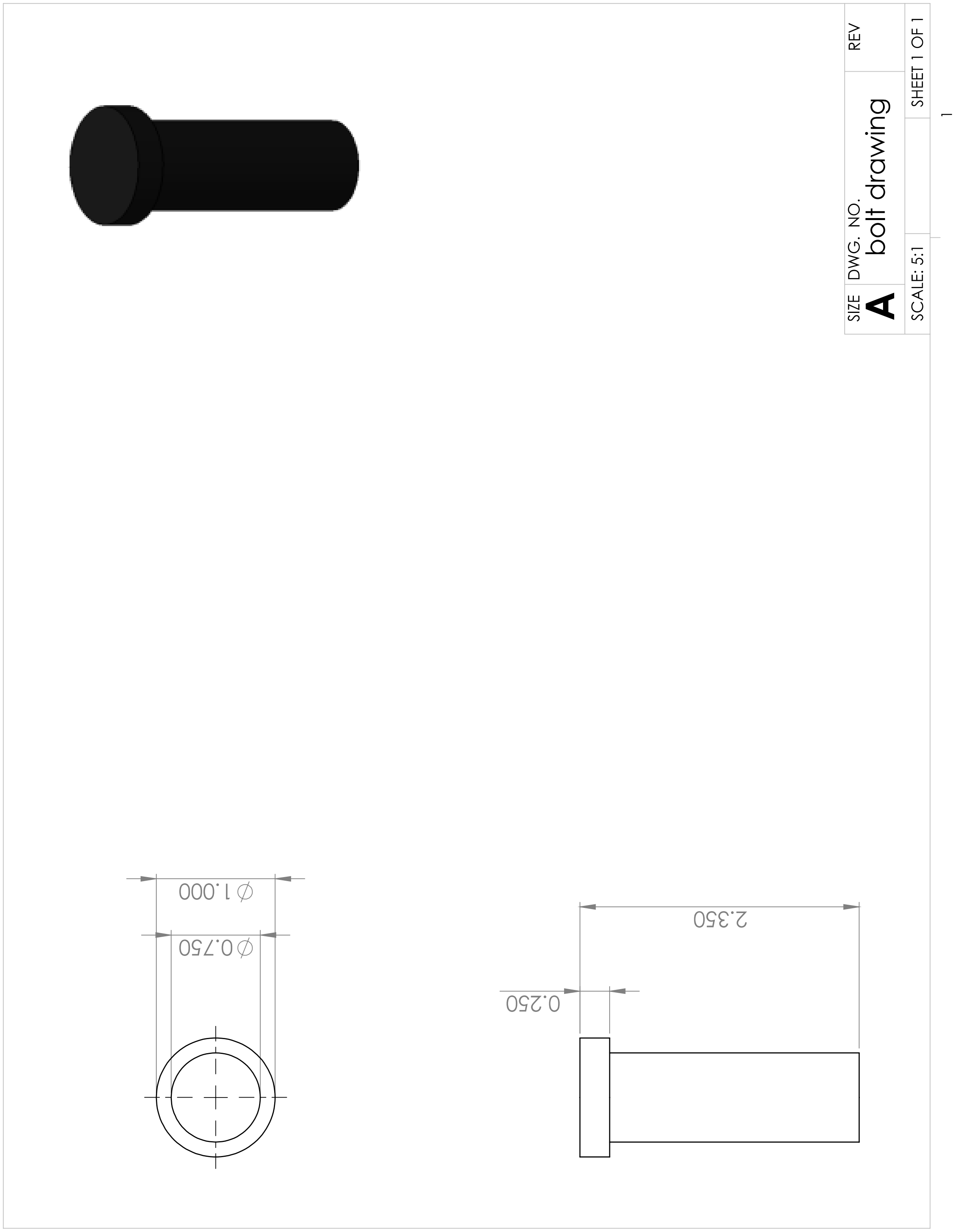

SIZE
A
DWG. NO.
spring drawing
REV
SCALE: 5:1
SHEET 1 OF 1
2.500
∅0.500



SIZE
DWG. NO.
REV
A
pressure vessel drawing
SCALE: 1:1
SHEET 1 OF 1
6.000
⌀1.550
⌀1.050
⌀0.770
1.0006.000
⌀0.210
⌀4.000
⌀4.000
⌀0.204
⌀0.210
2.856
⌀0.750
⌀1.550

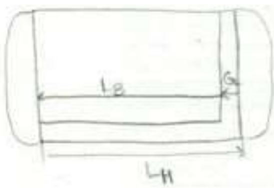


SIZE
DWG. NO.
A
end cap drawing
REV
SCALE: 5:1
SHEET 1 OF 1
⌀0.770
0.250
⌀1.550


∅1.000
∅0.750
2.350
0.250
SIZE
A
DWG. NO.
bolt drawing
REV
SCALE: 5:1
SHEET 1 OF 1
1

Appendix B – Closure Equations

Battery Module fitting into bottom for length



$L_H = 7.25''$

$L_B = 7.2''$

$0 = L_H - L_B - G_L$

$G_L = L_H - L_B$

$G_L = 7.25 - 7.2$

$G_L = 0.05$

$P = 0.008''$

$L_H = 7.25 \pm 0.008$

$L_B = 7.2 \pm 0.008$

$G_{min} = G_L - 0.008 - 0.008 = 0.034$

$G_{max} = G_L + 0.008 + 0.008 = 0.066$

$G_L = 0.05 \pm 0.016$

$\Delta L_H = P L_H = (0.008)(7.25) = 0.058$

$\Delta L_B = P L_B = (0.008)(7.2) = 0.0576$

$0 = (L_H - \Delta L_H) - (L_B + \Delta L_B) - (G_L + \Delta G)$

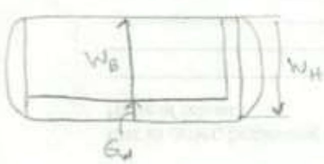
$\Delta G = L_H - \Delta L_H - L_B - \Delta L_B - G_L$

$= 7.25 - 0.058 - 7.2 - 0.0576 - 0.05$

$\Delta G = 0.1156$

---

for width



$W_H = 6.75''$

$W_B = 6.6''$

$0 = W_H - W_B - G_W$

$G_W = W_H - W_B$

$G_W = 6.75 - 6.6$

$G_W = 0.15$

$P = 0.008''$

$W_H = 6.75 \pm 0.008$

$W_B = 7.2 \pm 0.008$

$G_{Wmin} = G_W - 0.008 - 0.008 = 0.134$

$G_{Wmax} = G_W + 0.008 + 0.008 = 0.166$

$G_W = 0.15 \pm 0.016$

$\Delta W_H = P W_H = (0.008)(6.75) = 0.054$

$\Delta W_B = P W_B = (0.008)(6.6) = 0.0528$

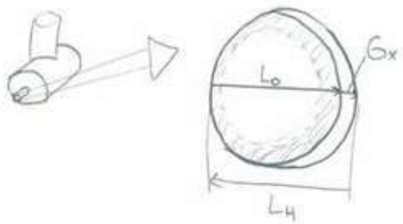
$0 = (W_H - \Delta W_H) - (W_B + \Delta W_B) - (G_W + \Delta G_W)$

$\Delta G_W = W_H - \Delta W_H - W_B - \Delta W_B - G_W$

$= 6.75 - 0.054 - 6.6 - 0.0528 - 0.15$

$\Delta G_W = 0.1068$

Hose attached to Pressure vessle



$L_H = 0.21$

$L_o = 0.21$

$G_x = L_H - L_o$

$= 0.21 - 0.21$

$G_x = 0$

$P = \text{tolerance} = \pm 0.008$

$L_H = 0.21 \pm 0.008$

$L_o = 0.21 \pm 0.008$

$\boxed{G_x = 0 \pm 0.016}$

$G_{x min} = G_x - 0.008 - 0.008 = 0 - 0.016 = -0.016$

$G_{x max} = G_x + 0.008 + 0.008 = 0 + 0.016 = 0.016$

$\Delta L_H = P L_H = 0.008(0.21) = 0.00168$

$\Delta L_o = P L_o = 0.008(0.21) = 0.00168$

$0 = (L_H - \Delta L_H) - (L_o + \Delta L_o) - (G_x + \Delta G_x)$

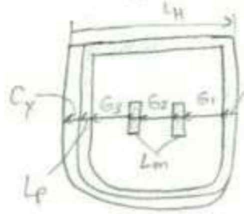
$\Delta G_x = L_H - \Delta L_H - L_o - \Delta L_o - G_x \Rightarrow 0.21 - 0.00168 - 0.21 - 0.00168 - 0$

$\boxed{\Delta G_x = -0.00336}$

* This value makes sense since this is a close fit assembly, and relies on the gap being zero which is why the ΔG_x is significantly small.

* since these pieces are circular it is assumed that the same values apply for every direction.

Battery Plug into bottom of housing Plate for Length



$L_H = 0.75''$

$L_m = 0.05''$

$L_p = 0.1''$

$G_1 = G_2 = G_3 = 0.15'' = G_x \quad P = 0.008$

$C_x = L_H - L_m - L_p - G_1 - G_2 - G_3$

$= 0.75 - 0.05 - 0.1 - 0.15 - 0.15 - 0.15$

$C_x = 0.15 \pm 0.048$

$\Delta L_H = P L_H = 0.008(0.75) = 0.006$

$\Delta L_m = P L_m = 0.008(0.05) = 0.0004$

$\Delta L_p = P L_p = 0.008(0.1) = 0.0008$

$\Delta G_x = P G_x = 0.008(0.15) = 0.0012$

$C_{xmax} = C_x + 6(0.008)$

$= 0.15 + 0.048 = 0.102$

$C_{xmin} = C_x - 6(0.008)$

$= 0.15 + 0.048 = 0.198$

$0 = (L_H - \Delta L_H) - (L_m + \Delta L_m) - (L_p + \Delta L_p) - 3(G_x + \Delta G_x) - (C_x + \Delta C_x)$

$\Delta C_x = L_H - \Delta L_H - L_m - \Delta L_m - L_p - \Delta L_p - 3G_x - 3\Delta G_x - C_x$

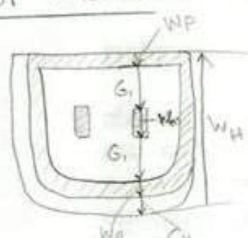
$= 0.75 - 0.05 - 0.1 - 0.006 - 0.0004 - 0.0008 - 0.0036 - 0.15$

$\Delta C_x = 0.439$

$L_H = 0.75 \pm 0.008 \quad L_p = 0.1 \pm 0.008$

$L_m = 0.05 \pm 0.008 \quad G_1 = G_2 = G_3 = G_x = 0.15 \pm 0.008$

for Width



$W_H = 0.75$

$W_p = 0.1$

$W_m = 0.2$

$G_1 = 0.15$

$G_2 = 0.2$

$P = 0.008$

$C_y = W_H - W_m - W_p - G_1 - G_2$

$= 0.75 - 0.1 - 0.2 - 0.15 - 0.2$

$C_y = .1 \pm 0.04$

$C_{ymin} = C_y - 5(0.008)$

$= 0.1 - 0.04 = 0.06$

$C_{ymax} = C_y + 5(0.008)$

$= 0.1 + 0.04 = 0.14$

$\Delta W_H = 0.75(0.008) = 0.006$

$\Delta W_m = 0.2(0.008) = 0.0016$

$\Delta W_p = 0.1(0.008) = 0.0008$

$\Delta G_1 = 0.15(0.008) = 0.0012$

$\Delta G_2 = 0.2(0.008) = 0.0016$

$0 = (W_H - \Delta W_H) - (W_m + \Delta W_m) - (W_p + \Delta W_p) - (G_1 + \Delta G_1) - (G_2 + \Delta G_2) - (C_y + \Delta C_y)$

$\Delta C_y = 0.75 - 0.1 - 0.2 - 0.15 - 0.2 - 0.006 - (0.0016)2 - 0.0012 - 0.0008$

$\Delta C_y = 0.1888 \approx 0.189$

$W_H = 0.75 \pm 0.008$

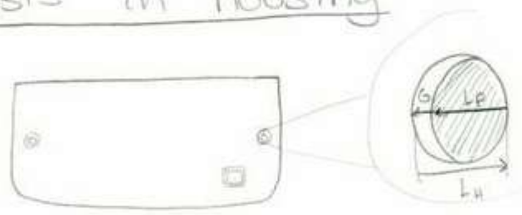
$W_p = 0.1 \pm 0.008$

$W_m = 0.2 \pm 0.008$

$G_1 = 0.15 \pm 0.008$

$G_2 = 0.2 \pm 0.008$

Posts in housing



$L_H = 0.27$ $\quad G_x = L_p - L_H$ $\quad P = 0.008$

$L_p = 0.25$ $\quad = .27 - .25$

$G_x = 0.02$ $\quad \boxed{G_x = 0.02 \pm 0.016}$

$G_{x_{min}} = G_x - 0.008 - 0.008$
$= 0.02 - 0.016 = 0.004$

$\Delta L_H = L_H P = 0.27(0.008) = 0.00216$

$\Delta L_p = L_p P = 0.25(0.008) = 0.002$

$G_{x_{max}} = G_x + 0.008 + 0.008$
$= 0.02 + 0.016 = 0.036$

$L_H = 0.27 \pm 0.008$

$L_p = 0.25 \pm 0.008$

$G_x = 0.02 \pm 0.008$

$0 = (L_H - \Delta L_H) - (L_p + \Delta L_p) - (G_x - \Delta G_x)$

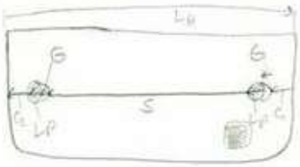
$\Delta G_x = L_H - \Delta L_H - L_p - \Delta L_p - G_x$

$= 0.27 - 0.25 - 0.02 - 0.00216 - 0.002$

$\Delta G_x = 0.00416 \approx 0.004$

* Assuming this pin is a perfect circle we can conclude that the final values for dimensions in the x-direction are the same as those in the y-direction. Therefore $G_x = G_y$; $L_H = W_H$; $L_p = W_p$

Bottom of adaptor to top of Housing for module



$L_H = 7.25$

$L_p = 0.25$

$G = 0.02$

$C_1 = C_2 = 1.0 = C$ $\quad p = 0.008$

$S = L_H - L_p - 2G - 2C$

$= 7.25 - 0.25 - 2(0.02) - 2(1.0)$

$\boxed{S = 4.96 \pm 0.048}$

$S_{min} = S - (0.008)6$

$= 4.96 - 0.048 = 4.912$

$S_{max} = S + (0.008)6$

$= 4.96 + 0.048 = 5.008$

$\Delta L_H = 7.25(0.008) = 0.058$

$\Delta L_p = 0.25(0.008) = 0.002$

$\Delta G = 0.02(0.008) = 0.00016$

$\Delta C = 1.0(0.008) = 0.008$

$L_H = L_p + 2G + 2C + S = 0$

$0 = (L_H - \Delta L_H) - (L_p + \Delta L_p) - 2(G + \Delta G) - 2(C + \Delta C) - (S + \Delta S)$

$\Delta S = -\Delta L_H - \Delta L_p - 2\Delta G - 2\Delta C$

$\boxed{\Delta S = 0.06816 \simeq 0.068}$

$L_H = 7.25 \pm 0.008$

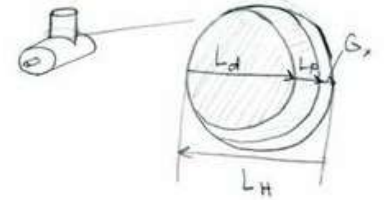
$L_p = 0.25 \pm 0.008$

$G = 0.02 \pm 0.008$

$C = 1.0 \pm 0.008$

$S = 4.96 \pm 0.048$

Pressure vessle Release valve



$L_H = 1.0$
$L_p = 1.0$
$L_d = .99 - 1.05$
$G_x = L_H - L_p - L_d$

$G_x = 1.0 - 1 - 1.0$

$G_x = 0 \pm 0.014$

$L_H \pm H = 1.0 \pm 0.008$
$L_p \pm P = 1.0 \pm 0.002$
$L_d \pm D = .99 - 1.05 \pm 0.004$
* H, P, D = tolerances per material

$G_{xmin} = G_x - 0.008 - .002 - 0.004$
$= 0 - .014 = -0.014$
$G_{xmax} = G_x + 0.008 + 0.002 + 0.004$
$= 0 + .014 = 0.014$

$\Delta L_H = L_H H = 1.0(.008) = 0.008$
$\Delta L_p = L_p P = 1.0(0.002) = 0.002$
$\Delta L_d = L_d D = .99(.004) = 0.00396$
$1.05(0.004) = 0.0042$
$\Delta L_d = 0.00396 - 0.0042$

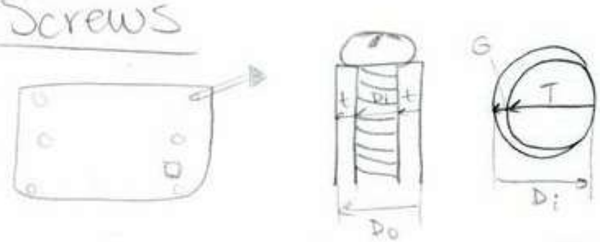
$0 = (L_H - \Delta L_H) - (L_p + \Delta L_p) - (L_d + \Delta L_d) - (G_x + \Delta G_x)$
$\Delta G_x = L_H - (\Delta L_H + L_p + \Delta L_p + L_d + \Delta L_d + G_x)$

$\Delta G_x = 0.034$

* Since this is a close fit the plastic disk fluctuates inside the piston and therefore is expected that all these parts would make the gap to be zero. The L_p is the diameter of the stainless steel plate that also is the exact size of the inner diameter of the abs piston cavity, to ensure a close fit.

* Since this is a circular part the dimensions do not differ from those in the y-direction

Screws



$T = 0.19$

$D_i = 0.20$

$G = D_i - T$

$G = 0.20 - 0.19$

$= 0.01$

$P = 0.002$

$\boxed{G = 0.01 \pm 0.01}$

$G_{min} = G - 0.002 - 0.008$

$= 0.01 - 0.01 = 0$

$G_{max} = G + 0.002 + 0.008$

$= 0.01 + 0.01 = 0.02$

$\Delta T = TP = 0.19(0.002) = 0.00038$

$\Delta D_i = D_i P = 0.20(0.008) = 0.0016$

$T = 0.19 \pm 0.002$

$D_i = 0.20 \pm 0.008$

$0 = (D_i - \Delta D_i) - (T + \Delta T) - (G + \Delta G)$

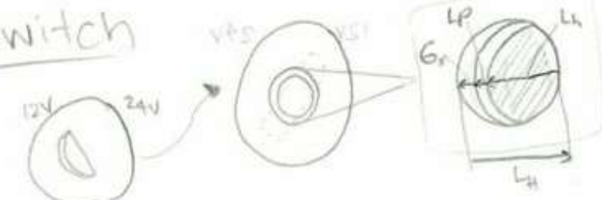
$\Delta G = D_i - \Delta D_i - T - \Delta T - G - \Delta G$

$= 0.20 - 0.19 - 0.00038 - 0.0016 - 0.01$

$\boxed{\Delta G = -0.00198}$

* Assuming this screw is perfectly circular, it is such a close fit that the screw will run into the abs plastic to provide a tight fit. And since it is circular all dimensions are the same in every direction.

Switch



$L_H = 0.5$ $\qquad G_x = L_H - L_h - L_p$

$L_p = 0.1$ $\qquad = 0.5 - 0.1 - 0.45$

$L_h = 0.35$ $\qquad G_x = 0.05$

$L_H = 0.5 \pm 0.008$ $\qquad P = 0.008$

$L_p = 0.1 \pm 0.008$ $\qquad \boxed{G_x = 0.05 \pm 0.024}$

$L_h = 0.35 \pm 0.008$

$$G_{x_{min}} = G_x - 0.008 - 0.008 - 0.008 = 0.05 - 0.024 = 0.026$$

$$G_{x_{max}} = G_x + 0.008 + 0.008 + 0.008 = 0.05 + 0.024 = 0.074$$

$$\Delta L_H = PL_H = 0.008(0.5) = 0.004$$

$$\Delta L_p = PL_p = 0.008(0.1) = 0.0008$$

$$\Delta L_h = PL_h = 0.008(0.35) = 0.0028$$

$$0 = (L_H - \Delta L_H) - (L_p + \Delta L_p) - (L_h + \Delta L_h) - (G_x + \Delta G_x)$$

$$\Delta G_x = L_H - \Delta L_H - L_p - \Delta L_p - L_h - \Delta L_h - G_x$$

$$= 0.5 - 0.004 - 0.1 - 0.0008 - 0.35 - 0.0028 - 0.05$$

$$\boxed{\Delta G_x = 0.0076}$$

* This P_x is small which provides a snug fit and allows for minimal room of error.
* Also because this piece of the assembly module is circular the dimensions remain the same all the way around the radius which leads us to assume the same values in the x-direction apply for the values in the y-direction i.e.) $L_H = W_H$; $L_p = W_p$; $L_h = W_h$; $G_x = G_y$ & the tolerance remains the same at 0.008.

Appendix C - References

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Appendix D – Assembly Charts

Handling Time Chart

Key: ONE HAND

Parts can be grasped and manipulated by one hand without the aid of grasping tools		parts are easy to grasp and manipulate					parts present handling difficulties (1)				
		thickness > 2 mm			thickness ≤ 2 mm		thickness > 2 mm			thickness ≤ 2 mm	
		size > 15 mm	6 mm ≤ size ≤ 15 mm	size < 6 mm	size > 6 mm	size ≤ 6 mm	size > 15 mm	6 mm ≤ size ≤ 15 mm	size < 6 mm	size > 6 mm	size ≤ 6 mm
		0	1	2	3	4	5	6	7	8	9
$(\alpha+\beta) < 360°$	0	1.13	1.43	1.88	1.69	2.18	1.84	2.17	2.65	2.45	2.98
$360° \le (\alpha+\beta) < 540°$	1	1.5	1.8	2.25	2.06	2.55	2.25	2.57	3.06	3	3.38
$540° \le (\alpha+\beta) < 720°$	2	1.8	2.1	2.55	2.36	2.85	2.57	2.9	3.38	3.18	3.7
$(\alpha+\beta) = 720°$	3	1.95	2.25	2.7	2.51	3	2.73	3.06	3.55	3.34	4

ONE HAND with GRASPING AIDS

Parts can be grasped and manipulated by one hand but only with the use of grasping tools			parts need tweezers for grasping and manipulation								parts need standard tools other than tweezers	parts need special tools for grasping and manipulation
			parts can be manipulated without optical magnification				parts require optical magnification for manipulation					
			parts are easy to grasp and manipulate		parts present handling difficulties (1)		parts are easy to grasp and manipulate		parts present handling difficulties (1)			
			thickness > 0.25 mm	thickness ≤ 0.25 mm	thickness > 0.25 mm	thickness ≤ 0.25 mm	thickness > 0.25 mm	thickness ≤ 0.25 mm	thickness > 0.25 mm	thickness ≤ 0.25 mm		
			0	1	2	3	4	5	6	7	8	9
$\alpha \le 180°$	$0 \le \beta \le 180°$	4	3.6	6.85	4.35	7.6	5.6	8.35	6.35	8.6	7	7
$\alpha \le 180°$	$\beta = 360°$	5	4	7.25	4.75	8	6	8.75	6.75	9	8	8
$\alpha = 360°$	$0 \le \beta \le 180°$	6	4.8	8.05	5.55	8.8	6.8	9.55	7.55	9.8	8	9
$\alpha = 360°$	$\beta = 360°$	7	5.1	8.35	5.85	9.1	7.1	9.55	7.85	10.1	9	10

TWO HANDS for MANIPULATION

		parts present no additional handling difficulties					parts present additional handling difficulties (e.g. sticky, delicate, slippery, etc.) (1)				
		$\alpha \le 180°$			$\alpha = 360°$		$\alpha \le 180°$			$\alpha = 360°$	
		size > 15 mm	6 mm ≤ size ≤ 15 mm	size < 6 mm	size > 6 mm	size ≤ 6 mm	size > 15 mm	6 mm ≤ size ≤ 15 mm	size < 6 mm	size > 6 mm	size ≤ 6 mm
		0	1	2	3	4	5	6	7	8	9
parts severely nest or tangle or are flexible but can be grasped and lifted by one hand (with the use of grasping tools if necessary) (2)	8	4.1	4.5	5.1	5.6	6.75	5	5.25	5.85	6.35	7

TWO HANDS required for LARGE SIZE

		parts can be handled by one person without mechanical assistance									two persons or mechanical assistance required for parts manipulation
		parts do not severely nest or tangle and are not flexible								parts severely nest or tangle or are flexible (2)	
		part weight < 10 lb				parts are heavy (> 10 lb)					
		parts are easy to grasp and manipulate		parts present other handling difficulties (1)		parts are easy to grasp and manipulate		parts present other handling difficulties (1)			
		$\alpha \le 180°$	$\alpha = 360°$	$\alpha \le 180°$	$\alpha = 360°$	$\alpha \le 180°$	$\alpha = 360°$	$\alpha \le 180°$	$\alpha = 360°$		
		0	1	2	3	4	5	6	7	8	9
two hands, two persons or mechanical assistance required for grasping and transporting parts	9	2	3	2	3	3	4	4	5	7	9

Manual Insertion Time Chart

MANUAL INSERTION—ESTIMATED TIMES (seconds)

Key:

PART ADDED but NOT SECURED

addition of any part (1) where neither the part itself nor any other part is finally secured immediately			after assembly no holding down required to maintain orientation and location (3)				holding down required during subsequent processes to maintain orientation or location (3)			
			easy to align and position during assembly (4)		not easy to align or position during assembly		easy to align and position during assembly (4)		not easy to align or position during assembly	
			no resistance to insertion	resistance to insertion (5)	no resistance to insertion	resistance to insertion (5)	no resistance to insertion	resistance to insertion (5)	no resistance to insertion	resistance to insertion (5)
			0	1	2	3	6	7	8	9
part and associated tool (including hands) can easily reach the desired location		0	1.5	2.5	2.5	3.5	5.5	6.5	6.5	7.5
part and associated tool (including hands) cannot easily reach the desired location	due to obstructed access or restricted vision (2)	1	4	5	5	6	8	9	9	10
	due to obstructed access and restricted vision (2)	2	5.5	6.5	6.5	7.5	9.5	10.5	10.5	11.5

PART SECURED IMMEDIATELY

addition of any part (1) where the part itself and/or other parts are being finally secured immediately			no screwing operation or plastic deformation immediately after insertion (snap/press fits, circlips, spire nuts, etc.)		plastic deformation immediately after insertion						screw tightening immediately after insertion (6)	
					plastic bending or torsion			rivetting or similar operation				
						not easy to align or position during assembly			not easy to align or position during assembly			
			easy to align and position with no resistance to insertion (4)	not easy to align or position during assembly and/or resistance to insertion (5)	easy to align and position during assembly (4)	no resistance to insertion	resistance to insertion (5)	easy to align and position during assembly (4)	no resistance to insertion	resistance to insertion (5)	easy to align and position with no torsional resistance (4)	not easy to align or position and/or torsional resistance (5)
			0	1	2	3	4	5	6	7	8	9
part and associated tool (including hands) can easily reach the desired location and the tool can be operated easily		3	2	5	4	5	6	7	8	9	6	8
part and associated tool (including hands) cannot easily reach desired location or tool cannot be operated easily	due to obstructed access or restricted vision (2)	4	4.5	7.5	6.5	7.5	8.5	9.5	10.5	11.5	8.5	10.5
	due to obstructed access and restricted vision (2)	5	6	9	8	9	10	11	12	13	10	12

SEPARATE OPERATION

		mechanical fastening processes (part(s) already in place but not secured immediately after insertion)				non-mechanical fastening processes (part(s) already in place but not secured immediately after insertion)				non-fastening processes	
		none or localized plastic deformation				metallurgical processes					
							additional material required				
		bending or similar processes	rivetting or similar processes	screw tightening (6) or other processes	bulk plastic deformation (large proportion of part is plastically deformed during fastening)	no additional material required (e.g. resistance, friction welding, etc.)	soldering processes	weld/braze processes	chemical processes (e.g. adhesive bonding, etc.)	manipulation of parts or sub-assembly (e.g. orienting, fitting or adjustment of part(s), etc.)	other processes (e.g. liquid insertion, etc.)
		0	1	2	3	4	5	6	7	8	9
assembly processes where all solid parts are in place	9	4	7	5	3.5	7	8	12	12	9	12

Appendix E - Plastic Identification Chart