Thermal Storage Solution for the Organic Rankine Cycle

Deliverable:

Design of Manufacturing

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Team: # 17

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Design for Manufacturing

Once all of the parts were sourced and ordered we were able to begin manufacturing the baffles. Using the water jet machine provided by the College of Engineering, we cut 19 holes in an aluminum sheet and then cut out the outer diameter of the circle. The baffle cut was then made making the baffles a semi-circle which will allow for the desired flow of the oil. When the salt arrived, Verdicorp began creating the phase change material (PCM) capsules. This process is patented and little details were given but, in summary the salt was poured into a steel cylindrical pipe, heated to an extremely high temperature, cooled, and solidified. This process was repeated multiple times for each PCM capsule. The baffle frame was created using four threaded rods and were spaced 3.05” apart. The tank was then constructed by welding the base to the bottom of the large cylindrical pipe shown in Figure – 1. It was then water tested to ensure no oil will leak out during the testing and operation processes. Inlet and outlet holes were drilled and threadolets were welded to the outside of those holes. Plugs were inserted into the threadolets to protect the holes from any damage until the system was ready for complete assembly. A top was manufactured by welding an aluminum ring, with a diameter slightly smaller than the inner diameter of the tank, to the base of a circular plate. A scrap piece of smooth metal was shaped into a half of a square and then welded to the top, opposite the side of the aluminum ring, as a

Figure 1. Tank with Baffles frame installed

handle. The next two components of the project were manufactured simultaneously. The heat source was constructed by using a 6" diameter circular pipe with a cap welded on one side. The inlet and outlet holes were drilled in the same manner as the tank and the threadolets were welded to both of the holes. The top cap was created by cutting 4 holes in it equally spaced apart one for the thermocouple and three for the heat cartridges to be inserted into. Since the heat cartridges need to be protected from the oil a thin metal alloy tube was inserted into the holes and welded to the cap within the heat source. The wires for all four components inserted into the heater cap will all stick out for easy wire connection and assembly. Two brackets were welded to the side of the heat source for easy mounting to the 80/20 frame shown in Figure – 2.

Figure 2. Heat Source with sensors

At the same time the load that represents the ORC was being constructed using a car heat exchanger and two small fans. The housing was constructed using a wall track material donated by Lowes. The piping and fin car heat exchanger was inserted into the housing and secured. An aluminum sheet was used to mount the fans onto the housing. Two holes the size of the fan were cut out of that aluminum sheet in order to allow air flow over the fin and piping heat exchanger. Figure – 3 shows an aluminum sheet with the fans attached being secured to the heat exchanger housing.

Figure 3. Load with fans attached to 80/20 frame

The pump was assembled and mounted to a thick sheet of metal for stability and easy mounting shown in the right side of Figure – 1. Once all of the components were assembled individually they were all mounted on a vertical frame of 80/20 material on wheels. The heat exchanger load was mounted to the top of the frame to avoid blowing hot air directly at whoever is testing the system. A base sheet of aluminum was mounted to the frame to provide a surface for the pump and tank to be attached to. The heat source was mounted vertically in the center of the 80/20 frame and piping was used to connect all of the components. Insulation was added to the tank, heat source, and piping to prevent unnecessary heat loss in the system.

A switch, shown in Figure – 4, was connected in series with the heat cartridges to provide a way to prevent overheating. This switch was mounted in a control box to protect it from the heat provided to the rest of the system. The flowmeter was placed right after the pump before the heat source. Thermocouples were used to display the temperatures directly before and after the thermal storage tank. These temperature displays will show if the system is successfully storing the heat within the PCM capsules and if that heat is being transferred sufficiently.

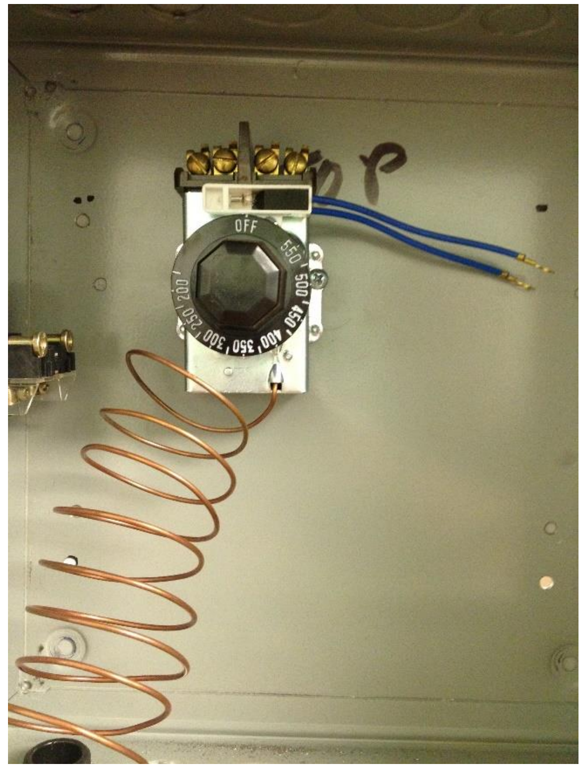


Figure 4. Switch within control box

The overall assembly went quite smoothly and ended up taking less time than expected. We set aside two weeks for construction and it took just over a week to complete. The most difficult part of the assembly was being able to visualize where all the components would fit on the 80/20 frame and how the piping would be oriented.

When considering the overall setup of the system and the project scope we were able to eliminate any extra components during the design phase. The incorporation of a reheat system and a cold storage tank in addition to our hot storage tank would make our simple system much more advanced and a better demonstration of Verdicorp's project goals.

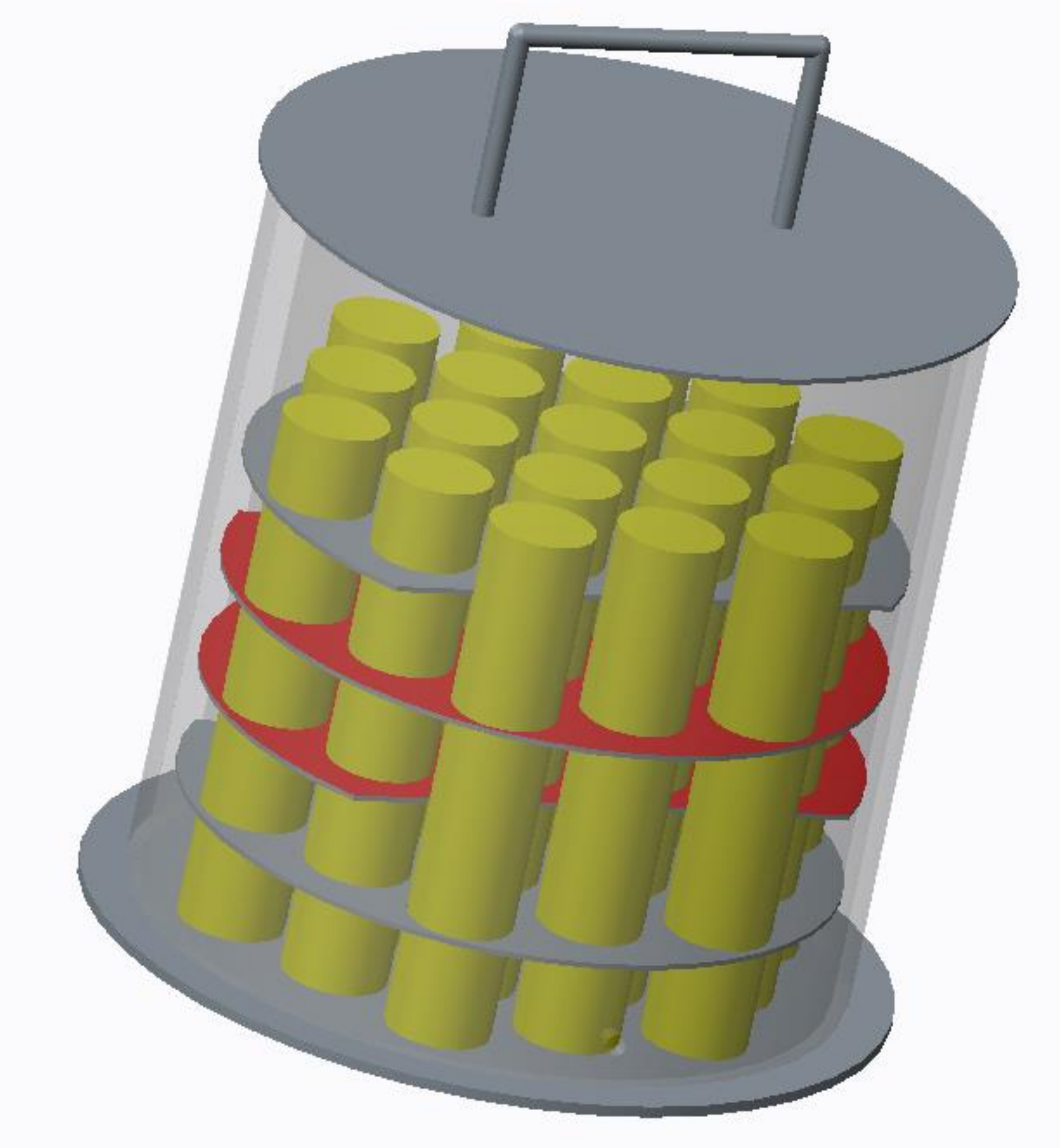
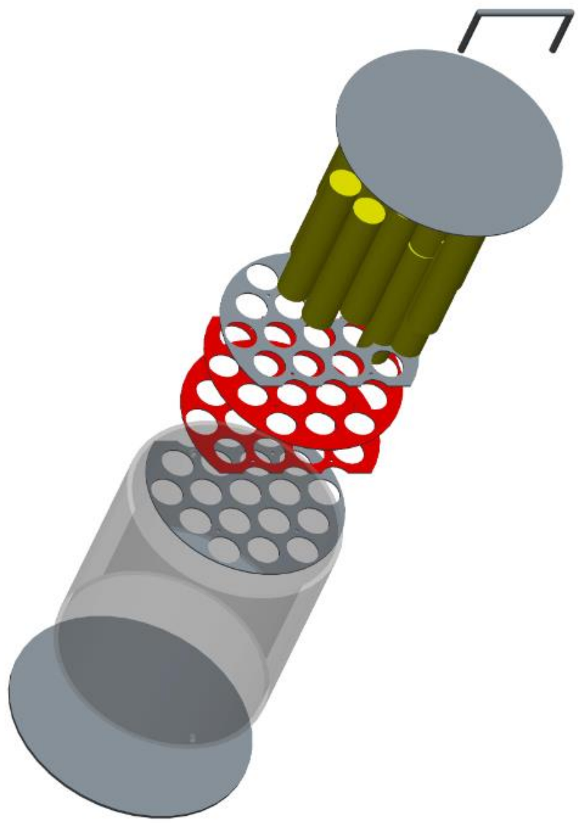


Figure 5. 3-D model of thermal storage tank



SCALE 0.250

Assembly 1	Verdicorp	04/3/15
Sketch 1	Jhamal, Belal, Cory, Bruce	Group 17

Figure 6. Exploded View of thermal storage tank

Design for Reliability

The main use of the prototype is to be used as a test rig for Verdicorp to experiment with different PCM salts as well as different capsule/baffle configurations on a small scale. The prototype will also be used as a portable model to demonstrate the PCM capsule technology to possible future customers.

With this in mind, the prototype is not meant to be an actual small scale operating thermal storage system, it is meant more to collect data under monitored use, and not to be left unattended as the large scale version would operate. The controls on the prototype are completely analog and must be monitored during use to prevent over-heating of the heat cartridges and possibly burning the working fluid. The mass flow rate must be regulated manually over the operating cycle of the prototype to simulate the controls of the full-scale device. Apart from these concerns with the controls, the prototype is designed very robust for its application.

The prototype is expected to run for multiple data gathering cycles before a maintenance must be conducted. The baffles and capsules will have to be cleaned due to fouling of the working fluid, depositing residue onto any component that is in contact with the oil. The copper piping system will also have to be flushed and possibly brushed for the same reasons. After each operating cycle it is recommended to check the interior of the tank for any anomalies, such as misalignment of the baffle frame and ruptures in the PCM capsules. The fittings and valves should be tightened after every ten cycles of operation, as well as the bolts holding down the pump and tank due to high vibration loading onto the frame. An FMEA table is depicted in Figure-7 which illustrates all major possible modes of failure.

In order to increase the reliability of the prototype a mechatronic system should be implemented with the use of the thermal sensors to control the mass flow rate, pressure, and heat input into the system. These controls would make the system safer and make data collection easier for the operating technician.

FMEA (FAILURE MODE AND EFFECTS ANALYSIS)

Failure Modes Effects Analysis

Team #:	17
Project Title	Verdicorp's Thermal Storage Solution for Continuous ORC

Key Process Step or Input	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes	OCC	Current Controls	DET	RPN	Actions Recommended	Resp.	Actions Taken	SEV	OCC	DET	RPN
What is the Process Step or Input?	In what ways can the Process Step or Input fail?	What is the impact on the Key Output Variables once it fails (customer or internal requirements)?	How **Severe** is the effect to the customer?	What causes the Key Input to go wrong?	How **often** does cause or FM **occur?**	What are the existing **controls** and procedures that prevent either the Cause or the Failure Mode?	How well can you **detect** the Cause or the Failure Mode?		What are the actions for reducing the occurrence of the cause, or improving detection?	Who is Responsible for the recommended action?	Note the actions taken. Include dates of completion.				
Pump	Rust, metallic flakes, and/or debris entering pump.	Pump malfunction will lead to a loss of pressure through the system.	8	Lack of proper grinding/cleaning of tank and piping components.	2	All components in contact with flow must be cleaned of debris.	5	80	Flush system with distilled water or motor oil without pump.	Assembly Technician.	Grinding of rust/debris, throughly vaccumed.	8	2	5	80
Heat Source	Heat cartridges over-heating and failing.	No heat input into working fluid.	8	Improper use of controls and/or lack of monitoring of system.	6	Temperature dial and thermal sensors.	4	192	Monitoring system thermocouples and thermometers.	Operation Technician.	Limit electrical input into heat cartridges through thermostat.	8	6	4	192
Thermal Storage Tank	Working fluid leaking from top and through welds.	Irregular flow, loss of pressure, loss of working fluid.	6	Improper attachment and securement of tank lid, incomplete	3	Lid secures under it's own weight.	3	54	Leak test storage tank, force close storage tank lid to top.	Assembly Technician.	Place locking mechanism onto lid.	6	3	3	54
Baffles	Misalignment and/or movement of baffle assembly.	Unstable flow in tank, improper heat transfer to PCM capsules.	5	Improper securement of baffle assembly, opration pressures higher than recommended.	4	Baffle assembly secured under its own weight and weight of PCM capsules.	7	140	Force close baffle frame between top and bottom of tank.	Assembly Technician.	Elongate baffle assembly links to lock it into place.	5	4	7	140
PCM Capsules	Rupture of capsules due to thermal expansion.	Contamination of PCM salt, corrosion of all components in contact with working fluid.	10	Improper securement of caps onto capsules, overfilling capsules with salts.	3	Testing individual capsules in convection oven before put into assembly.	8	240	Conduct multiple thermal loading tests on individual capsules before assembly and testing.	Operation Technician.	Reduce amount of salt in capsules if necessary.	10	3	8	240
Load	Melting of electrical wiring and/or major components of fans.	Power and control loss of load fans.	6	Mounting low heat resistance components near high temperature components.	3	Thermocouple monitoring.	5	90	Zip-tie wiring and/or relocate low temperature resistant components away from heat sources.	Assembly Technician.	Relocate delicate components away from heat sources.	6	3	5	90
Piping	Leaks and/or ruptures.	Loss of working fluid, melting of wiring and other components, safety hazard.	8	Improperly tightened valves and fittings, higher pressures in system than recommended.	3	Teflon tape applied to all valves and fittings.	3	72	Test piping pressures without heat inputs.	Assembly Technician.	Test piping with water at high pressures at ambient temperatures	8	3	3	72
Assembly Frame	Disassembly of major components.	Pipe ruptures/leaks, disconnection of wiring, loss of materials.	9	Vibration loading, loose bolts and hardware, improper weight distribution on frame.	5	Check tigthening on all bolts, balance weight loads on frame.	3	135	Placement of damping materials under pump and storage tank.	Assembly Technician.	Test pump at high pressures using water and without piping and wiring assembled.	9	5	3	135

Figure 7 Failuire Analysis Chart

Design for Economics

Our project revolves around creating a commercially viable thermal energy system for Verdicorp. The system would be placed in Birdsville, Australia to provide extended power to about 300 people. The scale of the project therefore is massive. After relentless research on the subject of thermal energy storage using phase change material, we have determined that 6,121 PCM capsules will be needed for the full scale model. These capsules would fit in a cylindrical aluminum tank 18ft in diameter, 22ft tall, and 1 inch thick. The materials alone to fill the tank with PCM salt and heat transfer oil would cost an upwards of $3.7 million, including the empty tank and capsules themselves. However that doesn't include cost of pump, flowmeter, piping, fittings, and everything else involved with the system. Let's not forget the cost of physically constructing the system. As one can infer, the bill for this project increases rapidly very early on.

The prototype on the other hand was relatively inexpensive and gives a great approximation for what to expect on the full model. To this point, the group has spent $1,442.41 of the $2,000 budget as seen in Figure-9. This includes all simulation, planning, purchasing, and physically building the system. Keep in mind Verdicorp creates Organic Rankine Cycle systems in their warehouse so they have an array of scrap metal and parts we were able to implement into our model, saving the team quite a bit of money. Sheet metal for the baffles, the pump, and heat source are all examples of things we were able to salvage out of there junk pile. They also have many thermocouples throughout the building and were able to use those in our system as well. The heat load was purchased by Verdicorp under a separate account and was therefore not included in the team's budget. Individual components and their cost may be seen in Figure-8.

After researching and discussing this project with advisors and sponsors, the team is not aware of anyone implementing a system such as this. There are systems that use PCM capsules, but they are contained in small spheres rather than large cylinders. Cost estimates for those kind of systems are incredibly hard to find. The best comparison the team could make is to compare the cost of our prototype and services to one of a professional consulting company. Ultimately what we provided to Verdicorp is a simulation of what to expect with the constraints given and building a physical system to prove those theories. We did all that for less than $1,500. Verdicorp could have went with PCM Thermal Solutions, a consulting company based out of the Chicago area, to provide them with advice and direction on their project, but it would have cost them $3,000. This only includes a simulation and advice for future work. The $3,000 figure does not include a physical system to back up their theories. Figure-xxx brilliantly compares the group's bill to that of PCM Thermal Solutions. The team essentially saved Verdicorp $1,500 providing the same services and also building the physical model on top of that.

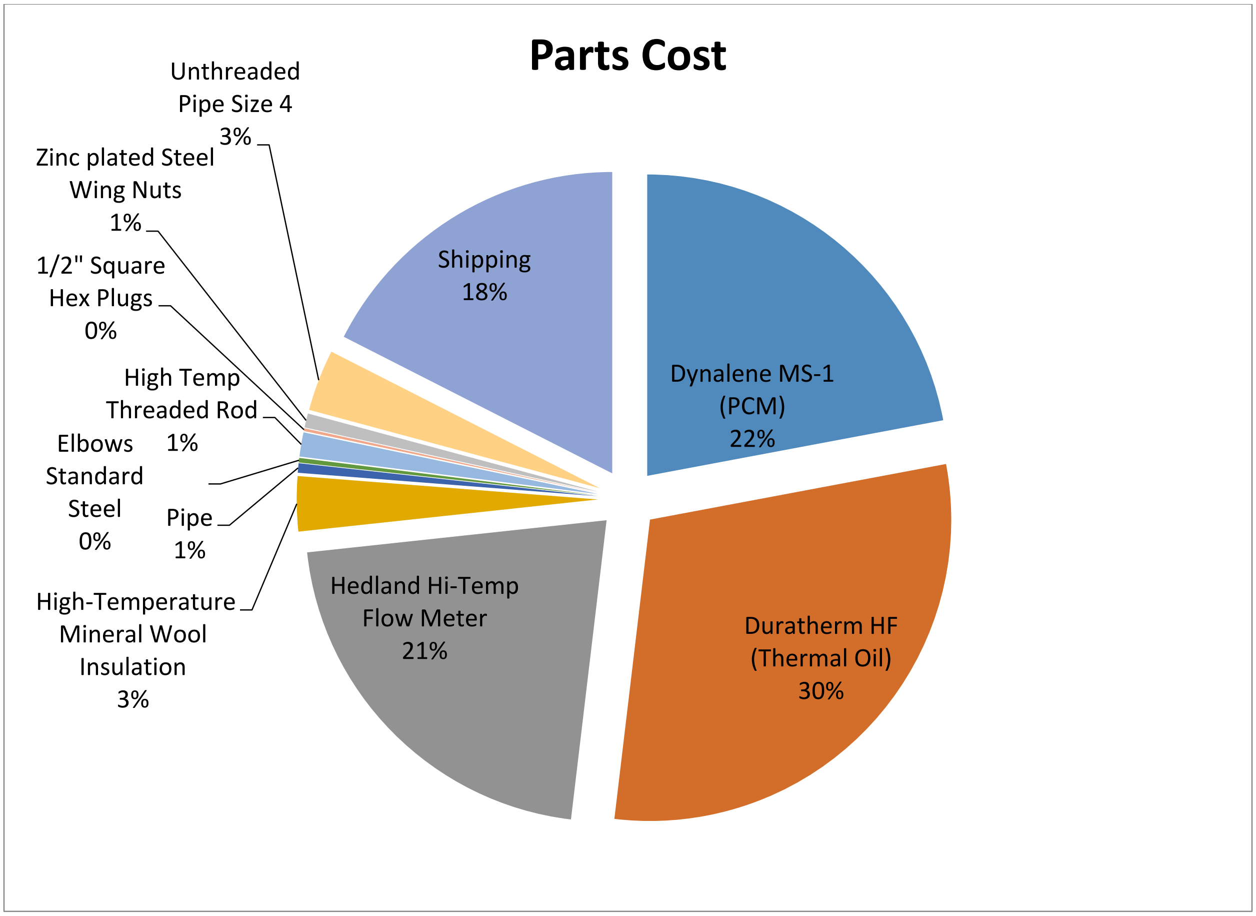


Figure 8 Budget Breakdown

BUDGET GRAPH AND STATEMENT

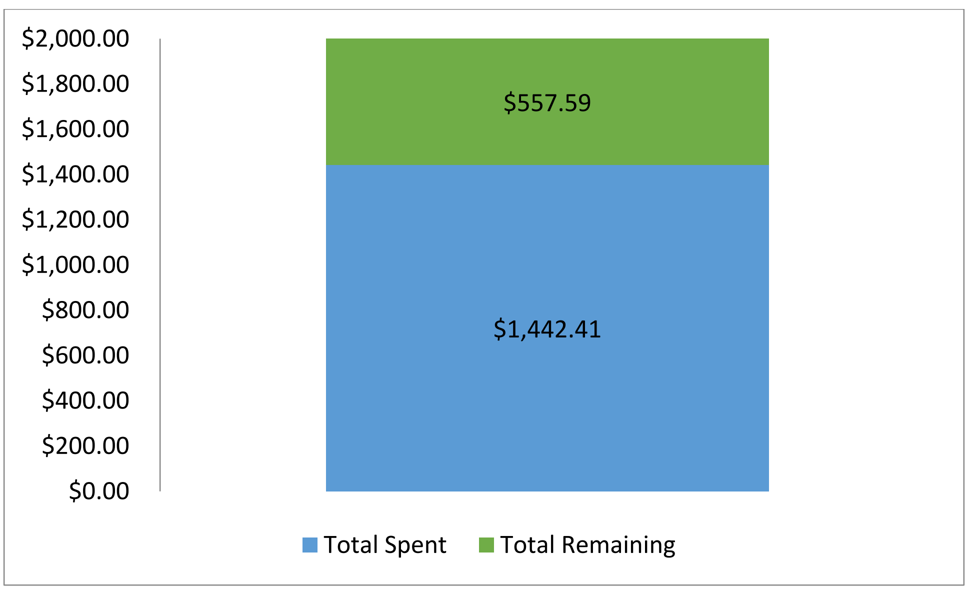


Figure 9. Overall Budget

A BAR GRAPH COMPARING OUR PRODUCT TO OTER COMMERICAL PRODUCTS LIKE OURS

http://www.pcm-solutions.com/thermalstorage.html

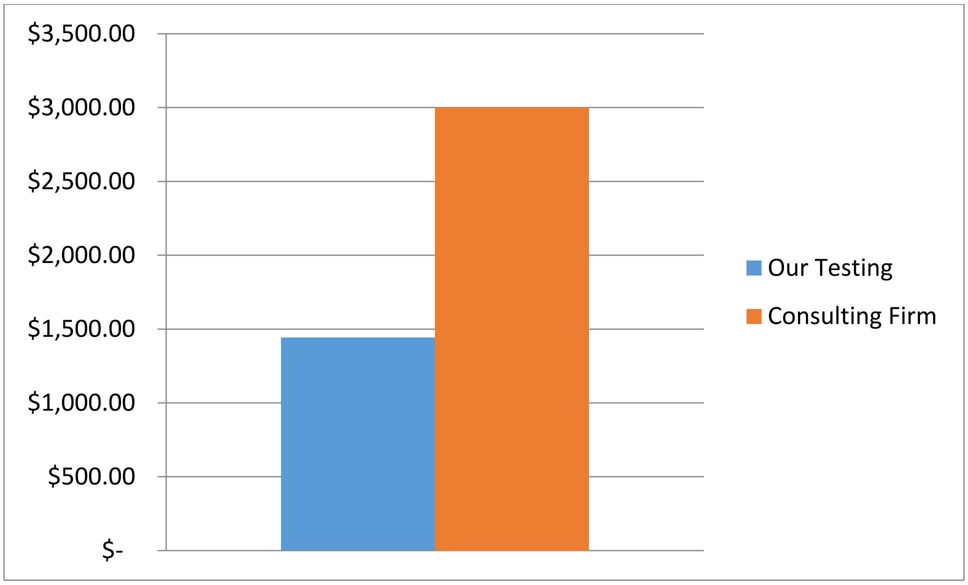
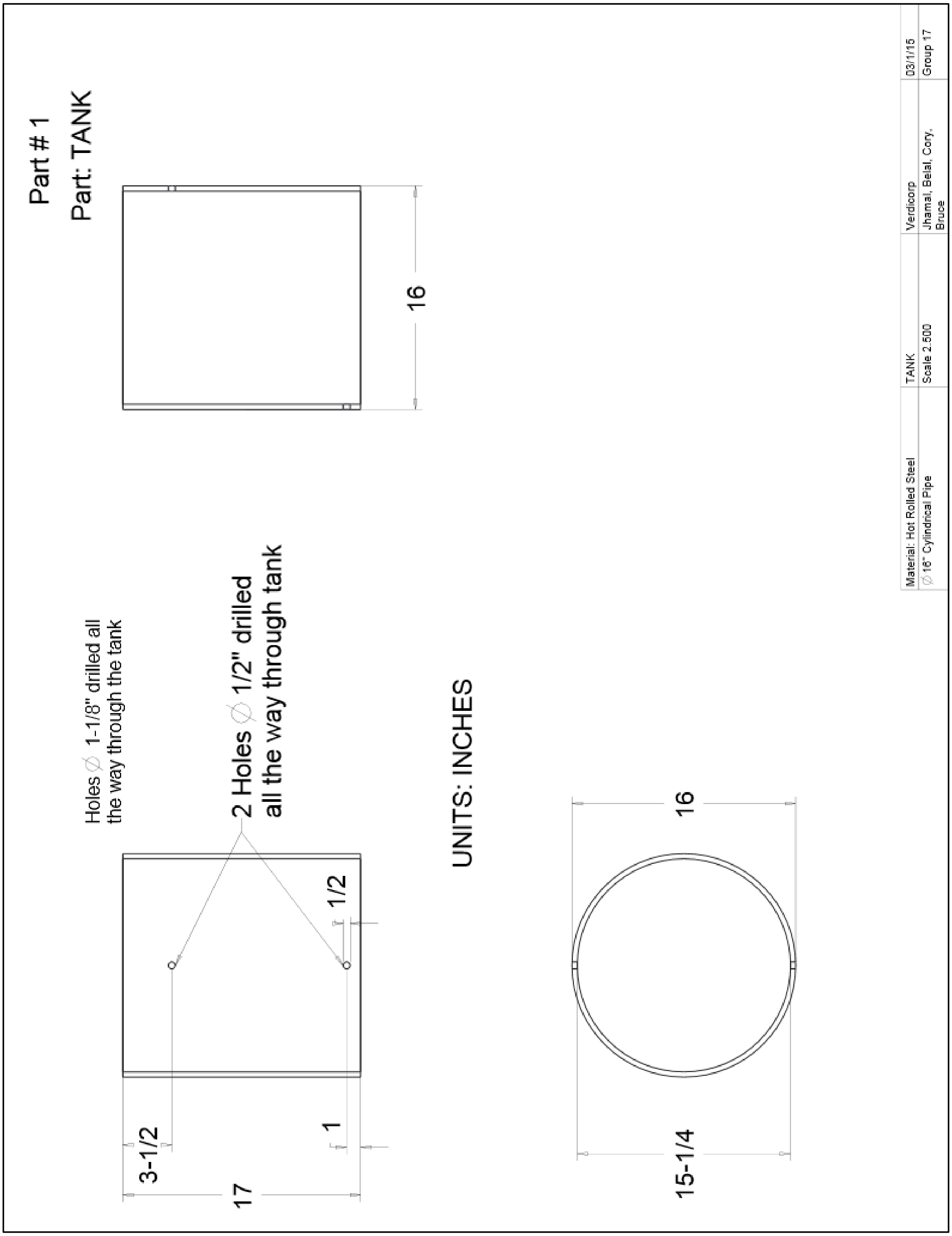


Figure 10. Our Analysis vs. a Competitor

Conclusion

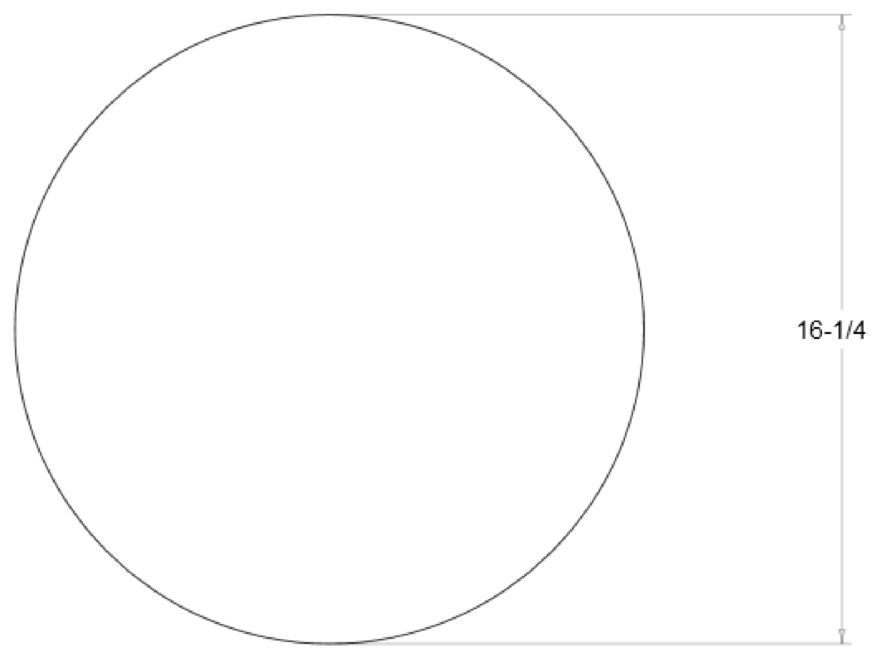
The overall manufacturing process went according to schedule. As a group we were all available to meet for at least 2 hours every day for a week to complete the assembly. We encountered a few difficulties with the manual labor portions such a drilling through thick metals, leveling the 80/20 material, and sanding the inside of the tank. With a little bit of help from expert welders and project managers from Verdicorp we were able to overcome these issues and complete the manufacturing process a few days ahead of schedule. We learned how to step drill, utilize tick welding, install threadolets, connect piping, configure a pump, insulate a system, and work with others as a group to complete an assembly project. This thermal storage demonstration system will help Verdicorp explain to potential customers how the full scale model will operate.

Appendix


Part # 1
Part: TANK
16
Holes ∅ 1-1/8" drilled all the way through the tank
2 Holes ∅ 1/2" drilled all the way through tank
1/2
3-1/2
1
17
UNITS: INCHES
16
15-1/4
Material: Hot Rolled Steel
∅ 16" Cylindrical Pipe
TANK
Scale 2.500
Verdicorp
Jhamal, Belal, Cory, Bruce
03/1/15
Group 17

Part # 2

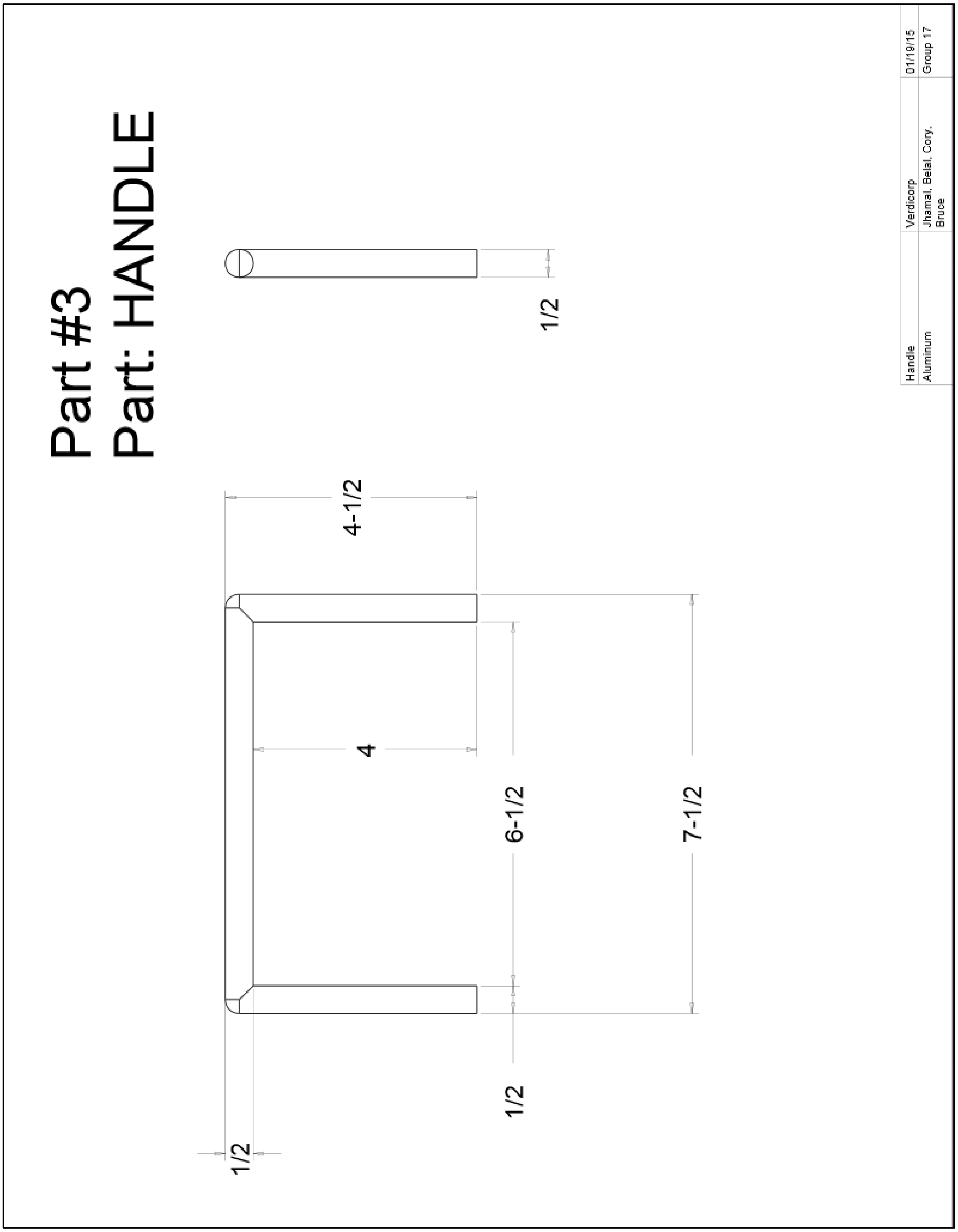
Part: TOP

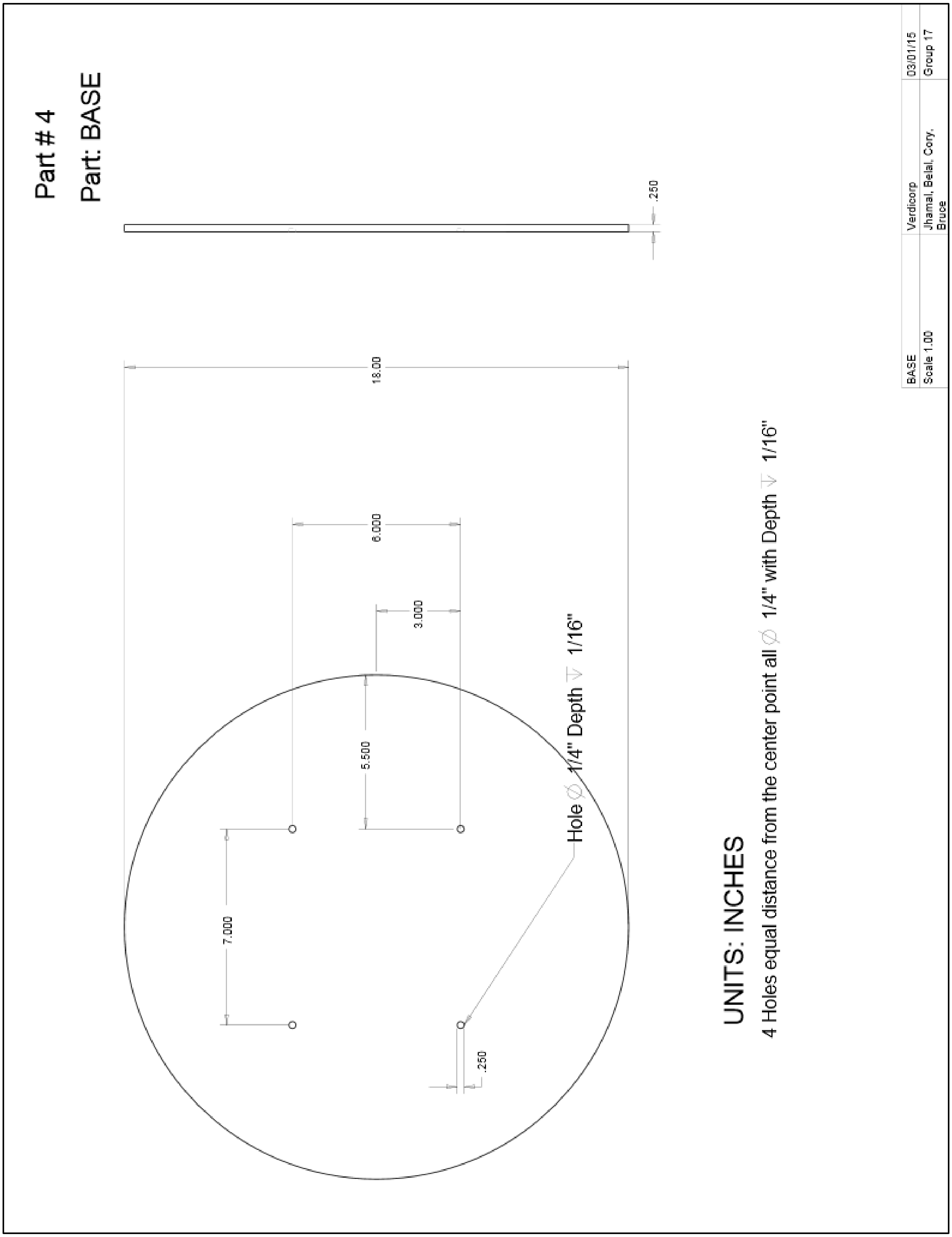


UNITS: INCHES

TOP 1/4" edge will be welded to LATCH HOOK

Material: Hot Rolled Steel	TOP	Verdicorp	03/01/15
∅ 16-1/4" 1/4" Thick Plate	SCALE: 0.500	Jhamal, Belal, Cory, Bruce	Group 17


Part #3
Part: HANDLE
4-1/2
4
6-1/2
7-1/2
1/2
1/2
1/2
Handle
Aluminum
Verdicorp
Jhamal, Belal, Cory, Bruce
01/19/15
Group 17


Part # 4
Part: BASE
.250
18.00
8.000
3.000
5.500
7.000
.250
Hole ∅ 1/4" Depth ↧ 1/16"
UNITS: INCHES
4 Holes equal distance from the center point all ∅ 1/4" with Depth ↧ 1/16"
BASE
Scale 1.00
Verdicorp
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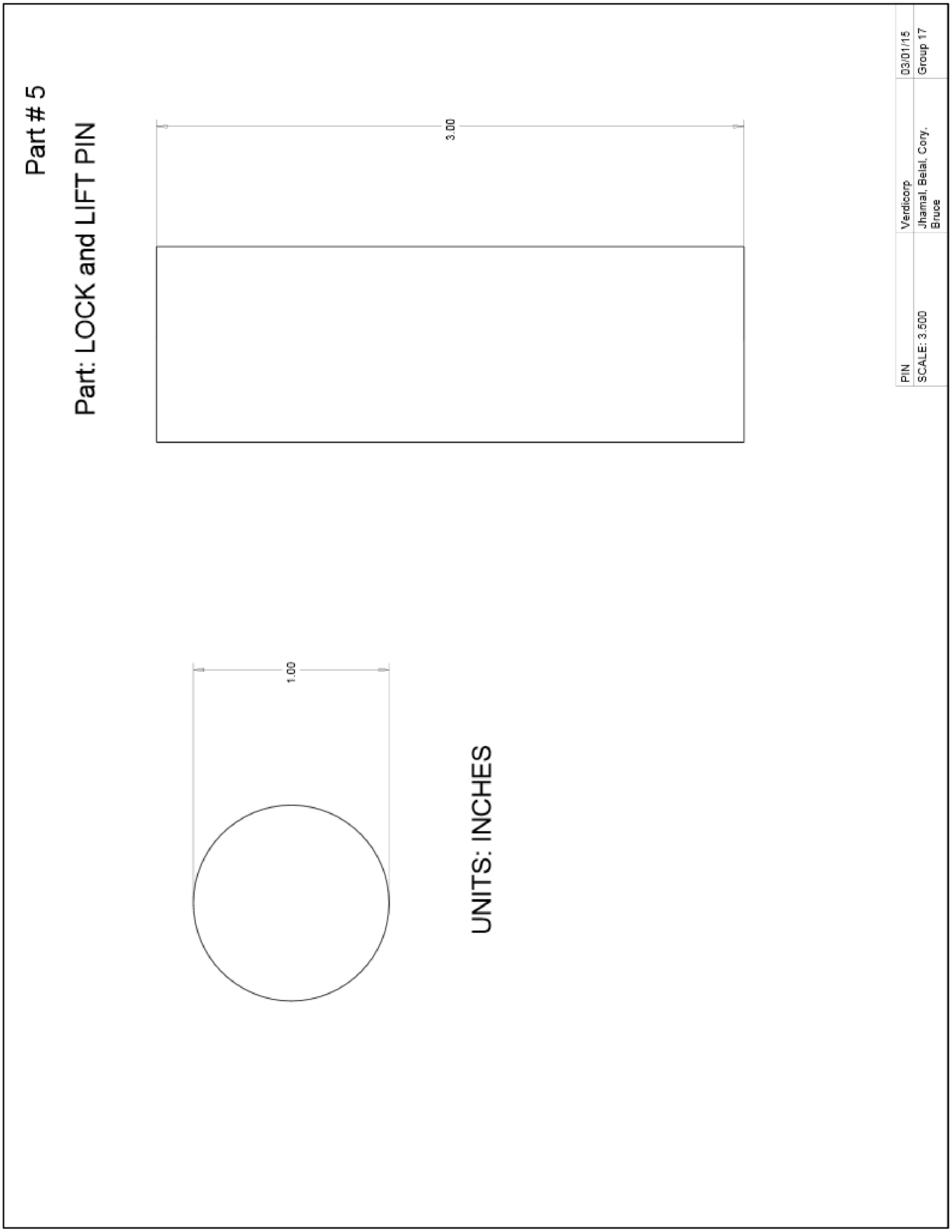
Group 17


Part # 5
Part: LOCK and LIFT PIN
3.00
1.00
UNITS: INCHES
PIN
SCALE: 3.500
Verdicorp
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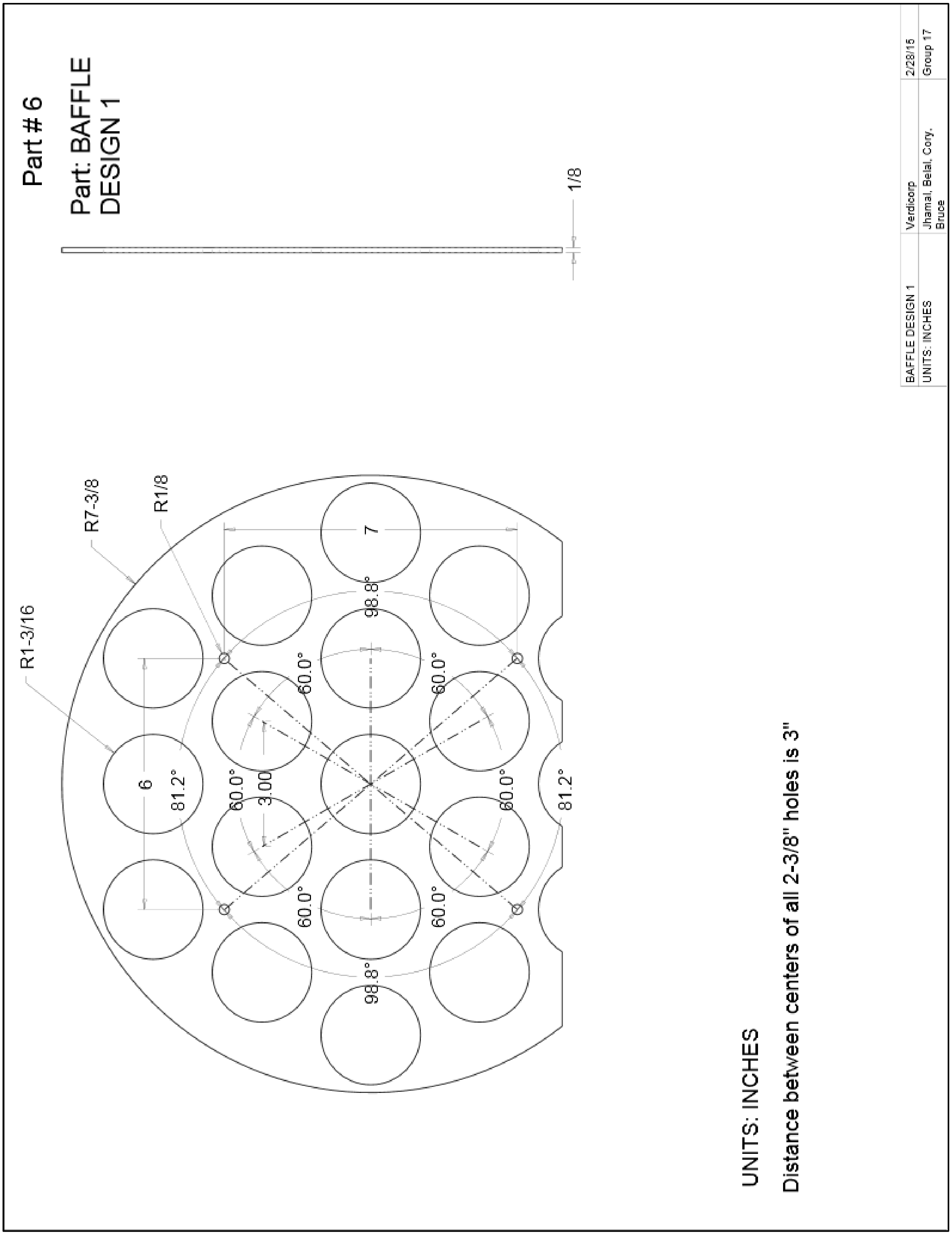
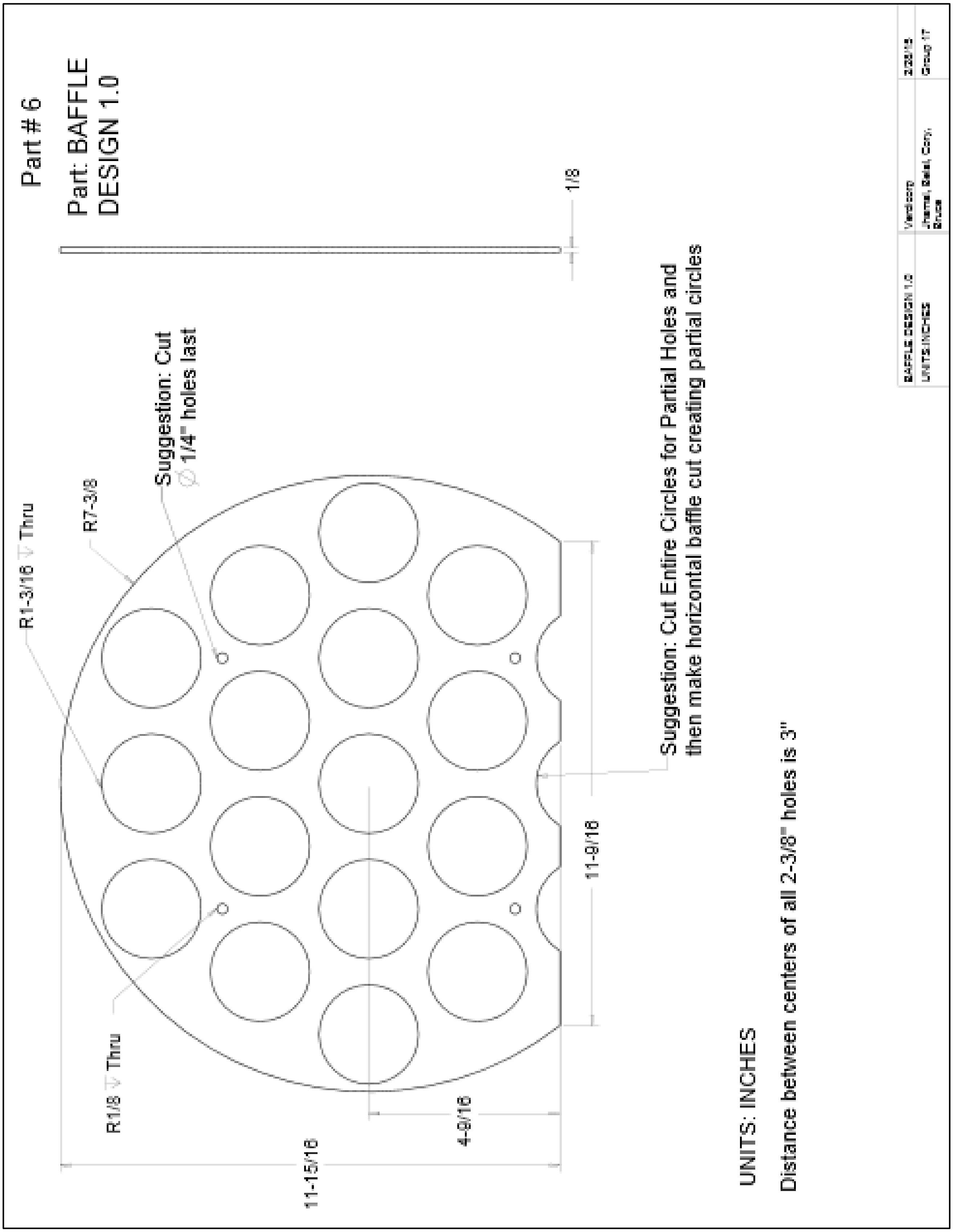
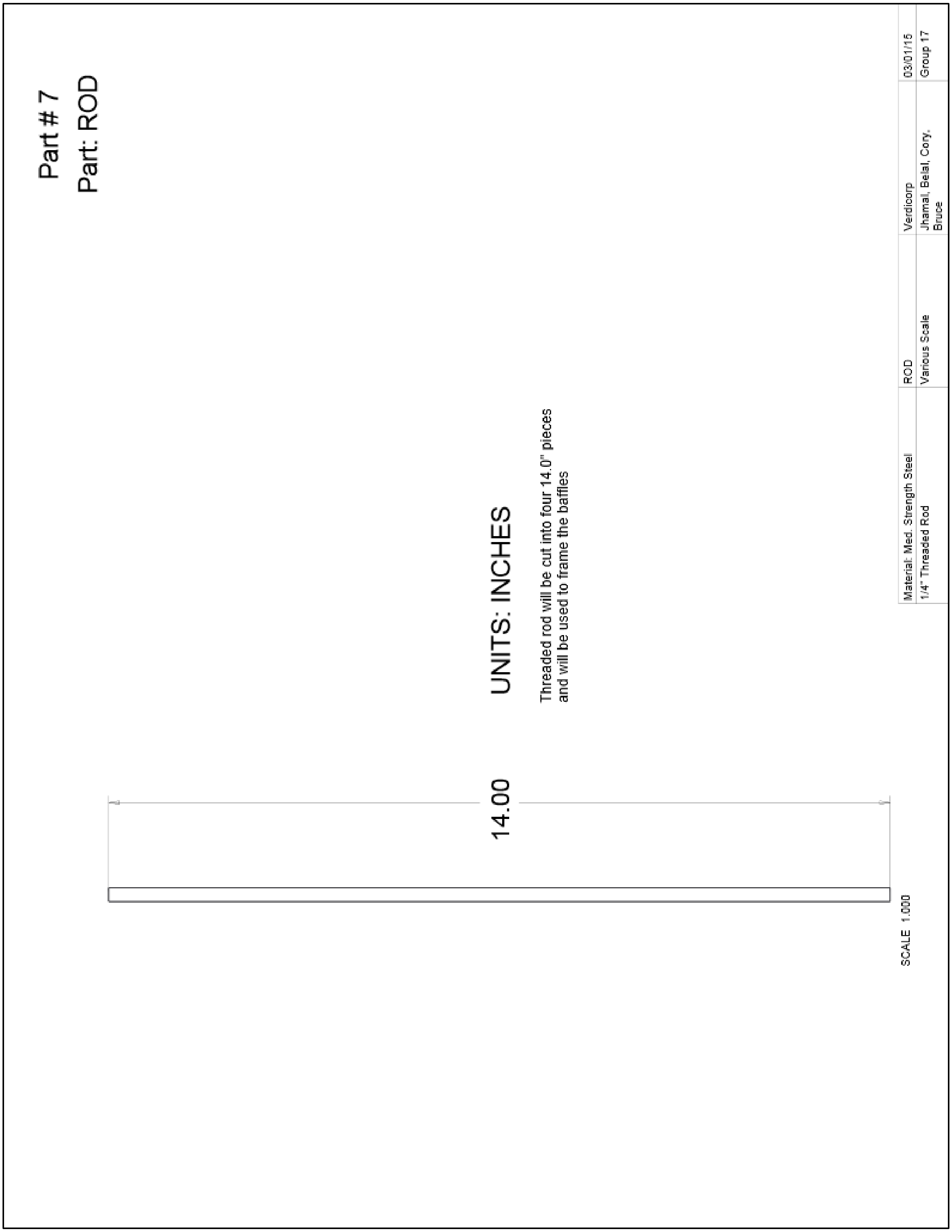
03/01/15
Group 17


Part # 6
Part: BAFFLE DESIGN 1
1/8
R1-3/16
R7-3/8
R1/8
7
6
3.00
98.8°
60.0°
81.2°
BAFFLE DESIGN 1
UNITS: INCHES
Verdicorp
Jhamal, Belal, Cory, Bruce
2/28/15
Group 17
UNITS: INCHES
Distance between centers of all 2-3/8" holes is 3"


Part # 6
Part: BAFFLE
DESIGN 1.0
R1-3/16 Thru
R7-3/8
Suggestion: Cut
∅ 1/4" holes last
1/8
Suggestion: Cut Entire Circles for Partial Holes and
then make horizontal baffle cut creating partial circles
11-9/16
R1/8 Thru
4-9/16
11-15/16
UNITS: INCHES
Distance between centers of all 2-3/8" holes is 3"


Part # 7
Part: ROD
UNITS: INCHES
Threaded rod will be cut into four 14.0" pieces
and will be used to frame the baffles
14.00
SCALE 1.000
Material: Med. Strength Steel
1/4" Threaded Rod
ROD
Various Scale
Verdicorp
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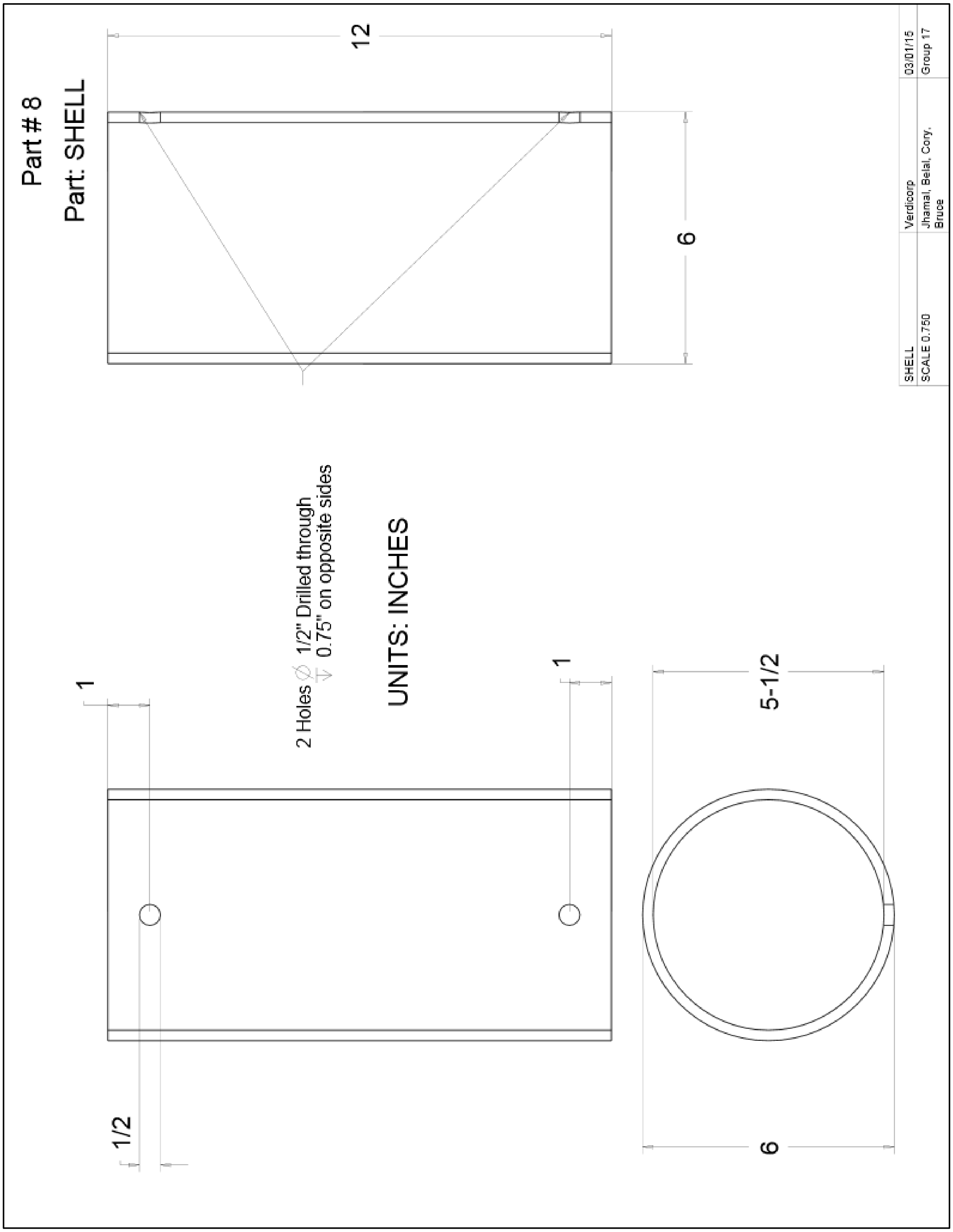
Part # 8
Part: SHELL
12
6
2 Holes ∅ 1/2" Drilled through
↧ 0.75" on opposite sides
UNITS: INCHES
1
1
1/2
5-1/2
6
SHELL
SCALE 0.750
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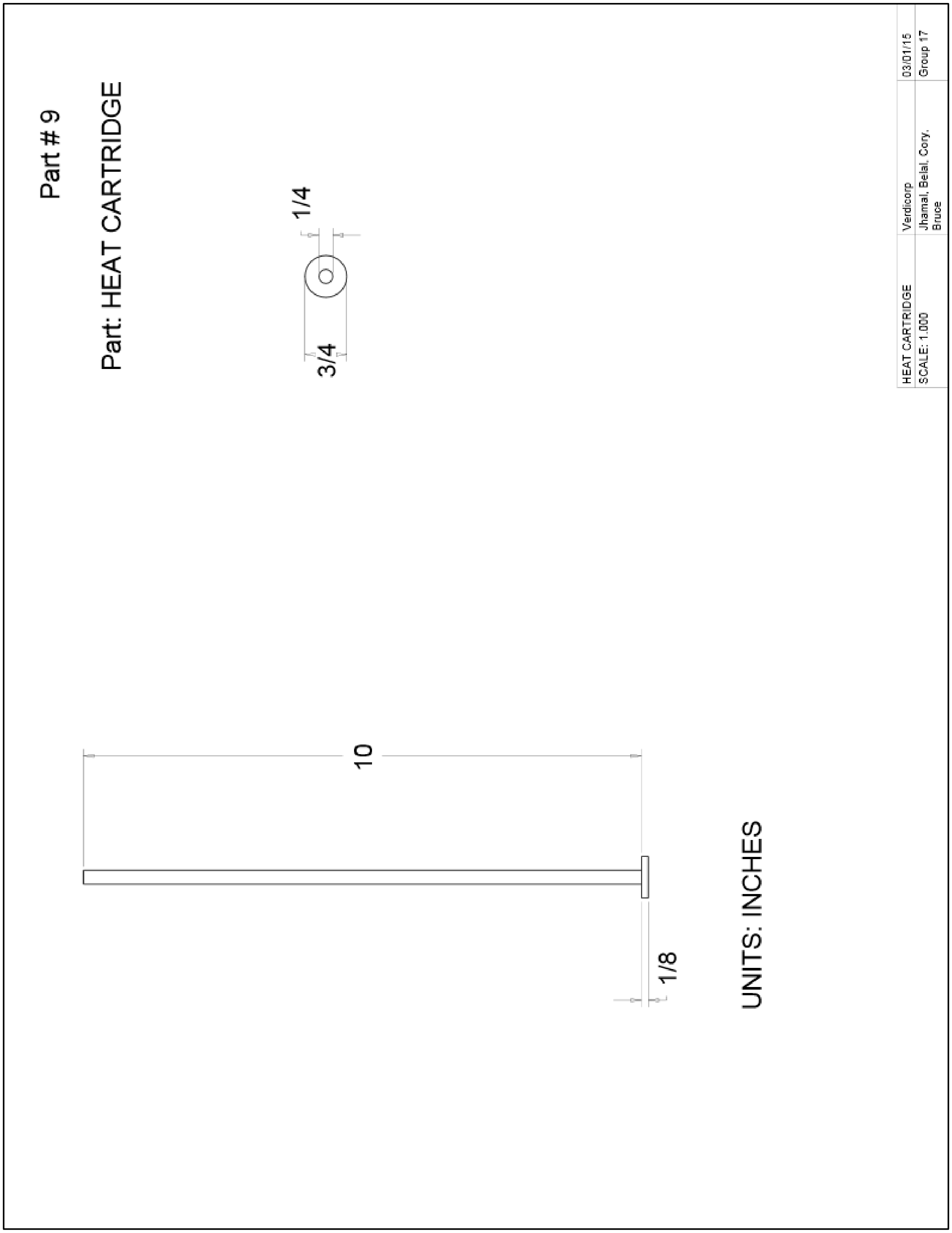
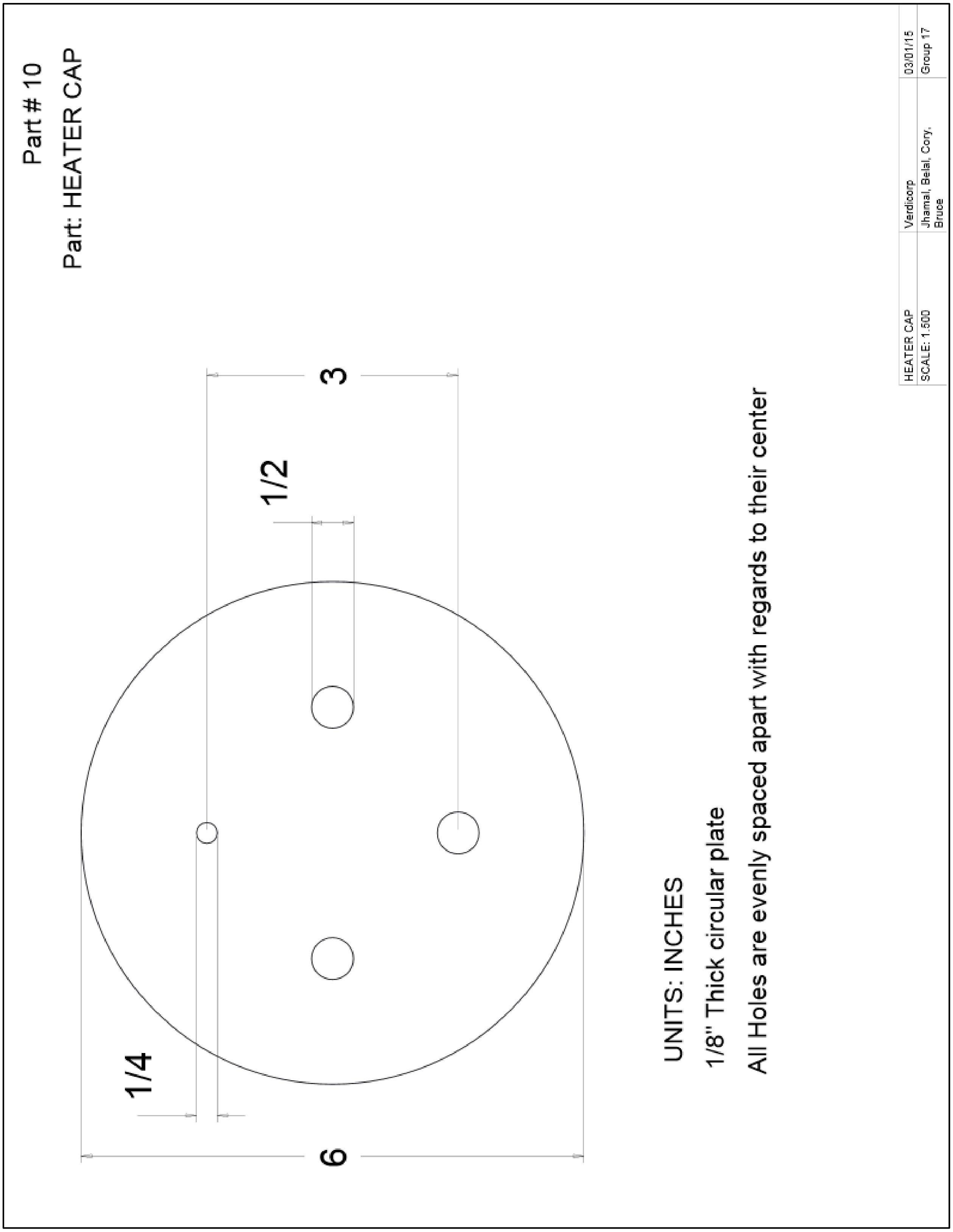
03/01/15
Group 17


Part # 9
Part: HEAT CARTRIDGE
1/4
3/4
10
1/8
UNITS: INCHES
HEAT CARTRIDGE
SCALE: 1.000
Verdicorp
Jhamal, Belal, Cory, Bruce
03/01/15
Group 17


Part # 10
Part: HEATER CAP
3
1/2
1/4
6
UNITS: INCHES
1/8" Thick circular plate
All Holes are evenly spaced apart with regards to their center
HEATER CAP
SCALE: 1.500
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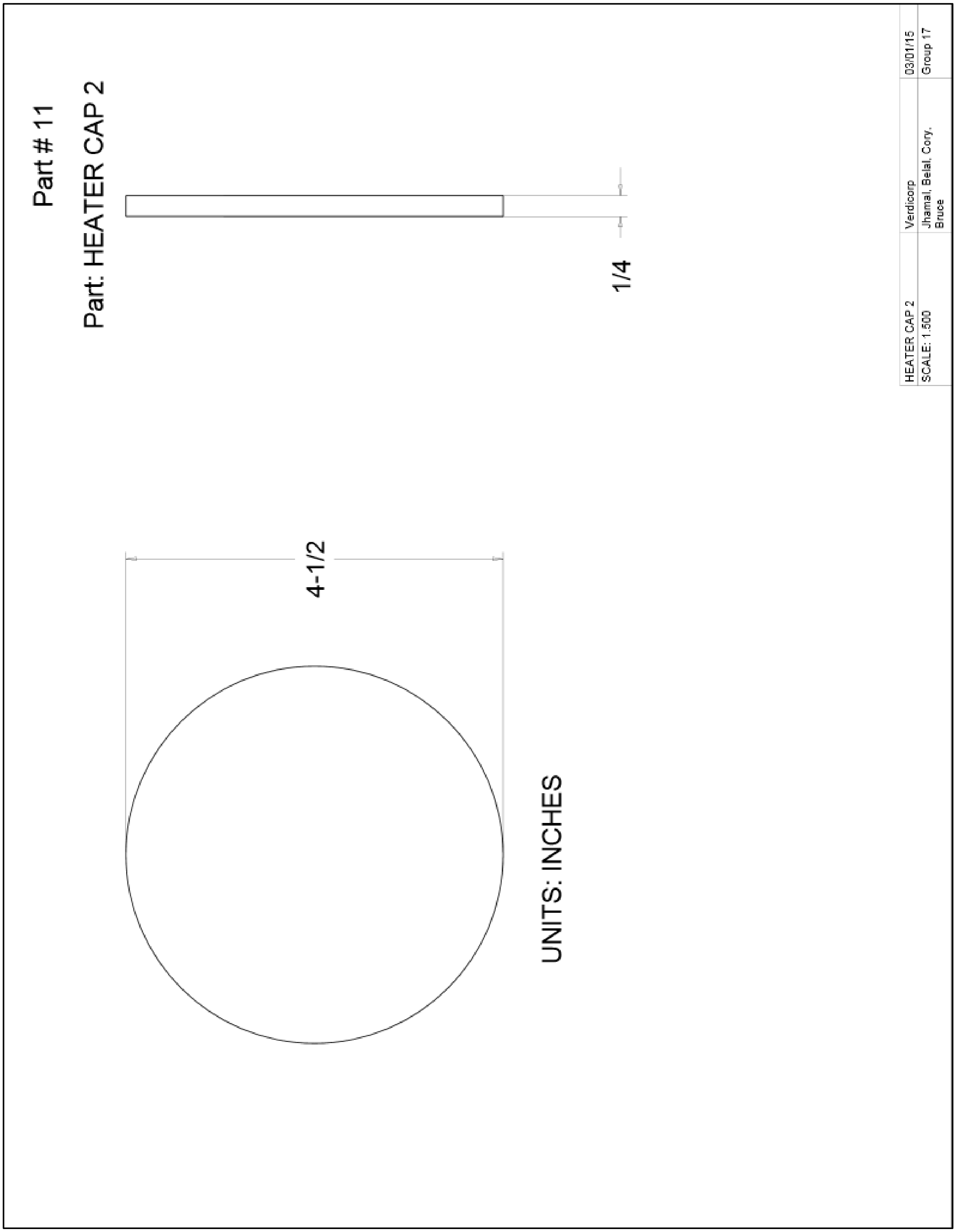
03/01/15
Group 17


Part # 11
Part: HEATER CAP 2
1/4
4-1/2
UNITS: INCHES
HEATER CAP 2
SCALE: 1.500
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03/01/15
Group 17