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Heat Exchanger

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HEAT EXCHANGER

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Central Washington University
MET 489 Senior Project Engineering Report

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Abstract

A water jet cutting machine can cause excess heat and humidity within a closed building, while also making it more difficult for the user to pick material off the cutting table. Water temperatures can reach as high as 150 degrees Fahrenheit in the tank. A system that would reduce the temperature of the water in a water jet tank would be beneficial for the occupants in the room in providing a better more comfortable work environment.

Data was collected while the machine was in use. The data includes; temperature of water leaving the nozzle, the rate of change of tank water temperature over time. This data was used in determining design requirements for a heat exchanger system to keep water below 100 degrees Fahrenheit. A water to air heat exchanger with a rating of 20 kW was determined to be suitable for the application, assuming operation in a 88 degree Fahrenheit ambient air operating conditions.

With the heat exchanger in place the temperature of the water increased at rate of 0.05 degrees Fahrenheit per minute during a 12-hour period. Without the heat exchanger in place the water temperature increased at a rate of 0.08 degrees Fahrenheit per minute. With the heat exchanger in place, the water increased in temperature 38% slower than without the heat exchanger.

Keywords: water jet, heat exchanger

1: INTRODUCTION

a. Description

When a waterjet is being used for extended periods of time continuously the water in the water tank can become hot. When the water becomes too hot it makes it difficult for the user to grab parts off the cutting table. It also begins to raise room temperature. Engineering can address this problem by designing a system that will lower water temperature.

b. Motivation

Motivation behind this project was to help create a more comfortable work environment inside the shop.

c. Function Statement

A device is needed to reduce the water temperature in a water jet machine tank.

d. Requirements

- Keep 2000 gallons of water below 100 degrees Fahrenheit.
- Be able to run 12 hours a day.
- Device cannot obstruct normal operation.
- Maintain cooling in ambient temperatures of 40 to 100 degrees Fahrenheit
- Flow rate 3-5 GPM
- Entire unit must be no larger than 48 cubic feet

e. Engineering Merit

This project will require analysis of appropriate dimensions of heat exchanger to have enough surface area to pull heat from the water in given temperatures. Calculations of required flow rate, tube size, number and size of fins, number of bends in the tubing carrying the hot water are also required for this project.

f. Scope of this effort

The scope of this project will include the heat exchanger unit, pump, and tubing/hose required to cycle water out and back into the tank.

g. Benchmark

There are available units that cool and recycle tank water back to the pump of the water jet. This project is not aimed at returning water back to be used again through the pump, it is only aimed at putting water back into the tank at a cooler temperature.

h. Success of the Project

Success of this project is dependent on how well the heat exchanger works. It should be able to maintain 2000 gallons of water at a temperature at or below 100 degrees Fahrenheit.

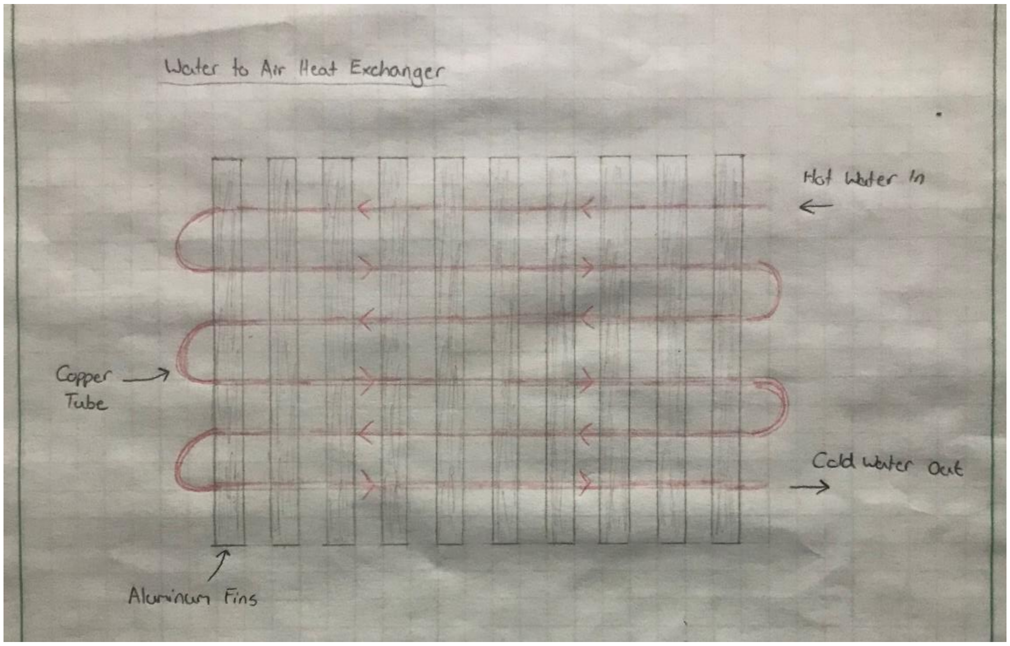
2: DESIGN AND ANALYSIS

a. Approach: Proposed Solution

The approach to this project will be to design a water to air heat exchanger.

b. Design Description

The water to air heat exchanger will consist of copper tubes making multiple passes through aluminum fins and a fan that will be attached to one side.



c. Benchmark

There is not an available portable unit that cools the water in a water jet cutting machine water tank. Similar size water to air heat exchangers have a rating of 40kW. This water to air heat exchanger is lower due to less surface area.

d. Performance Predictions

This heat exchanger will reduce the temperature of water, but not very fast when the unit is in ambient temperatures above 90 degrees Fahrenheit. This heat exchanger will perform its best when left running over night when machine is not in use and outside ambient air is much cooler.

e. Description of Analysis

The amount energy being put into the tank was first analyzed. This amount of energy was used as a base number to aim for when designing the heat exchanger. If this amount of energy is being put into the water, then a heat exchanger that can take out the same amount of heat would be ideal. Analysis of surface area, flow rate, and air flow where then performed.

f. Scope of Testing and Evaluation

The heat exchanger will be tested at the shop location or just hot water can be ran through it to record temperature drop of water leaving the heat exchanger.

g. Analyses

One analysis that was done to find a parameter to fulfil a certain requirement was surface area. $20ft^2$ of surface area was the amount of surface area calculated (A-5) to meet heating requirement of 20kW (A-1). $18ft^2$ is too much area to fit into the requirement of the heat exchanger unit volume of $48ft^3$. Due to this, fins will be added to the heat exchanger tubes to increase surface area. Fins will be made of 6061 aluminum that are 1/16in thick. The length of the fins will be between 1/4in and 1/2in. 1/4in fin length gives $16ft^2$ (under $18ft^2$) and 1/2in fin length gives $20ft^2$ (over $18ft^2$). Using 1/4in fins will save $2592in^2$ of aluminum than if 1/2in length fins were used, while only loosing 1% efficiency, but overall effectiveness reduces by 30%. The heat transfer rate with 1/4in fins is calculated to be 19.4kW vs. 5kW if no fins were to be used. This parameter of fin geometry can be seen in the fin part drawing 20-0001 in appendix B.

Another analysis was done to determine the size of the angle needed to support the weight of the entire heat exchanger and components. Moments and forces were determined in the beam. From that the max shear and max moment was found using moment and shear diagrams. The first type of beam analyzed was 1/8in x 1-1/2in x 1-1/2in angle. Areas, centroidal distances, centroid, moment of inertia were calculated to then find the deflection of the beam. The 1/8in thick angle had a calculated deflection of 0.116 inches which is to much so the next available size of 3/16in thick angle was analyzed. Following the same calculations that was done for the 1/8in thick angle, the calculated deflection of the 3/16in beam was 0.082in. This amount of deflection will be ok. The direct shear stress and transverse shear stress were then calculated using the dimensions of 3/16in x 1-1/2in x 1-1/2in angle. All calculations for this analysis can be found in appendix A-9. Beam part design can be found in drawing 20-0010 in appendix B-4.

i. A-1: Energy Leaving Jet and Entering Tank

- 19kW is the amount of energy leaving the water jet nozzle and entering the water tank.
- Assume 20 kW is the required amount of energy the heat exchanger needs to remove from tank water.

ii. A-2: Time Required for Given Water Temperature

- 8 hours to reach 38°C (100°F) (starting at room temperature)
- Water is at 46°C (115°F) after 12 hours

iii. A-3: Analysis of Water Flow Rate Through Heat Exchanger

- Calculated flow rate of water through heat exchanger is 0.319 kg/s.

iv. A-4: Analysis of Output air temperature of Heat Exchanger.

- When the heat exchanger is used in 27 °C air temperature, the air exiting the heat exchanger will be 31°C.

v. A-5: Analysis of Required Surface Area

- The required surface area for the heat exchanger when operating in 27°C air is $2.7m^2$.

vi. A-6: Surface Area of Fins

- The total surface area of all the fins is $1.7m^2$.

vii. A-7: Analysis of Heat Exchanger Unit Weight

- The weight of the entire heat exchanger unit will be around 110 lb.

viii. A-8: Larger Flow Rate Analysis

- Using a larger flow rate will reduce the heat transfer rate of the heat exchanger to around 12 kW. A larger flow rate will be used when running at night when air temperature is much cooler.

ix. A-9: Stand Bottom Beam Analysis

- The thickness of angle iron required is 3/16 inches.

x. A-10: Upper Limit for Heat Transfer Rate

- Maximum possible heat transfer in this heat exchanger is 33.25 kW.

xi. A-11: Analysis of Heat Exchanger Effectiveness

- The calculated heat exchanger effectiveness is 0.8.

xii. A-12: Analysis of Fin Efficiency and Effectiveness

- Fin efficiency is 30% and fin effectiveness is 2.68.

h. Device: Parts, Shapes, and Conformation

The heat exchanger will consist of fins, tubes, and a stand. The shape of the heat exchanger will be a tall thin square, about 36 inches wide and 2 inches thick.

i. Device Assembly and Attachments

The heat exchanger will be attached to a stand that will be welded together. The heat exchanger itself will be a series of copper tubes that will be soldered together. The fins will be attached together via spacer and rod that will sandwich them together.

j. Tolerances

The heat exchanger design is designed to provide a heat transfer rate of 20kW from water to air. Due to various temperatures of air in which the heat exchanger operates, the heat transfer rate is acceptable if within a range of 12kW and higher.

k. Operation Limits

The heat exchanger is not recommended to operate in air temperatures higher then 100°F due to there not being a larger enough temperature difference between the water and air and the rate of heat transfer will be very minimal. Although operation during higher air temperatures does not pose any safety or damage concerns.

The heat exchanger is not recommended to operate in air temperatures lower than 37°F. Operating in temperatures any lower than 37°F may cause ice buildup between fins and/or in water manifold and tubes causing damage to the unit.

3: METHODS AND CONSTRUCTION

a. Description

The project was conceived at Precision Industrial Equipment in Moxee WA. The design and analysis of this project has been done at CWU and will be manufactured and assembled partly outside of CWU and partly at Precision Industrial Equipment.

b. Construction

i. Description

PIPE (20-0002) (34 required)- The copper pipe in the heat exchanger will carry the water to dissipate heat to the air. The pipe is 3/8" Type M copper tube size with a ½" OD and an actual ID of 0.44". The pipe is the thinnest wall thickness available for best heat transfer characteristics. The pipe will require cutting to size with a copper pipe cutter and cleaning and reaming to be a ready part.

MOUNT (20-0008) (2 required)- The mount part is intended to attach the heat exchanger to the stand. It slides over the bottom 10 copper tubes (20-0002) and the heat exchanger assembly rod (20-0009) to secure it to the heat exchanger. The bottom of the mount will be bolted to the stand. The mount was manufactured using a milling machine to accurately drill the hole locations.

MOUNT SUPPORT (20-0012) (2 required)- The mount support parts purpose is to brace the heat exchanger mount (20-0008) to the stand. The part will be cut on the water jet out of 3/16" stainless sheet metal. The part was drawn on SolidWorks then converted to a DWG file that could be downloaded to the water jet program. Issues with cutting the part out on the water jet is a bur is formed along where the jet has cut. This issue is resolved using a flap disk on a grinder to remove the bur. Burs inside of holes are removed with a drill bit or reamer.

FIN (20-0001) (116 required)- The fins are made out of 1/16" aluminum sheet. To reduce water jet run time the fins were cut using a shear press instead. Then the fins were stacked and the holes drilled through. The risk of manufacturing the fins this way, instead of the water jet, is the holes may not be drilled in the exact locations and the exact size for a tight fit over the copper pipe. To keep the fins stacked together a jig was welded to the welding table to keep them together so they could all be drilled at once to save time and have all the fins turn out the same for easier assembly.

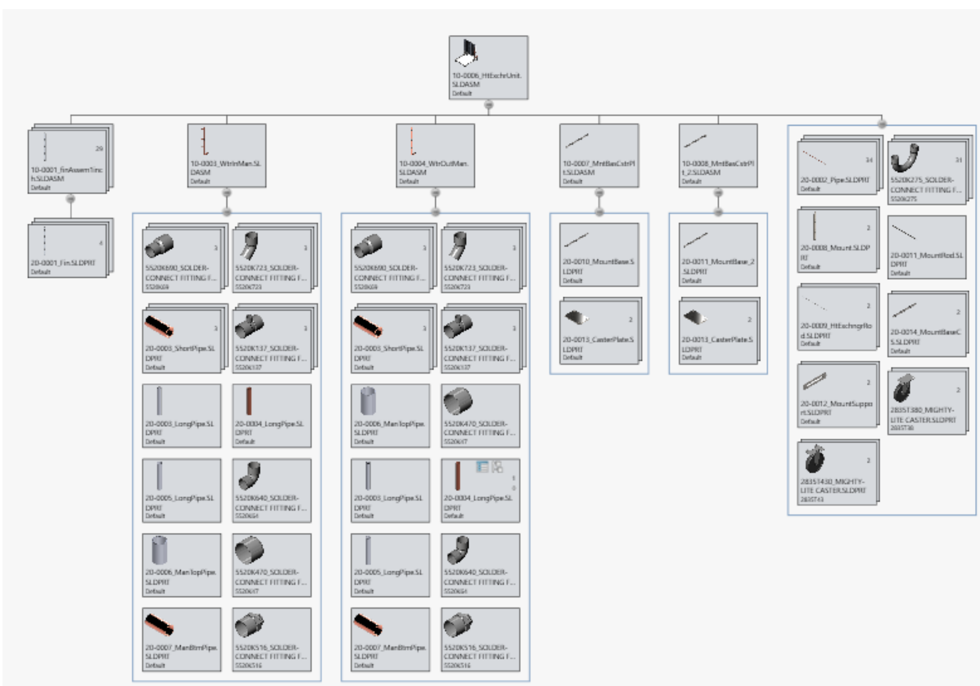
ii. Manufacturing Issues

Some manufacturing issues will mostly be machine run time. When the fins are being cut on the water jet, there is many fins and many holes in each fin so the jet will be constantly starting and stopping and then traversing through the cutting process. This may cause some issues with the machine such as nozzle plug up and or tip needing to be replaced. All other procedures and operations of constructing heat exchanger and components do not pose any issues.

To reduce cutting times on the water jet, some of the fins will be drilled on the mill, rather than have the water jet cut all the holes.

When the copper pipes were first received (20-0002), they were bent and disformed on the ends. The pipe was ordered in 10-foot sticks and cut to size. In the design of this project it was not expected that the pipe would not be straight and perfectly round. Having straight pipe and minimal deformation is important for assembling the heat exchanger. To resolve the issue of deformation of the pipe ends, an adjustable wrench was set to ½" and then rotated around the pipe. When the wrench was rotated around the pipe it helped the pipe return back to a more cylindrical shape. Doing this will prevent leaks when the fittings are soldered onto the ends of the pipe.

iii. Drawing Tree



iv. Device Operation

The heat exchanger will be a portable unit that can be pushed outside of the shop area to release heat from the tank water to the outside air instead of the air inside the shop. Water will run through a series of copper pies fitted inside aluminum fins to assist in heat transfer. There will be two tubes or hoses running from inside the tank to the heat exchanger unit, one a supply line and one a return line. A jet pump on the unit will supply a flow of water through the heat exchanger and back to the tank at a cooler temperature. This will help reduce room temperature and humidity inside the shop. The jet pump and fan on the heat exchanger unit will be ran off electric motors that require 120V-60Hz power supply. So, there will only need to be a simple extension cord to plug into any available power outlet and nothing will be hard wired.

4: TESTING METHOD

a. Introduction

The heat exchanger will be tested on how well it cools off hot water in a given amount of time.

b. Method and Approach

Resources required for this test are a 300-gallon tank, a circulating pump, heat source (wood stove or large propane burner), Microsoft excel, flow meter, thermocouple. Data will be collected using built in thermometers in the manifolds of the heat exchanger and a thermocouple will be used to measure air temperature leaving surface of heat exchanger as well as ambient air temperature.

The heat exchanger will be tested by placing a temperature probe in the water intake manifold and a temperature probe in the water outtake manifold. This will show how much heat is being taken out of the water by the heat exchanger. The hot water source will be a tank of water that is heated to 120 degrees Fahrenheit and the cooled water will be returned to the tank so a rate can be determined of how long it took the heat exchanger to cool X amount gallons of water to a desired temperature. A higher temperature water will be run through the heat exchanger as well. Using water at a higher temperature will result in a larger temperature difference between the water and the air, this will establish a different rating of the heat exchanger when used in a setting of a large temperature difference. To heat the water to a much higher temperature, the water tank will be set on top of a propane burner. The goal will be to have the water enter the heat exchanger at a temperature higher than 120 degrees Fahrenheit. The burner will stay going to simulate continuous heat being added to the water tank like the water jet would be doing. A piece of insulation will remain on top of tank during test to help minimize heat loss via conduction. Data described in the next section will be collected to determine the rating of the heat exchanger in kW or Btu/hr.

Operational limitations of testing this device will be tank size, a 300-gallon water tank will be used. The accuracy of temperature taken will be ± 1.5° Fahrenheit. Data will be recorded on paper and the data will be used in calculating heat transfer rate and overall heat transfer coefficient. The results will be put into Microsoft excel to graph temperature vs time and present the data taken.

c. Test Procedure Description

The test procedure will begin first by heating a tank of water to 150 degrees Fahrenheit. The hot water ran through the heat exchanger using circulating pump. Water leaving the heat exchanger will be returned to the tank.

The test will require the following Data to be recorded:

- Intake water temperature over at rate of time (every 5 min)

- Outtake water temperature over a rate of time (every 5 min)
- Tank water temperature (every 5 min)
- Air temperature leaving heat exchanger surface (every 5 min)
- Ambient air temperature
- Volume flow rate of water
- Volume flow rate of air

d. Deliverables

The test will deliver data on how well and how much faster the heat exchanger cools a given amount of water as a replacement for of letting the water cool to the surrounding air.

Test 1: Rate of Heat Transfer

The requirement of the heat exchanger is it must have a heat transfer rate of 20 kW. This was tested by the method described above and can also be found in appendix G of this report.

The test resulted in a max rate of heat transfer, with 150-degree Fahrenheit water temperature, of 18 kW. The heat exchanger did better than what was expected. Assuming an ideal heat exchanger, the calculated rate of heat transfer was 25kW in the given conditions. It was clear that the heat exchanger would not achieve this due to construction imperfections. The heat exchanger cooled the tank water off to about 95 degrees Fahrenheit before it leveled off and the tank water was only changing by a degree. This test also showed that it kept tank water below 100 degrees Fahrenheit, which was a requirement.

Improvements that can be made to the heat exchanger to help improve results of this test will be to add a hardening liquid to the areas where the copper meets the aluminum fins. This will make the fins more effective and increase heat transfer rate.

e. Testing Issues

Issues with Test 1 was that the heat exchanger was only used on a 100-gallon water tank on a propane burner, not the water jet tank with the water jet operating. The problem with this is the burner may not have been transferring as much energy to the water as the water jet would be doing. Due to Covid-19, manufacturing with water jet has slowed which has allowed time for pump rebuild, cleaning, and other repairs so testing was not used with the water jet operating.

5: BUDGET

a. Part Suppliers

For this project Ryerson materials will be used for stock material. Pipe and fittings will be ordered from Inland Pipe or Keller Supply. Spacers and other hardware will be ordered from McMaster-Carr. The pump will be ordered from Akland Pump.

Stock material such as the aluminum sheet will be ordered first due to length of time to cut the fins. All other items will be ordered as needed.

b. Outsourcing Rates and Estimate Costs

The material ordered for this project such as sheet metal and other bar stock had associated delivery fees which will be near 50.00 dollars. Hardware from McMaster-Carr had a delivery cost of around 20.00 dollars. All other parts ordered and delivered through in store location had no delivery costs.

c. Labor

The labor for this project was mostly done by the project manager. Soldering of fittings was done with the assistance of Anthony Linarez.

d. Total Project Cost

Estimated project parts will have a total of around 1100 dollars and other fees of around 100. No labor costs. Total project cost is **<u>1300 dollars.</u>**

e. Funding Sources

Precision Industrial Equipment provided many resources needed for this project. Also the Linarez family provided pipe and all other plumbing related fittings.

f. Budget Changes/Issues

Initial total budget was estimated to be 1000 dollars. The budget total increased to 1200 dollars. The 11 sticks of 3/8” copper pipe costed more than what was initially estimated at $12.00 per 10ft stick. The pipe costed $15.40 per stick. There was also fuel cost to drive to Pasco to pick up the pipe.

There were issues with receiving the copper pipe. When the pipe was first received it contained many pieces that were bent and bowed. Bent pieces of pipe would not work for the project. It took two more weeks for the pipe to be returned and 11 new sticks shipped to a Grainger branch in Pasco. This put the project behind schedule but was resolved once the new pipe was received.

All other parts ordered to date have been in stock and have not caused the project to fall behind schedule.

g. Testing Costs

Costs involved with testing included test equipment and propane gas. A pressure test gauge was used to perform the pressure test. This required the purchase of a ¾ NPT female test gauge assembly that includes a coupling, gauge, and a Schrader valve to allow for air to be pumped into the unit. Also, there was propane gas required in heating the water, a total of 5 gallons of propane gas was used which had an associated cost of 22 dollars. Other testing equipment included a thermocouple that had a cost of 45 dollars. This was needed so temperatures of air and water could easily and accurately be measured during *Test 1: Heat Transfer Rate*. No other additional equipment or items were needed to perform testing on the device.

6. SCHEDULE

a. High level Gantt Chart

The schedule for this project is guided by the MET 489 class and is show in appendix E. This project was started at the beginning of the school year in October 2019 and will be completed by the end of the school year in June of 2020.

b. Specific Tasks

Tasks for this project include design/analysis, manufacture, and test. Specific tasks can be found in appendix E.

c. Task Dates and Sequence

This project is divided into three quarters. Fall quarter, October 2019 – December 2019, is focused on design and analysis. Winter quarter, January 2020 – March 2020, is focused on manufacturing of the project. Spring quarter, April 2020 – June 2020 involves testing the project. Specific task dates can be found in appendix E.

d. Milestones and Deliverables

Milestone	**Deliverable**
December 2019	Proposal Completed
January 2020	Analysis Completed Parts Documented
February 2020	Modifications and Parts manufactured
March 2020	Project Assembled
April 2020	Project Evaluation
May 2020	Deliverables
June 2020	Project Completed

e. Estimate Total Project Time

Total time to complete the project is estimated at **180 hours.**

f. Schedule Issues and Changes

The project to date is following the schedule closely with actual hours being close to estimated hours. One area that requires more time than what was estimated is updating the website. It was estimated that updating the website would take 1 hour for part construction and 1 hour for device construct. Updating the website took 5 hours which is 3 hours over schedule. This was not a serious issue due to other tasks taking less time than what was estimated.

Part construction has been behind schedule due to pipe being backordered and not arriving on time. Other major parts are based off the exact pipe size like the fins and mount, so with no pipe the other parts remained on standby to be manufactured until the copper pipe arrived.
Schedule changes were minimal except for the deliverables section was updated, which takes the total project time for 175 hours to 180 hours. This schedule change was done after the updating website task had shown a pattern of requiring more time than what was previously estimated.
Testing the device required more time than what was initially estimated. To perform all the tests on the heat exchanger unit took nearly 6 hours, 2 hours is what was estimated. There were no issues with testing that resulted in a time increase, the time required was just under estimated. As well as the actual testing, writing the testing report and creating a slide presentation both required more time than what was estimated. These tasks and time required can be seen in the Gantt chart, in the appendix of this report. After testing, testing report, and a slide presentation was completed the project is still 28 hours under the estimated total project time.

7. PROJECT MANAGEMENT

a. Human Resources

Human Resources for this project include Chance Linarez who is performing the project. Other human resources include faculty at CWU such as John Choi, Charles Pringle, and Craig Johnson.

b. Physical Resources

Physical resources for this project include:

- Omax 80x Water Jet Cutting Machine
- Lathe
- Mill
- Drill Press
- Grinder
- Map Gas Torch

c. Soft Resources

Soft Resources for this project include:

- SolidWorks
- AutoCAD
- Microsoft Word
- Microsoft Excel

d. Financial Resources

Financial Resources for this project will be provided by Precision Industrial Equipment and the Linarez family. Precision Industrial Equipment will provide the water jet, lathe, and mill as well as most of the materials. The Linarez family will provide materials.

8. DISSCUSSION

a. Initial Design

At the start of this project the design was not going to be a water-to-air heat exchanger. The design was a tube and shell that would have refrigerant lines chilling the water which would be flowing through a shell. After some analysis it became apparent that a water-to-air heat exchanger would meet the requirements of the project and be cheaper and easier to manufacture.

b. Use and Functionality

A water-to-air heat exchanger will function better as a tool in the shop then a tube and shell would. A water-to-air heat exchanger will have less components, less weight for easier mobility, and cheaper maintenance costs than a refrigerant tube and shell. Reasoning for claiming a water-to-air heat exchanger will be better in the shop is because the heat exchanger can be used as a heater during the winter season. The heat exchanger can be moved to different parts of the shop where there is no source of heat and can be used as a heat source while also doing its job at cooling the water.

c. Project Success

This project will be successful based on if the heat exchanger fulfils the requirements and works well in the shop. If it becomes an obstruction or needs to much maintenance, it will disrupt workflow and not be considered a success.

A major requirement that needed to be met for this project to be considered a success was a 20kW heat transfer rate. After completing the first test the heat exchanger had a heat transfer rate of 18.7 kW. This result is close to meeting the requirement. With a few modifications a 20kW heat transfer rate should be obtainable.

The heat exchanger unit also meets the requirement of being portable. It has been moved around and proved to be rigid enough to not bend or tweak when moving the unit.

d. Project Risk Analysis

A risk of this project is the time required to manufacture parts, specifically cutting time of all the fins on the water jet. Calculations show the fins will drastically help performance but if the fin do not help much than there is machine cutting time and usage that will be wasted. Most of the parts for the rest of the project do not have much manufacturing time associated with them, as well as being structural and a required part.

e. Manufacturing Issues

One of the biggest issues with manufacturing included the fins, there were many fins to cut, and would take too long to cut on the water jet. The first alternative to manufacture the fins was to shear the fins. 36-inch aluminum sheet was used so length requirement was already fulfilled and they could be sheared in 2-inch strips to meet the design width. The problem that arose with this is the shear wanted to bend the metal more than shear it. After several attempts the fins were not meeting satisfaction. So, another method was used to manufacture the fins that worked well. The aluminum sheet was laid on a table and a straight edge clamped across the metal, this provided a guide to use a skill saw and rip cut the 2-inch-wide fins. Doing this provided a clean cut and no rolling of the edge like the shear was doing.

Another manufacturing issue was the drill bit in the mill would walk when trying to drill a hole through the mounts and angle iron for the stand. To help reduce this a much smaller dill bit was initially used to drill the hole as a pilot hole. Then the needed size drill was used.

f. Assembly Issues

Problems arose when trying to assemble the tubes through the fins. Each tube was not exactly 0.50 inch outside diameter. The tubes varied between 0.495 inch to as large as 0.506 inch. This made choosing a hole size for the tubes to slide through difficult. The holes in the fins were all drilled with a 31/64-inch drill size initially. This undersized all the holes and they would be reamed out as necessary until the tubes would tightly squeeze through. A tight fit for the fins over the tubes was crucial because if the aluminum wasn't in tight contact with the copper it would increase contact resistance between the copper and the aluminum and the fins would be less effective.

g. Design Modifications

One design modification was adding an extra hole in the fins for another assembly rod to slide through all the fins to hold them together more securely. The hole can be seen in the fin drawing 20-0001. It is located on the upper half of the fin. Initially there was only one ¼" hole near the bottom center of the fin, and this would be the only rod to hold the fins together. The new hole will be the same size so the same assembly rod can be used.

h. Testing

Testing the heat exchanger for heat transfer rate had some issues. The main issue was trying to get a large amount of water to a higher temperature. This was to simulate the water jet tank but on a smaller scale. The propane burner under the tank was sensitive to wind or breezes, and would constantly go out. This caused periods of time where the tank was not receiving any heat. Another problem with this set up was the burner could have been adding more or less heat to the tank water than what the water jet would be doing, not to mention the tank was much smaller as well.

Other tests on the heat exchanger included stand deflection, transportability, and pressure test. The pressure test had minor issues and the heat exchanger was able to hold 100 psi for 30 minutes. The first attempt at this test, there was one leak detected that was very small, the pressure dropped by 4 psi in 20 minutes. After spraying all fittings with soap and water the leak was found and repaired making the next test successful.

The heat exchanger unit proved to be rigid enough to withstand moving across various terrain without bending, tweaking, or breaking. This test was done to simulate what it may experience when actually put into use.

The stand deflection test showed that the stand is able to withstand the weight of the heat exchanger plus water and other components. The stand did bend a small bit but it was within the acceptable range of the amount of deflection. There were no issues with this test and the procedure and results were successful.

More information and data about testing procedures can be found in *Appendix G* of this report.

9. CONCLUSION

This project was aimed at creating a more comfortable work environment inside the shop at Precision Industrial Equipment, by cooling the water temperature in a water jet cutting machine water tank.

A heat exchanger has been analyzed and designed to meet the requirements presented. Parts have been sourced and budgeted for the heat exchanger to be manufactured.

This project meets all the requirements for a successful senior project, including:

1. Having substantive engineering merit in thermodynamics and heat transfer.
2. Creating a useful solution to solve an engineering problem.
3. Being of great interest to the principal investigator.

The heat exchanger had several requirements including, a required 20 kW heat transfer rate, withstand a pressure of 100 psi, not be over 48 cubic feet, be portable, and operate in ambient temperatures of 40 to 100 degrees Fahrenheit. The project met the requirements except for the required heat transfer rate. The heat exchanger was tested using a tank of hot water to measure the heat transfer rate from the tank water through the heat exchanger. On testing day, it was predicted to have a heat transfer rate of 24 kW due to the cooler outside conditions. This was assuming a set heat transfer coefficient as well as all design parameter were calculated assuming the heat exchanger would be operating in ambient temperatures of 88 degrees Fahrenheit. The actual heat transfer rate was a maximum 18.7 kW.

Reasons for not successfully meeting the requirement are due to construction flaws of the heat exchanger as well as some assumptions made during calculations may have been incorrect for the application.

The project took 160 hours to complete, which was under the estimated 180 hours.

The project did have some spending expenditures that were not initially accounted for such as some testing equipment and other consumables to complete the construction of the project. Initially the budget was estimated at 1000 dollars but the actual amount needed to complete the project was 1300.

All analysis, drawings, schedule, budget, and the testing report can be found in the appendix of this report.

10. ACKNOWLEDGEMENTS

Special thanks to…

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The Linarez family for proving materials and funding.

CWU Faculty member John Choi for mentoring.

CWU Faculty member Charles Pringle for mentoring.

CWU Faculty member Dr. Craig Johnson for mentoring.

CWU for lab and equipment use.

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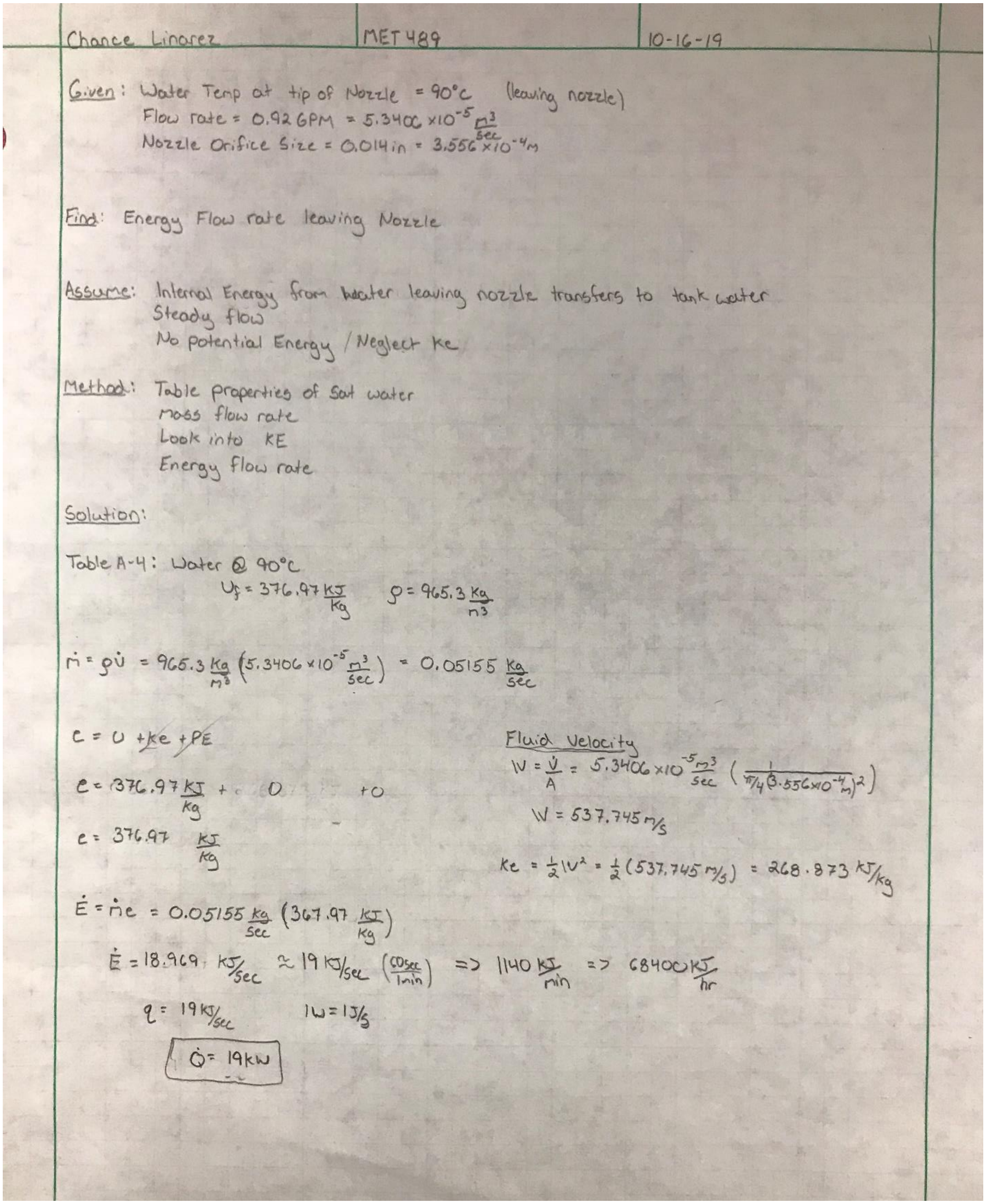
APPENDIX A

A-1 – Energy Flow Rate Leaving Water Jet Nozzle



Chance Linarez | MET 489 | 10-16-19

Given: Water Temp at tip of Nozzle = 90°C (leaving nozzle)
Flow rate = 0.92 GPM = $5.3406 \times 10^{-5}\ \frac{m^3}{sec}$
Nozzle Orifice Size = 0.014 in = 3.556×10^{-4} m

Find: Energy Flow rate leaving Nozzle

Assume: Internal Energy from water leaving nozzle transfers to tank water
Steady flow
No potential Energy / Neglect ke

Method: Table properties of Sat water
mass flow rate
Look into KE
Energy flow rate

Solution:

Table A-4: Water @ 90°C

$U_f = 376.97\ \frac{KJ}{kg}$ $\rho = 965.3\ \frac{kg}{m^3}$

$\dot{m} = \rho \dot{V} = 965.3\ \frac{kg}{m^3}\left(5.3406 \times 10^{-5}\ \frac{m^3}{sec}\right) = 0.05155\ \frac{kg}{sec}$

$e = U + ke + PE$

$e = 376.97\ \frac{KJ}{kg} + 0 + 0$

$e = 376.97\ \frac{KJ}{kg}$

Fluid Velocity

$V = \frac{\dot{V}}{A} = 5.3406 \times 10^{-5}\ \frac{m^3}{sec}\left(\frac{1}{\pi/4\,(3.556 \times 10^{-4}\ m)^2}\right)$

$V = 537.745\ m/s$

$ke = \frac{1}{2}V^2 = \frac{1}{2}(537.745\ m/s) = 268.873\ KJ/kg$

$\dot{E} = \dot{m}e = 0.05155\ \frac{kg}{sec}\left(367.97\ \frac{KJ}{kg}\right)$

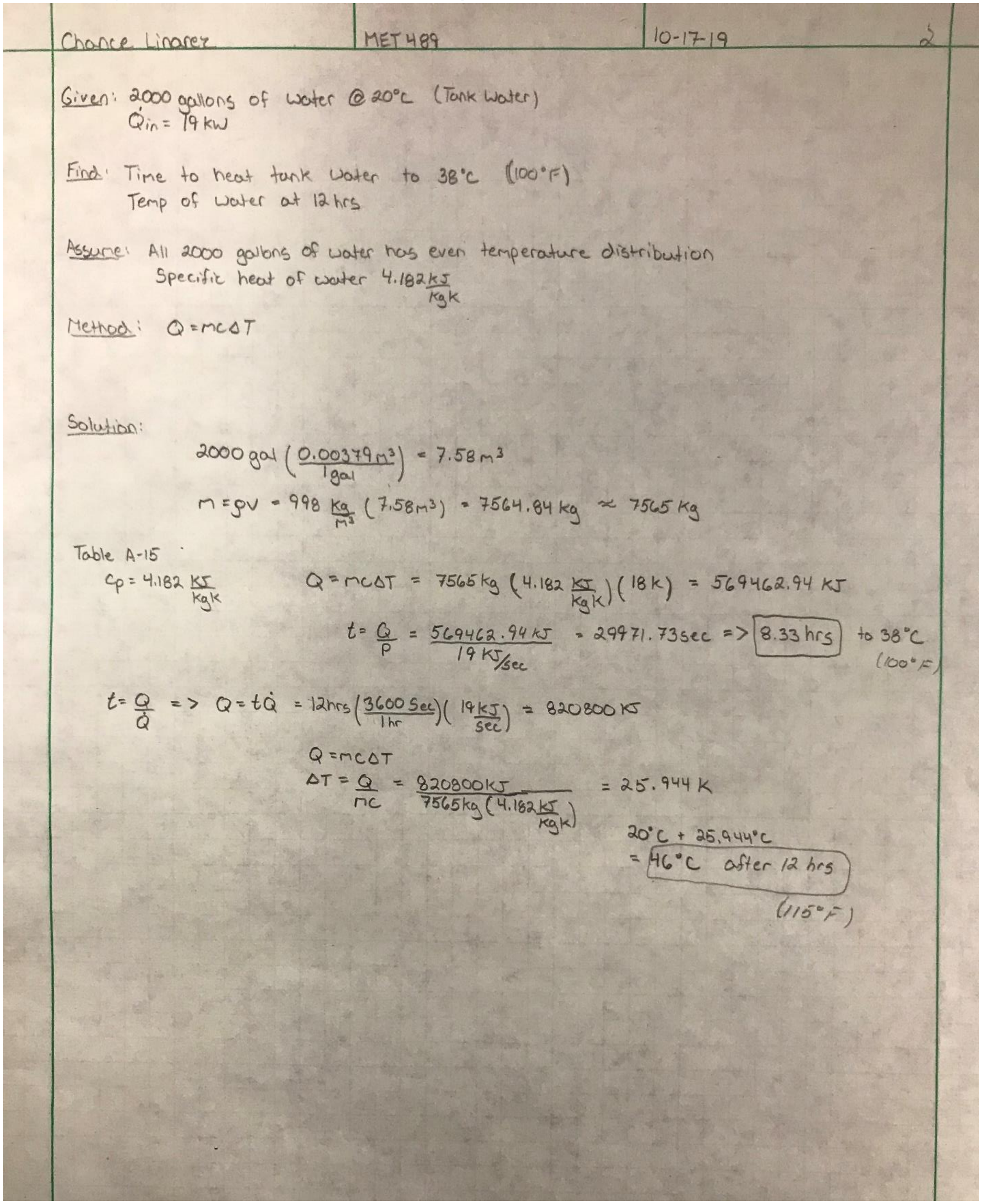
$\dot{E} = 18.969\ KJ/sec \approx 19\ KJ/sec\left(\frac{60 sec}{1 min}\right) \Rightarrow 1140\ \frac{KJ}{min} \Rightarrow 68400\ \frac{KJ}{hr}$

$q = 19\ KJ/sec$ $1W = 1J/s$

$\boxed{\dot{Q} = 19 kW}$

[1] Calculation to find the heat transfer rate (Q-dot) from the water jet nozzle to the tank water.

A-2 – Temperature of Water After Running Time



Chance Linarez | MET 489 | 10-17-19 | 2

Given: 2000 gallons of water @ 20°C (Tank Water)
$\dot{Q}_{in} = 19\ kW$

Find: Time to heat tank water to 38°C (100°F)
Temp of water at 12 hrs

Assume: All 2000 gallons of water has even temperature distribution
Specific heat of water $4.182 \frac{kJ}{kgK}$

Method: $Q = mc\Delta T$

Solution:

$$2000\ gal \left(\frac{0.00379\ m^3}{1\ gal}\right) = 7.58\ m^3$$

$$m = \rho V = 998 \frac{kg}{m^3} (7.58\ m^3) = 7564.84\ kg \approx 7565\ kg$$

Table A-15
$c_p = 4.182 \frac{kJ}{kgK}$

$$Q = mc\Delta T = 7565\ kg \left(4.182 \frac{kJ}{kgK}\right)(18\ K) = 569462.94\ kJ$$

$$t = \frac{Q}{P} = \frac{569462.94\ kJ}{19\ kJ/sec} = 29971.73\ sec \Rightarrow \boxed{8.33\ hrs} \text{ to } 38°C$$
(100°F)

$$t = \frac{Q}{\dot{Q}} \Rightarrow Q = t\dot{Q} = 12\ hrs\left(\frac{3600\ Sec}{1\ hr}\right)\left(19 \frac{kJ}{sec}\right) = 820800\ kJ$$

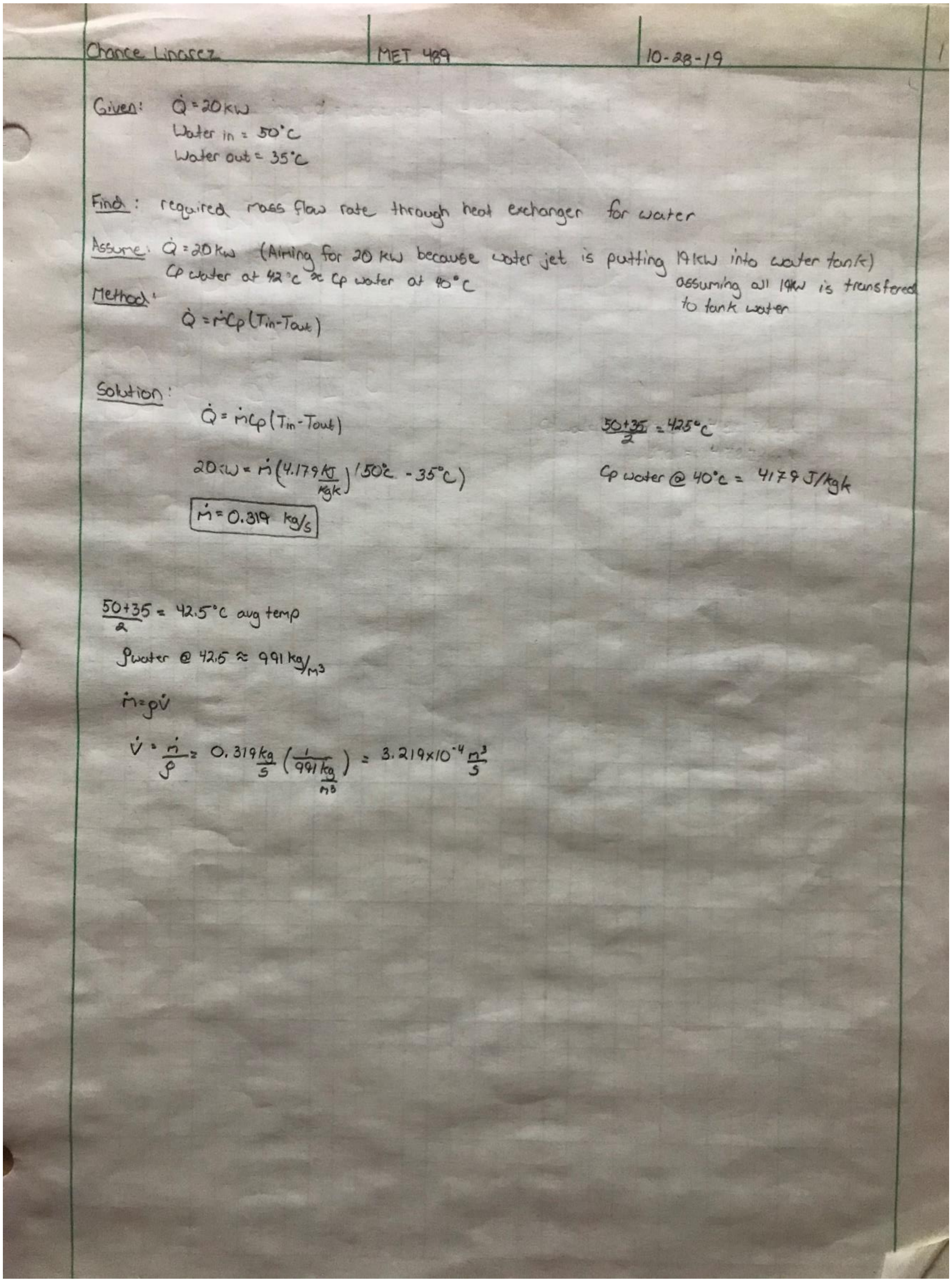
$$Q = mc\Delta T$$

$$\Delta T = \frac{Q}{mc} = \frac{820800\ kJ}{7565\ kg\left(4.182 \frac{kJ}{kgK}\right)} = 25.944\ K$$

20°C + 25.944°C
= 46°C after 12 hrs
(115°F)

[2] Using Q-dot from A-1, calculations to find time taken to heat tank water from room temperature to 38°C. Also, what temperature the water is after 12 hours of runtime.

A-3 – Analysis of Water Flow Rate Through Heat Exchanger



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Given: $\dot{Q} = 20\,kW$
Water in = 50°C
Water out = 35°C

Find: required mass flow rate through heat exchanger for water

Assume: $\dot{Q} = 20\,kW$ (Aiming for 20 kW because water jet is putting 19 kW into water tank)
Cp water at 42°C ≈ Cp water at 40°C
assuming all 19kW is transfered to tank water

Method:
$\dot{Q} = \dot{m} C_p (T_{in} - T_{out})$

Solution:
$\dot{Q} = \dot{m} C_p (T_{in} - T_{out})$

$20\,kW = \dot{m}\left(4.179 \frac{kJ}{kgK}\right)(50°C - 35°C)$

$\boxed{\dot{m} = 0.319\ kg/s}$

$\frac{50+35}{2} = 42.5°C$

Cp water @ 40°C = 4179 J/kgK

$\frac{50+35}{2} = 42.5°C$ avg temp

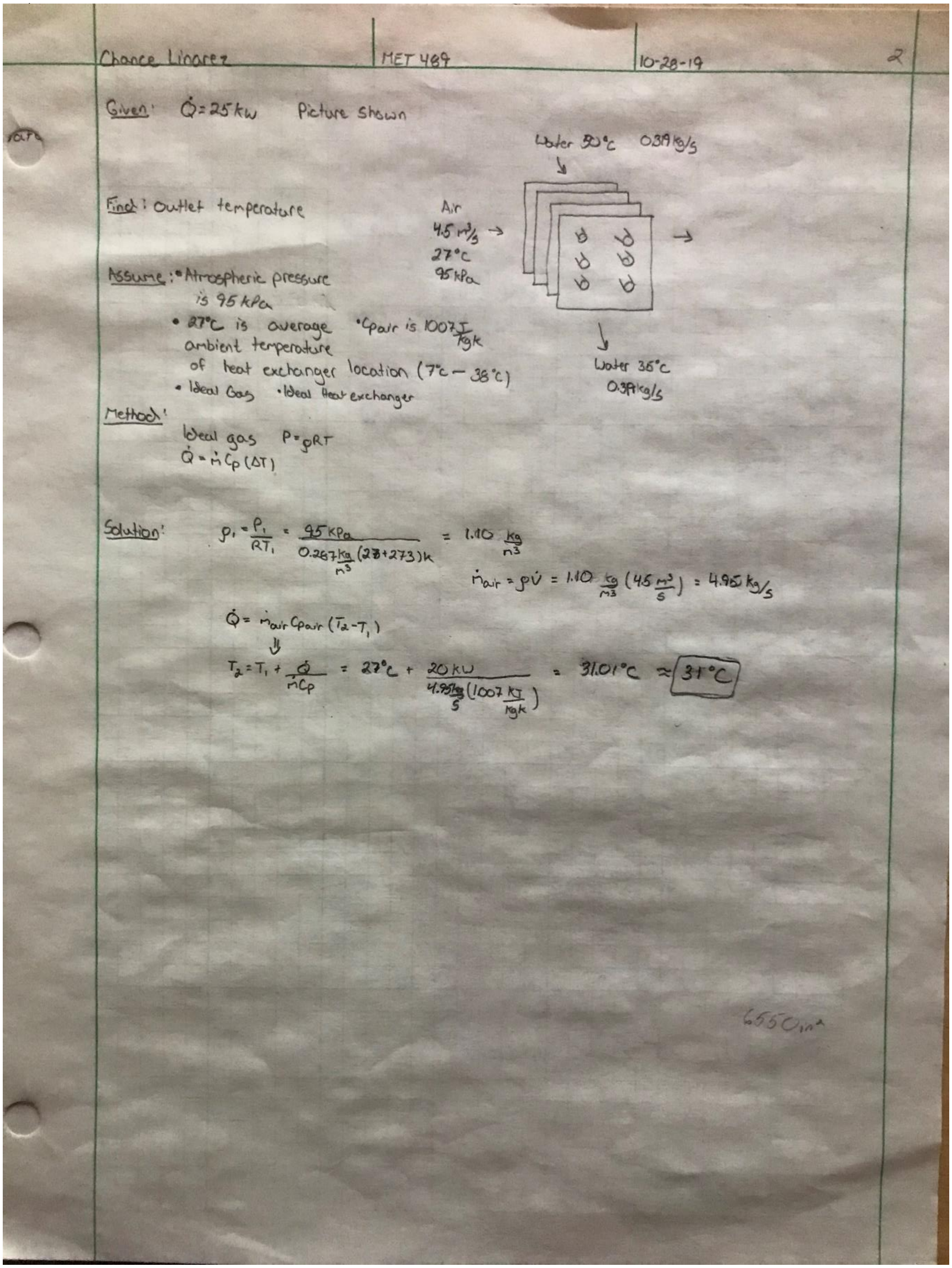
ρ_{water} @ 42.5 ≈ 991 kg/m³

$\dot{m} = \rho \dot{V}$

$\dot{V} = \frac{\dot{m}}{\rho} = 0.319 \frac{kg}{s}\left(\frac{1}{991 \frac{kg}{m^3}}\right) = 3.219 \times 10^{-4} \frac{m^3}{s}$

[3] Calculation to approximate a required flow rate through the heat exchanger that has a rating of 20kW.

A-4 – Analysis of Output Air temperature of Heat Exchanger



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Given: $\dot{Q} = 25\ kw$ Picture Shown

Find: Outlet temperature

Assume: • Atmospheric pressure is 95 kPa
• 27°C is average ambient temperature of heat exchanger location (7°c – 38°C)
• Cpair is 1007 $\frac{J}{kgk}$
• Ideal Gas • Ideal Heat exchanger

Method:
Ideal gas $P = \rho RT$
$\dot{Q} = \dot{m} C_p (\Delta T)$

Solution:

$$\rho_1 = \frac{P_1}{RT_1} = \frac{95\ kPa}{0.287 \frac{kg}{m^3} (27+273) k} = 1.10\ \frac{kg}{m^3}$$

$$\dot{m}_{air} = \rho \dot{V} = 1.10\ \frac{kg}{m^3} \left(4.5 \frac{m^3}{s}\right) = 4.95\ kg/s$$

$$\dot{Q} = \dot{m}_{air} C_{pair} (T_2 - T_1)$$

$$T_2 = T_1 + \frac{\dot{Q}}{\dot{m} C_p} = 27°C + \frac{20\ kW}{4.95 \frac{kg}{s} \left(1007 \frac{KJ}{kgk}\right)} = 31.01°C \approx \boxed{31°C}$$

655 O in²

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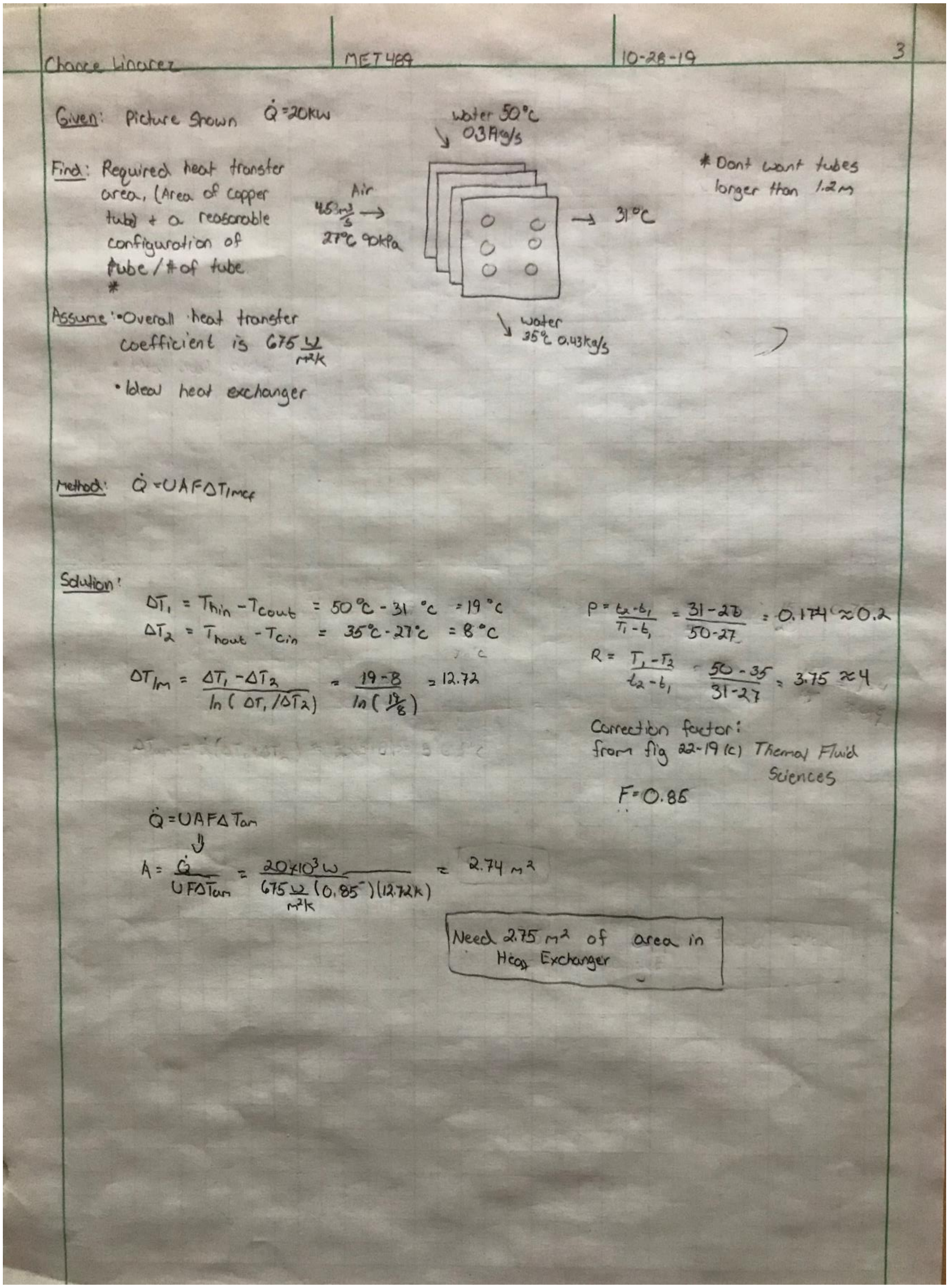
[4] Calculation to find a theoretical output air temperature of the heat exchanger.

A-5 – Analysis of Required Surface Area for Heat Exchanger



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Given: Picture Shown $\dot{Q} = 20kW$

* Dont want tubes longer than 1.2 m

Find: Required heat transfer area, (Area of copper tube) + a reasonable configuration of tube / # of tube
*

Assume: • Overall heat transfer coefficient is $675 \frac{W}{m^2K}$

• Ideal heat exchanger

Method: $\dot{Q} = UAF\Delta T_{lmcf}$

Solution:

$\Delta T_1 = T_{hin} - T_{cout} = 50°C - 31°C = 19°C$

$\Delta T_2 = T_{hout} - T_{cin} = 35°C - 27°C = 8°C$

$\Delta T_{lm} = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1/\Delta T_2)} = \frac{19-8}{\ln(19/8)} = 12.72$

$P = \frac{t_2 - t_1}{T_1 - t_1} = \frac{31-27}{50-27} = 0.174 \approx 0.2$

$R = \frac{T_1 - T_2}{t_2 - t_1} = \frac{50-35}{31-27} = 3.75 \approx 4$

Correction factor:
from fig 22-19 (c) Thermal Fluid Sciences

$F = 0.85$

$\dot{Q} = UAF\Delta T_{lm}$

$A = \frac{\dot{Q}}{UF\Delta T_{lm}} = \frac{20 \times 10^3 W}{675 \frac{W}{m^2K}(0.85)(12.72K)} = 2.74 m^2$

Need 2.75 m² of area in Heat Exchanger

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[5] Calculation to find a required heat transfer area of the heat exchanger.

A-6 – Surface Area of Fins

[6]

Chance Linarez | MET489 | 11-7-19

Given: 72 fins

12 Tube passes (x3) – 0.375in Ø Tube – 36in long finned, 2in unfinned
12 in fin length
2 in fin width
0.0625in fin thickness

Find: Total Surface Area

Assume: Copper Tube Ø is close to OD of tube
Neglect 180° fitting Area, Tube fits tight inside fin

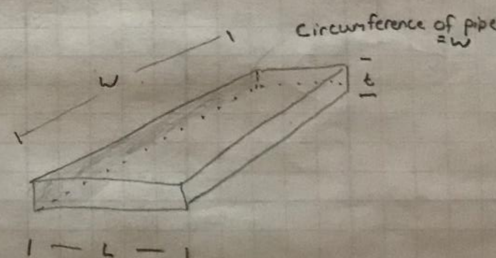
Method:

Solution:
0.375in = 0.009525m   12in = 0.3048m
36in = 0.9144m
2in = 0.0508m
0.0625in = 0.0015875m

Tube Area
$C = \pi D = \pi(.009525m) = 0.0299m$

$C \cdot L = 0.0299m(.9144m + .0508m) = 0.0289m^2 \times 12 \text{ Tubes} = 0.3468m^2 \times 3 \text{ sets} = 1.04m^2$

Fin Area



$A_{fin} = 2 \times W \times L + W \times t$
$= 2(.0299m)(.0508m) + (.0299m)(.0015875m)$
$= 0.00309m^2$
$\rightarrow \times 72 \text{ fins}$
$= 0.222m^2$
$\rightarrow \times 3 = 0.666m^2$

Total Surface Area = $1.71m^2$

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[6] Calculation to find surface area of heat exchanger with a given configuration of tubes and fins.

A-7 – Analysis of Heat Exchanger Unit Weight[7]

Chance Linarez | MET 484 | 11-14-19

Given: Parts in entire Heat exchanger unit weigh about 80lbs
2-1¼ copper manifolds filled with water ≈36 in long
34 - 3/8 tube filled with water ≈ 38 in long
Fan will approx weigh 30lb

Find: weight of heat exchanger unit

Assume: Solidworks weight value for parts is close to actual part weight
Avg temp of water in heat exchanger is 110°F
Neglect weight of water in 180° fittings

Method: ρ_{water}
vol_{water}

Solution: ρ_{water} @ 110°F $= 61.86 \frac{lbm}{ft^3}$

Volume of water manifolds:

$A = \frac{\pi}{4} D^2 = \frac{\pi}{4}(1\tfrac{1}{4})^2 = 1.227 in^2$
$(36 in) = 44.18 in^3$ per manifold
$\hookrightarrow \times 2 = \boxed{88.36 in^3}$

Volume of water in 3/8 tube

$A = \frac{\pi}{4} D^2 = \frac{\pi}{4}(\tfrac{3}{8} in)^2 = 0.110 in^2$
$(38 in) = 4.2 in^3$ per tube
$\times 34 = \boxed{142.7 in^3}$

Total volume of water in Heat Exchanger unit $= 88.36 in^3 + 142.7 in^3 = \boxed{231.06 in^3}$

$61.86 \frac{lbm}{ft^3} \left(\frac{1 ft^3}{1728 in^3}\right)\left(\frac{1 lbf \cdot ft/s^2}{32.174 lbm \cdot ft/s^2}\right)(231.06 in^3) = 0.257 lbf$ of water in unit

Total weight of heat exchanger unit (to date) $= 80 lb + 30 lb + 0.26 lb \approx \boxed{110.26 lb}$

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[7] Calculation to find approximate weight of heat exchanger unit.

A-8 – Larger Flow Rate Analysis

Chance Linarez | MET 489 | 11-14-19

Given: Pump that provides 3 GPm flow rate

Water in = 50°C

Water Out = 35°C

Find: $\dot{Q}$ with this given flow rate

Assume: Ideal heat exchanger

C_p water @ 42°C ≈ 40°C $= 4.179 \frac{kJ}{kgK}$

$\frac{50+35}{2} = 42$

ρ_{water} @ 42°C ≈ 991 kg/m³

Method:

$$\dot{Q} = \dot{m} C_p (T_{in} - T_{out})$$

Solution:

$$\dot{V} = \frac{3\,gal}{min}\left(\frac{231\,in^3}{1\,gal}\right)\left(\frac{1\,m^3}{61023.7\,in^3}\right)\left(\frac{1\,min}{60\,sec}\right) = 1.893\times10^{-4}\,m^3/s$$

$$\dot{m} = \rho\dot{V} = 991\frac{kg}{m^3}\left(1.893\times10^{-4}\,m^3/s\right) = \boxed{0.1876\,kg/s}$$

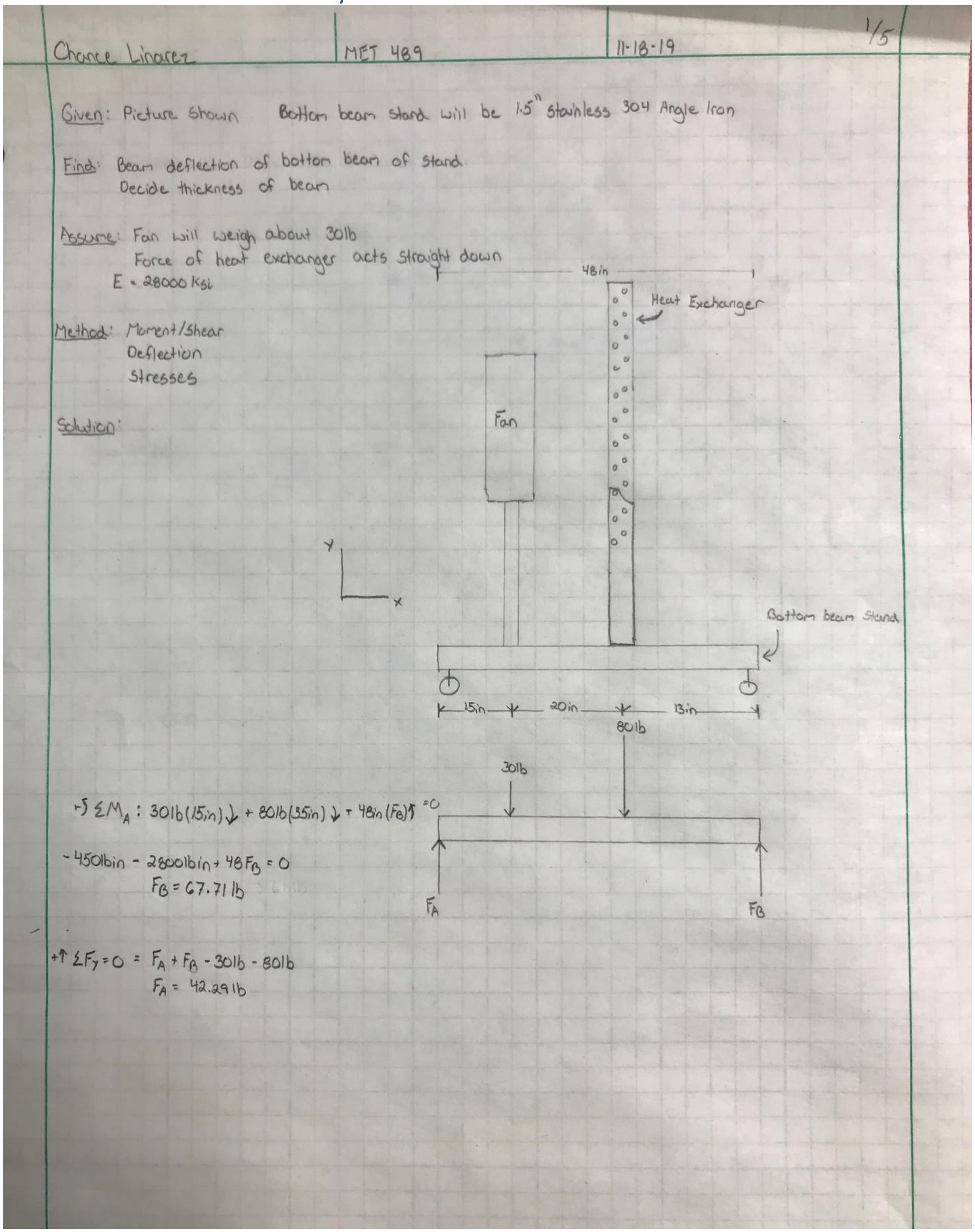
$$\dot{Q} = 0.1676\frac{kg}{s}\left(4.179\frac{kJ}{kgK}\right)(50°c - 35°c)$$

$$\boxed{\dot{Q} = 11.76\,kW}$$

Using a larger flow rate would give a $\dot{Q}$ value of 11.76 kW which may be to small when ambient temperature is high.

[8] Calculation to find Q dot value if a pump with a larger flow rate were to be used.

A-9 – Stand Bottom Beam Analysis



Chance Linarez | MET 489 | 11-18-19 | 1/5

Given: Picture Shown. Bottom beam stand will be 1.5" stainless 304 Angle Iron

Find: Beam deflection of bottom beam of stand
Decide thickness of beam

Assume: Fan will weigh about 30lb
Force of heat exchanger acts straight down
$E = 28000\ ksi$

Method: Moment/Shear
Deflection
Stresses

Solution:

$\circlearrowleft \sum M_A: 30lb(15in)\downarrow + 80lb(35in)\downarrow + 48in(F_B)\uparrow = 0$

$-450lbin - 2800lbin + 48F_B = 0$

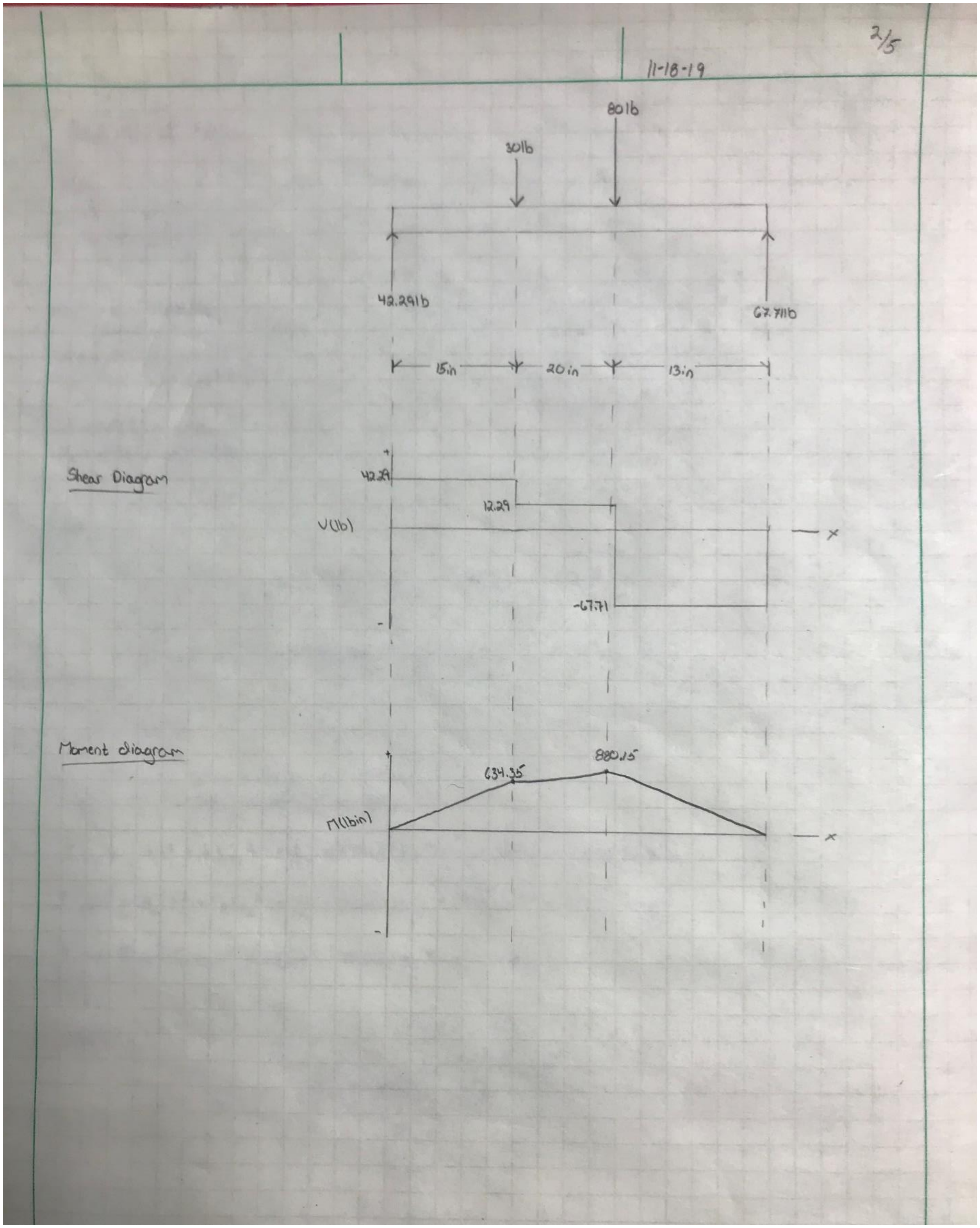
$F_B = 67.71\ lb$

$+\uparrow \sum F_y = 0 = F_A + F_B - 30lb - 80lb$

$F_A = 42.29\ lb$

[9] Sketch of heat exchanger and calculation showing forces on bottom beam.

A-9.1



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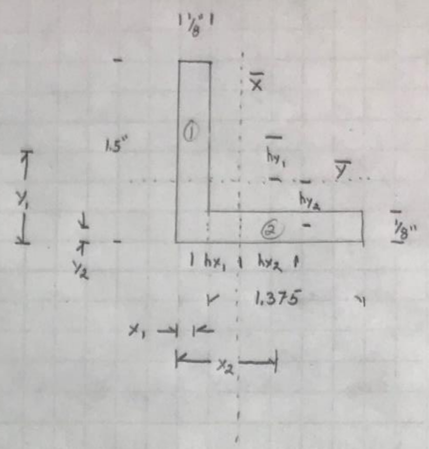
[10] Moment and Shear Diagram of bottom beam.

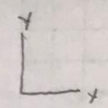
A-9.2

3/5

11-18-19

1/8" × 1.5" × 1.5" Angle





Areas

$A_1 = (1.5)(.125) = .1875\,in^2$

$A_2 = (1.375)(.125) = .172\,in^2$

Centroidal Distances

$x_1 = 0.125(1/2) = 0.0625\,in$

$x_2 = 1.375(1/2) = 0.6875\,in$

$y_1 = 1.5(1/2) = 0.75\,in$

$y_2 = .125(1/2) = 0.0625\,in$

Centroid

$$\bar{x} = \frac{A_1 x_1 + A_2 x_2}{A_1 + A_2} = \frac{0.1875(.0625) + .172(.6875)}{.1875 + .172} = 0.362\,in$$

$$\bar{y} = \frac{A_1 y_1 + A_2 y_2}{A_1 + A_2} = \frac{.1875(.75) + .172(.0625)}{.1875 + .172} = 0.421\,in$$

Moment of Inertia

$h_{y_1} = y_1 - \bar{y} = 0.75\,in - .421\,in = .329\,in$

$h_{y_2} = \bar{y} - y_2 = .421\,in - .0625\,in = .359\,in$

$$I_{1xx} = \frac{1}{12} b_1 L_1^3 + A_1 h_{y_1}^2 = \frac{1}{12}(.125)(1.5^3) + .1875(.329^2) = .0555\,in^4$$

$$I_{2xx} = \frac{1}{12} b_2 L_2^3 + A_2 h_{y_2}^2 = \frac{1}{12}(1.375)(.125^3) + .172(.359^2) = .0224\,in^4$$

$$I_{xx} = I_{1xx} + I_{2xx} = 0.0555\,in^4 + 0.0224\,in^4 = .0779\,in^4$$

Deflection

$$y_{max} = \frac{-PL^3}{48EI} = \frac{-110\,lb\,(48\,in)^3}{48(28\times10^6\,\frac{lb}{in^2})(.0779\,in^4)} = \boxed{-0.116\,in}$$

Not Good

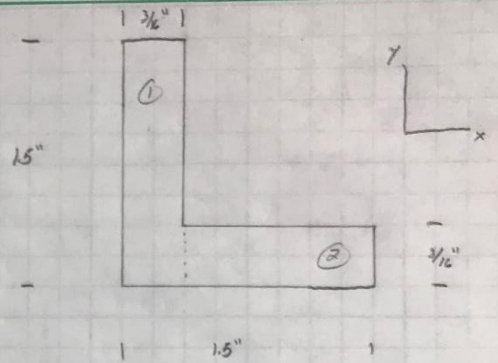
Use thicker angle

[11] Calculation to determine deflection of bottom beam if 1/8” thick angle iron were to be used.

A-9.3

11-18-19

4/5



3/16" × 1.5" × 1.5" Angle

AREAS

$A_1 = 1.5(.1875) = 0.281\,in^2$

$A_2 = 1.3125(.1875) = 0.246\,in^2$

Centroidal Distances

$x_1 = .09375\,in$

$x_2 = .656\,in$

$y_1 = 0.75\,in$

$y_2 = .0938\,in$

*SEE PG 3 FOR DIMENSION LABLES

Centroid

$$\bar{x} = \frac{A_1x_1 + A_2x_2}{A_1 + A_2} = \frac{.281(.094) + .246(.656)}{.281 + .246} = .356\,in$$

$$\bar{y} = \frac{A_1y_1 + A_2y_2}{A_1 + A_2} = \frac{.281(.751) + .246(.094)}{.281 + .246} = .444\,in$$

Moment of Inertia

$hy_1 = y_1 - \bar{y} = 0.75 - .444\,in = .306\,in$

$hy_2 = \bar{y} - y_2 = .444\,in - .0938\,in = .3502\,in$

$I_{1xx} = \frac{1}{12} b_1L_1^3 + A_1hy_1^2 = \frac{1}{12}(.1875)(1.5^3) + .281(.306^2) = 0.079\,in^4$

$I_{2xx} = \frac{1}{12} b_2L_2^3 + A_2hy_2^2 = \frac{1}{12}(1.3125)(.1875^3) + .246(.3502^2) = 0.031\,in^4$

$I_{xx} = 0.110\,in^4$

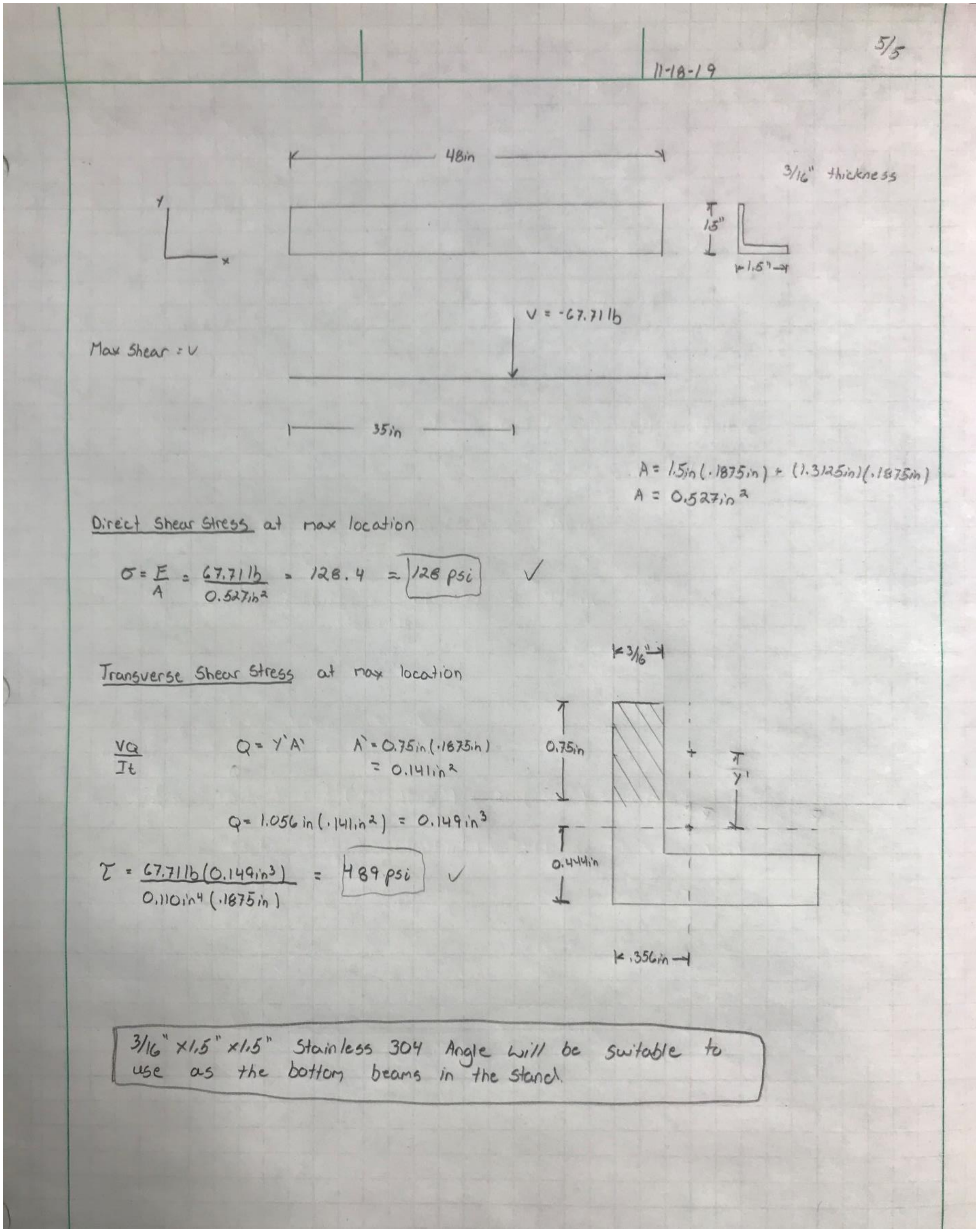
Deflection

$$y_{max} = \frac{-PL^3}{48EI} = \frac{-110\,lb(48in)^3}{48(28\times10^6\frac{lb}{in^2})(0.110in^4)} = -0.082\,in$$

Good Enough

[12] Calculation to determine deflection of bottom beam if 3/16” thick angle iron were to be used.

A-9.4



[13] Calculation determining stresses in the bottom beam.

A-10 – Upper Limit for Heat Transfer Rate[14]

Chance Linarez | MET 489 | 11-21-19

Given: Air at 30°C flows through Water to Air heat Exchanger
$1.41 \frac{m^3}{s}$

Water flows @ $0.319 \frac{kg}{s}$

Find: Upper Limit for heat transfer in a heat exchanger

Assume: C_p water $= 4.18 \frac{kJ}{kg \cdot K}$

C_p air @ 30°C $= 1.007 \frac{kJ}{kg K}$

Steady operating conditions
Fluid properties are constant.

Method: C_c
C_h
$\dot{Q}_{max}$

Solution:

$$C_h = \dot{m}_h C_{ph} = 0.319 \frac{kg}{s} \left(4.18 \frac{kJ}{kg K}\right) = 1.33 \frac{kW}{K}$$

$$C_c = \dot{m}_c C_{pc} = 1.648 \frac{kg}{s} \left(1.007 \frac{kJ}{kg K}\right) = 1.660 \frac{kW}{K}$$

$$C_{min} = C_h = 1.33 \frac{kW}{K}$$

$$\dot{Q}_{max} = C_{min}(T_{h,in} - T_{c,in}) = 1.33 \frac{kW}{K}(55°C - 30°C) = \boxed{33.25 \text{ kW}}$$

Maximum possible heat transfer rate in this heat Exchanger is 33.25 kW

This number will vary depending on air temperature where heat exchanger is located. Avg temp where heat exchanger will be is assumed 30°C.

[14] Calculation to find maximum heat transfer rate from heat exchanger.

A-11 – Effectiveness of Heat Exchanger[15]

Chance Linarez | MET 489 | 11-21-19

Given: $\dot{Q}_{max}$ of water to air heat exchanger = 33.25 kW

Water through heat exchanger = 0.319 kg/s @ 55°C

Air passes through heat exchanger at 30°C and 1.41 m³/s C = 0.881

Find: Effectiveness of heat exchanger

Assume: C_p water = 4.18 kJ/kgK C_p air = 1.007 kJ/kg

Fluid properties are constant

Steady operating conditions

Method: $\frac{\dot{Q}}{\dot{Q}_{max}}$

Solution:

$$\dot{Q} = \dot{m} c_p (T_{in} - T_{out})_{water} = 0.319\ \text{kg/s}\ (4.18\ \text{kJ/kgK})(55 - 35) = 26.67\ \text{kW}$$

$$\varepsilon = \frac{\dot{Q}}{\dot{Q}_{max}} = \frac{26.67\ \text{kW}}{33.25\ \text{kW}} = 0.802$$

$$\varepsilon = 1 - \exp\left\{ \frac{NTU^{.22}}{c} \left[\exp(-c\,NTU^{.78}) - 1 \right] \right\} = 2.19$$

[15] Calculation to find effectiveness.

A-12 – Analysis of Fin Efficiency and Effectiveness

Chance Linarez | MET 489 | 12-1-19 | 1/3

Given: 1/2" OD copper tube by 38 in long (.0127m × .96m) 12 passes

$T_\infty = 27\,°C$

T_{water} entering tubes = 55°C

Find: Should 1/2" or 1/4" fins be used, or fins be used at all (Aluminum fins)

Assume: $h = 12 \frac{W}{m^2K}$ $\quad k_{al} = 237 \frac{W}{mK}$

Adiabatic fin tip

h value is constant

Method: $\dot{Q}_{fin}$

η_{fin}

ε_{fin}

ε_{fin} overall

Solution:

Circumference of pipe: $\pi D = \pi(.0127m) = .0399m$

Using 1/16" Aluminum fin:

$A_c = .0016m(.0399m) = 6.384\times10^{-5} m^2$

1/2" fin length

$\dot{Q}_{cond} = -kA_c\frac{\Delta T}{\Delta x} = 237\frac{W}{mK}(6.384\times10^{-5}m^2)\left(\frac{55-27c}{.013m}\right) = 32.59\,W$

$T(x) = T_\infty + (T_b - T_\infty)e^{-x\sqrt{\frac{hp}{kA_c}}} = 27 + (55-27)e^{-.013\sqrt{\frac{.012(.0399)}{.237(6.384\times10^{-5})}}} = 53$

Temp of fin at tip = 53 °C

$\dot{Q}_{long\,fin} = \sqrt{hpkA_c}\,(T_b - T_\infty) = \sqrt{.012(.0399)(0.237)(6.384\times10^{-5})}\,(55-27) = 0.0024\,kW$

$\dot{Q}_{fin} = \sqrt{hpkA_c}\,(T_b - T_\infty)\tanh(mL) = \sqrt{.012(.0399)(.237)(6.384\times10^{-5})}\,(55-27)\tanh\left(\sqrt{\frac{.012(.0399)}{.237(6.384\times10^{-5})}}\,(.0127)\right)$

$= 1.143\times10^{-4}\,kW$

[16] Calculation showing Qdot of long fin and Qdot of actual fin and temperature at tip of the 1/2 " length fin.

A-12.1

Chance Linarez | MET 487 | 12-2-19 | 2/3

$A_{fin} = .0016(.0399) + (.6127(.0399))2 = .0011 m^2$

$\dot{Q}_{finmax} = hA_{fin}(T_b - T_\infty) = .012 \frac{kW}{m^2K}(.0011 m^2)(55-27)$

$\dot{Q}_{finmax} = 3.69 \times 10^{-4}$ kW

$\eta_{fin} = \frac{\dot{Q}_{fin}}{\dot{Q}_{finmax}} = \frac{1.143 \times 10^{-4}}{3.69 \times 10^{-4}} = .309 = 31\%$

1/4" fin length

$A_{fin} = .0016(.0399) + (.0064(.0399))2 = 5.746 \times 10^{-4} m^2$

$T(x) = T_\infty + (T_b - T_\infty)e^{-x\sqrt{\frac{hp}{KA_c}}} = 27 + (55-27)e^{-.0064\sqrt{\frac{.012(.0399)}{.237(6.384 \times 10^{-5})}}}$

$T(x) = 54°C$

Temp at end of 1/4" fin length is 54°C which is less than temp of base and more than T_∞.

$\dot{Q}_{fin} = \sqrt{hpKA_c}(T_b - T_\infty)\tanh(mL) = \sqrt{.012(.0399)(.237)(6.384 \times 10^{-5})}(55-27)\tanh\left(\sqrt{\frac{.012(.0399)}{.237(6.384 \times 10^{-5})}}(.0064)\right)$

$\dot{Q}_{fin} = 5.76 \times 10^{-5}$ kW

$\dot{Q}_{finmax} = hA_{fin}(T_b - T_\infty) = .012(5.746 \times 10^{-4})(55-27) = 1.931 \times 10^{-4}$ kW

$\eta_{fin} = \frac{\dot{Q}_{fin}}{\dot{Q}_{finmax}} = \frac{5.76 \times 10^{-5}}{1.931 \times 10^{-4}} = .298 \approx 30\%$

Almost the same as a 1/2" fin length but less mat'l.

Fin Effectiveness:

1/2" fin length

$\varepsilon_{fin} = \frac{A_{fin}}{A_b}\eta_{fin} = \frac{.0011}{6.384 \times 10^{-5}}(.309) = 3.9$

1/4" fin length

$\varepsilon_{fin} = \frac{A_{fin}}{A_b} = \frac{5.746 \times 10^{-4}}{6.384 \times 10^{-5}} .298 = 2.68$

[17] Calculations to find ½" length fin efficiency and effectiveness and ¼' length fin efficiency and effectiveness.

A-12.2

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Fin Effectiveness Overall

½" fin length:

$$\varepsilon_{fin\,overall} = \frac{A_{unfin} + \eta_{fin} A_{fin}}{A_{no\,fin}} = \frac{.352 + .309(1.9)}{.462} = 2.03$$

$A_{unfin} = (.9652m - .2304m)\pi(.0127m) = 0.029m^2 \Rightarrow \times 12$ passes $= 0.352m^2$

$A_{fin} = .0011m^2 \times 1728$ fins in 12 passes $= 1.9m^2$

$A_{nofin} = (.9652m)\pi(.0127) = .0385m^2 \Rightarrow \times 12$ passes $= 0.462m^2$

¼" fin length:

$$\varepsilon_{fin\,overall} = \frac{A_{unfin} + \eta_{fin} A_{fin}}{A_{no\,fin}} = \frac{.352 + .298(.993)}{.462} = 1.40$$

$A_{unfin} = .352m^2$

$A_{fin} = 5.746\times10^{-4} m^2 \times 1728$ fins in 12 passes $= 0.993$

$A_{nofin} = 0.462m^2$

Using ¼" fins will save $2592 in^2$ of Aluminum than if ½" fins were used, while only loosing 1% efficiency, but overall effectiveness reduces by roughly 30%.

Heat Transfer Ratio:

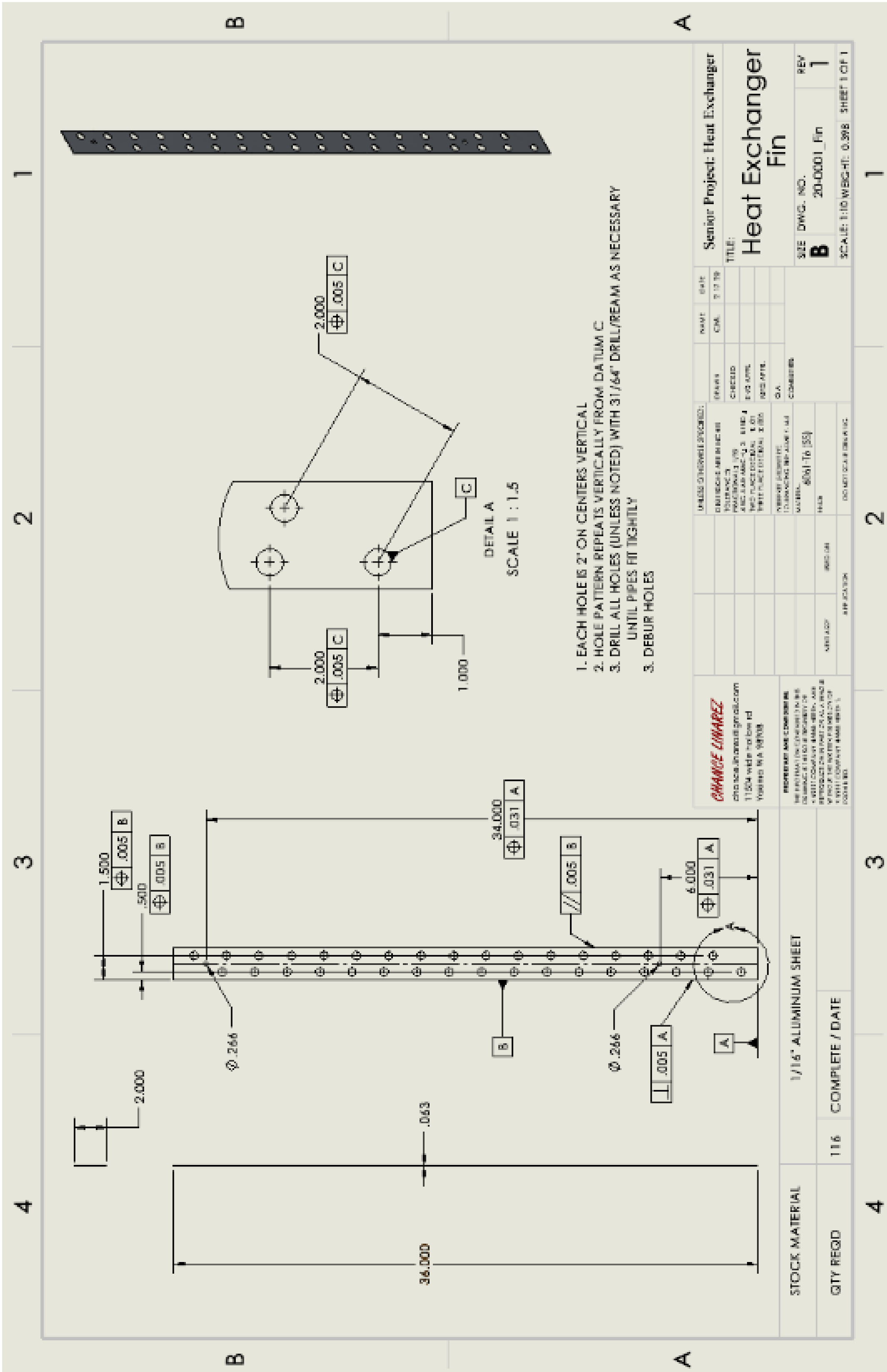
½" fin length: $\frac{\dot{Q}_{fin}}{\dot{Q}_{Longfin}} = \tanh mL \Rightarrow \frac{1.143\times10^{-4}}{.0024} = .048$

¼" fin length: $\frac{\dot{Q}_{fin}}{\dot{Q}_{Longfin}} = \tanh mL \Rightarrow \frac{5.76\times10^{-5}}{.0024} = .024$

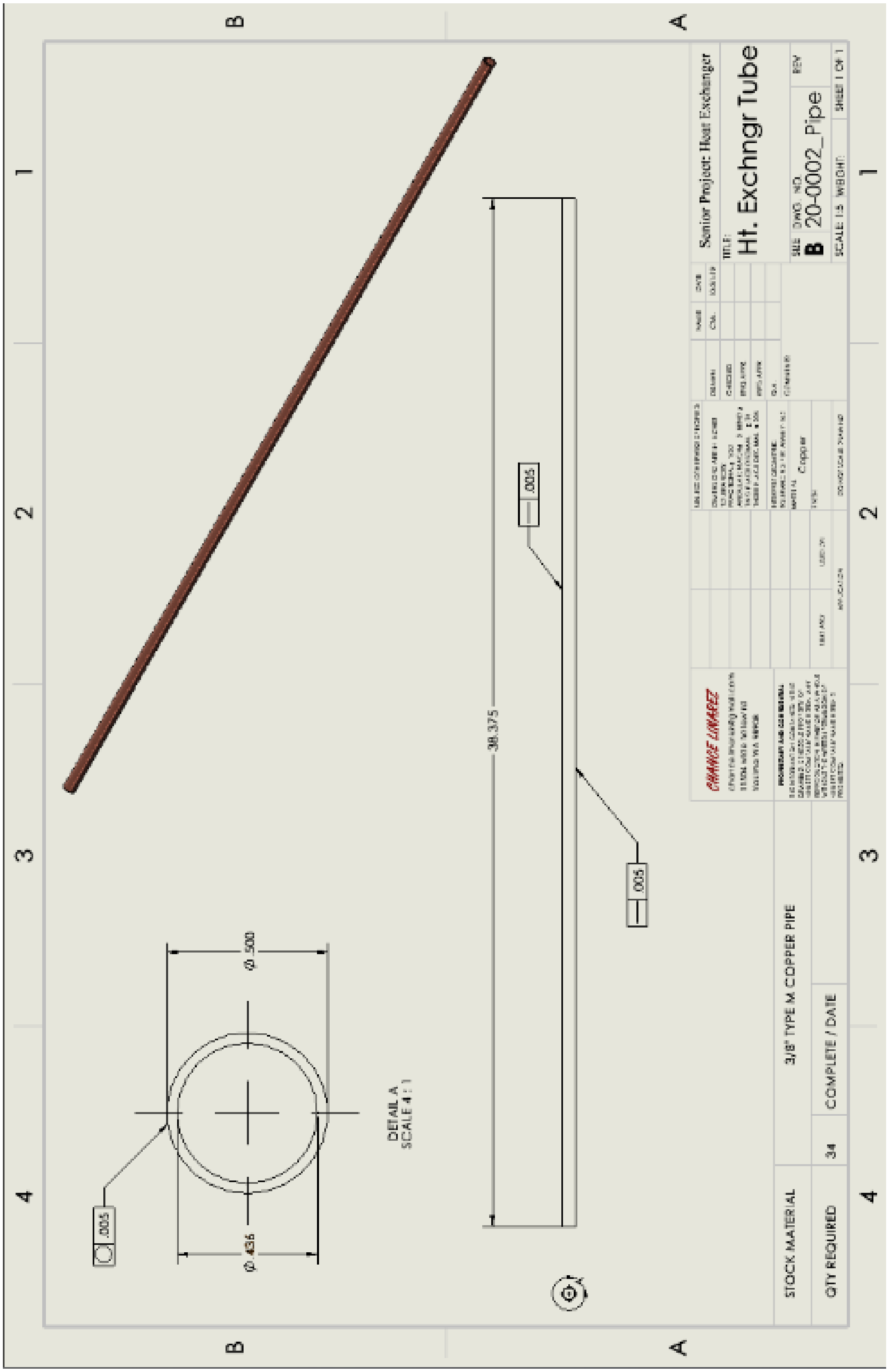
[18] Calculations to find overall fin effectiveness for the entire heat exchanger.

APPENDIX B

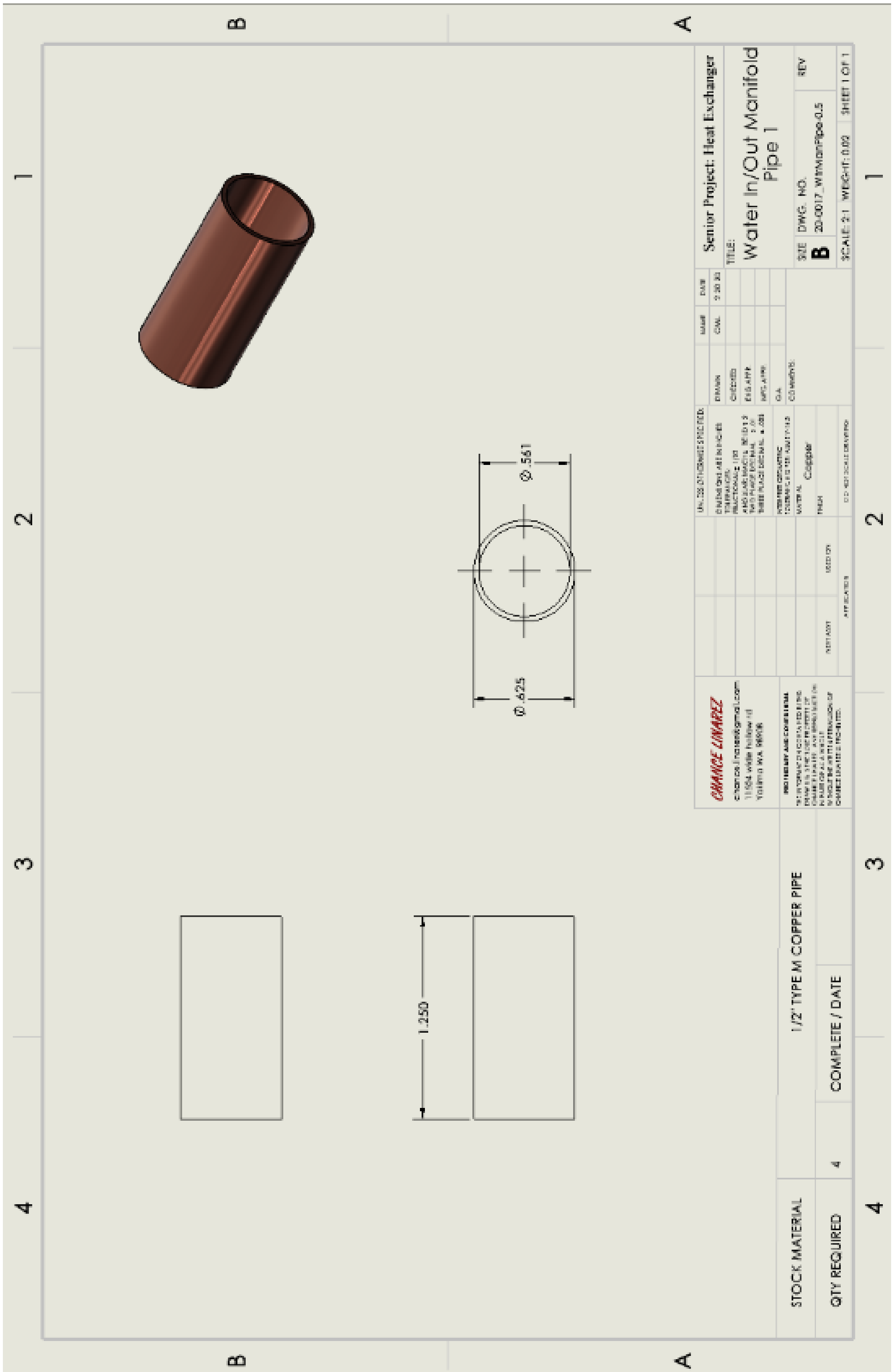
B-1 – Fin Part



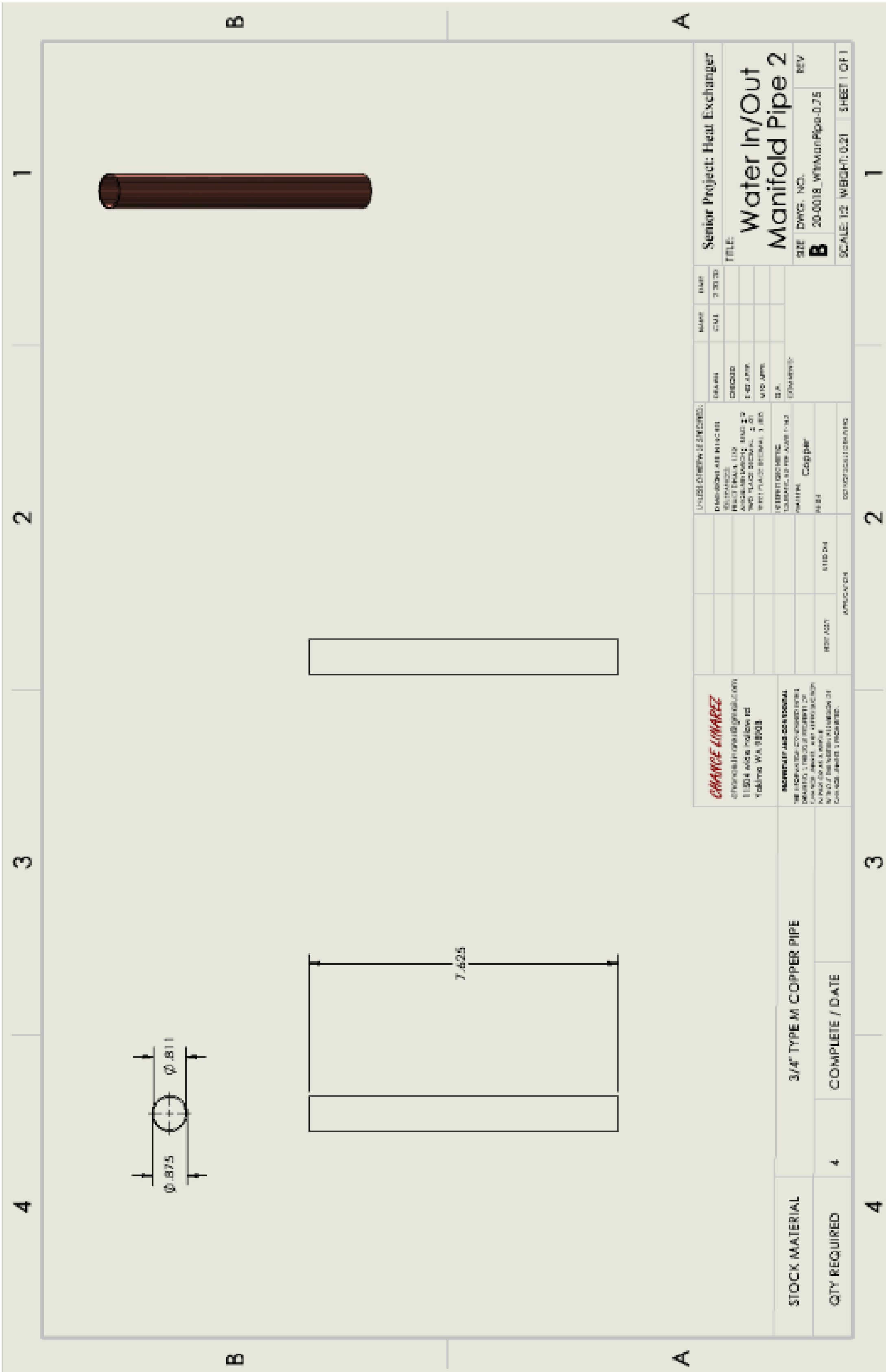
B-2 – Heat Exchanger Inner Tube Part



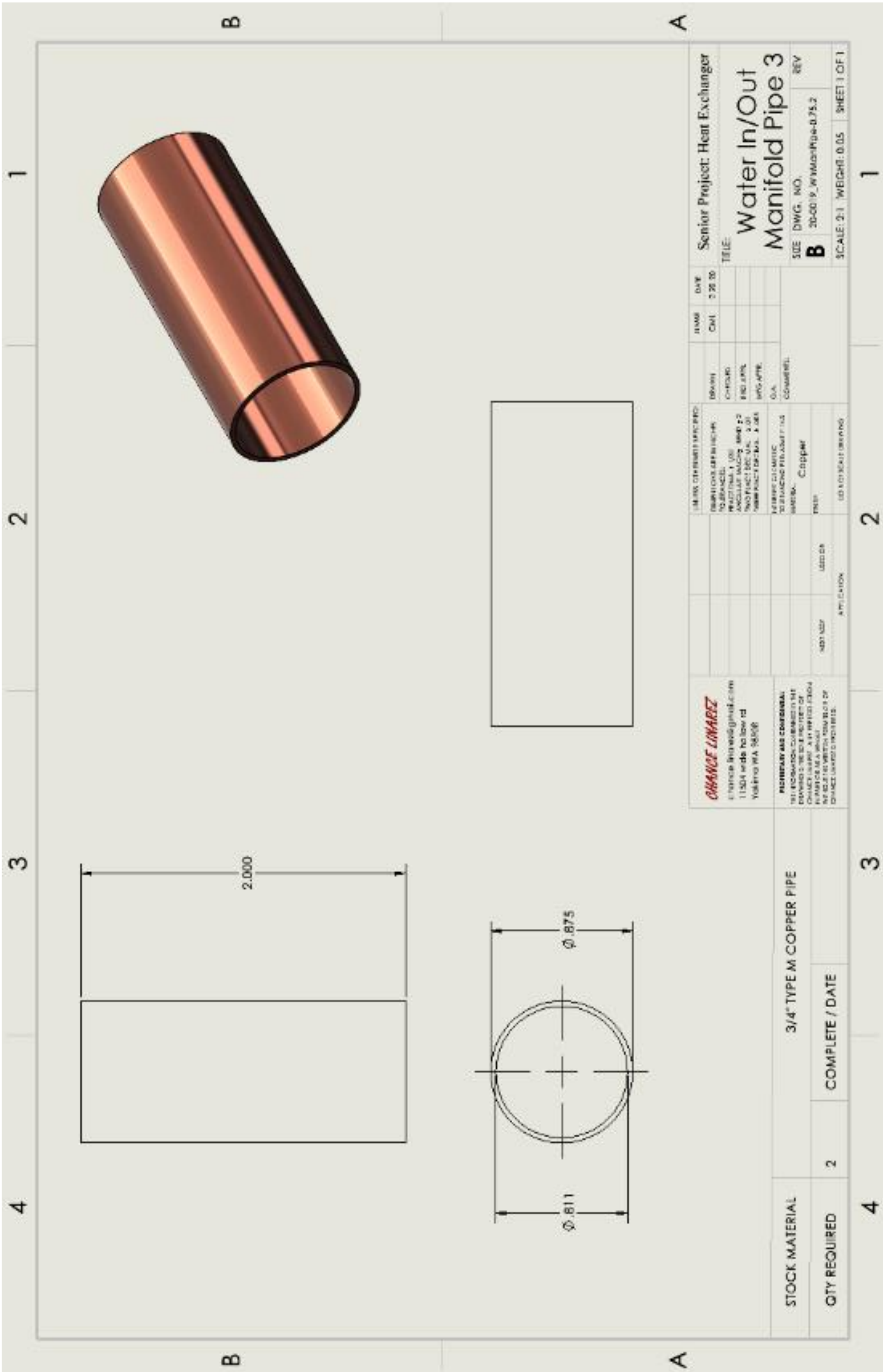
B-3 – Water Manifold Pipe Part 1



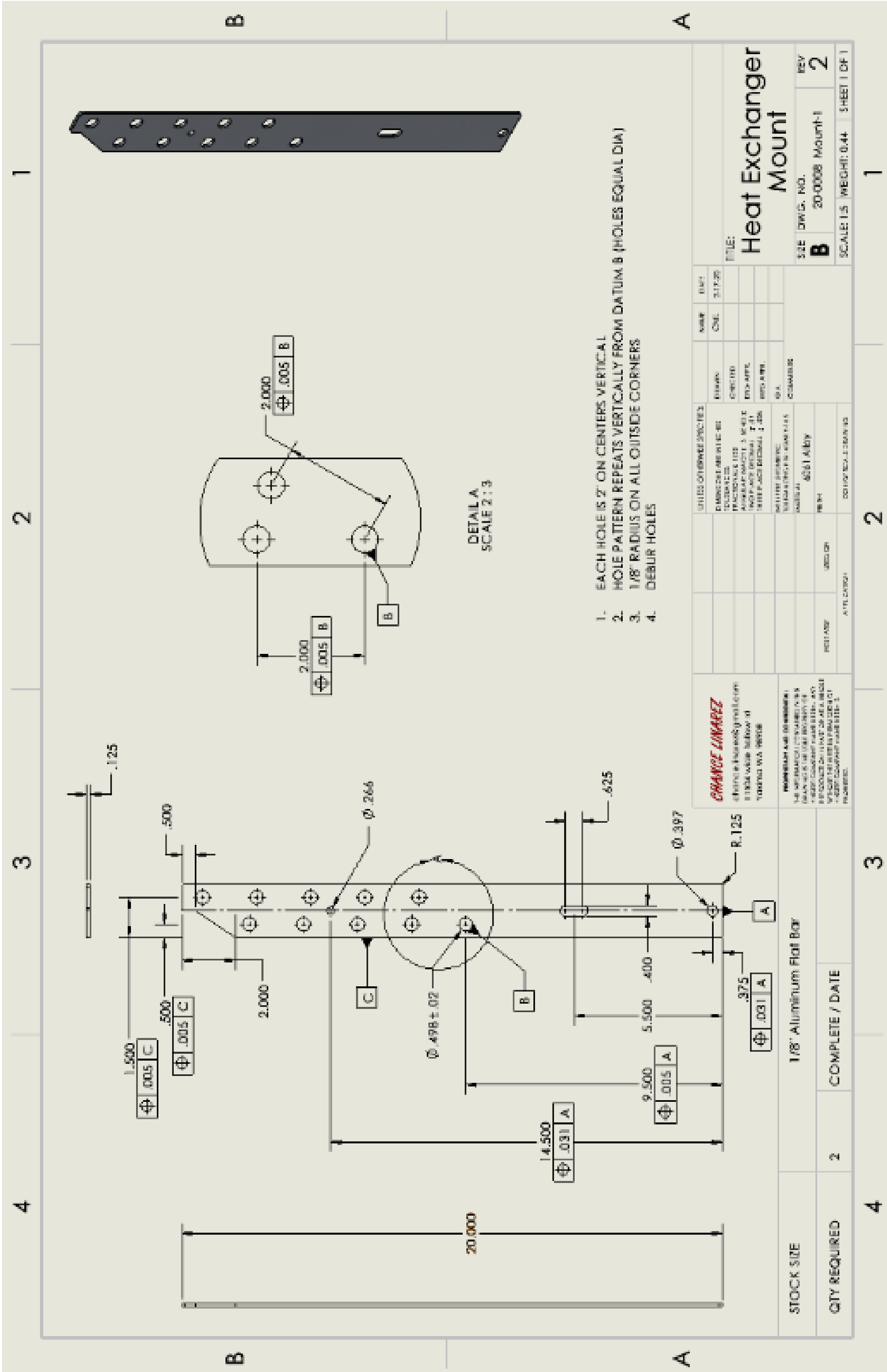
B-4 – Water Manifold Pipe 2



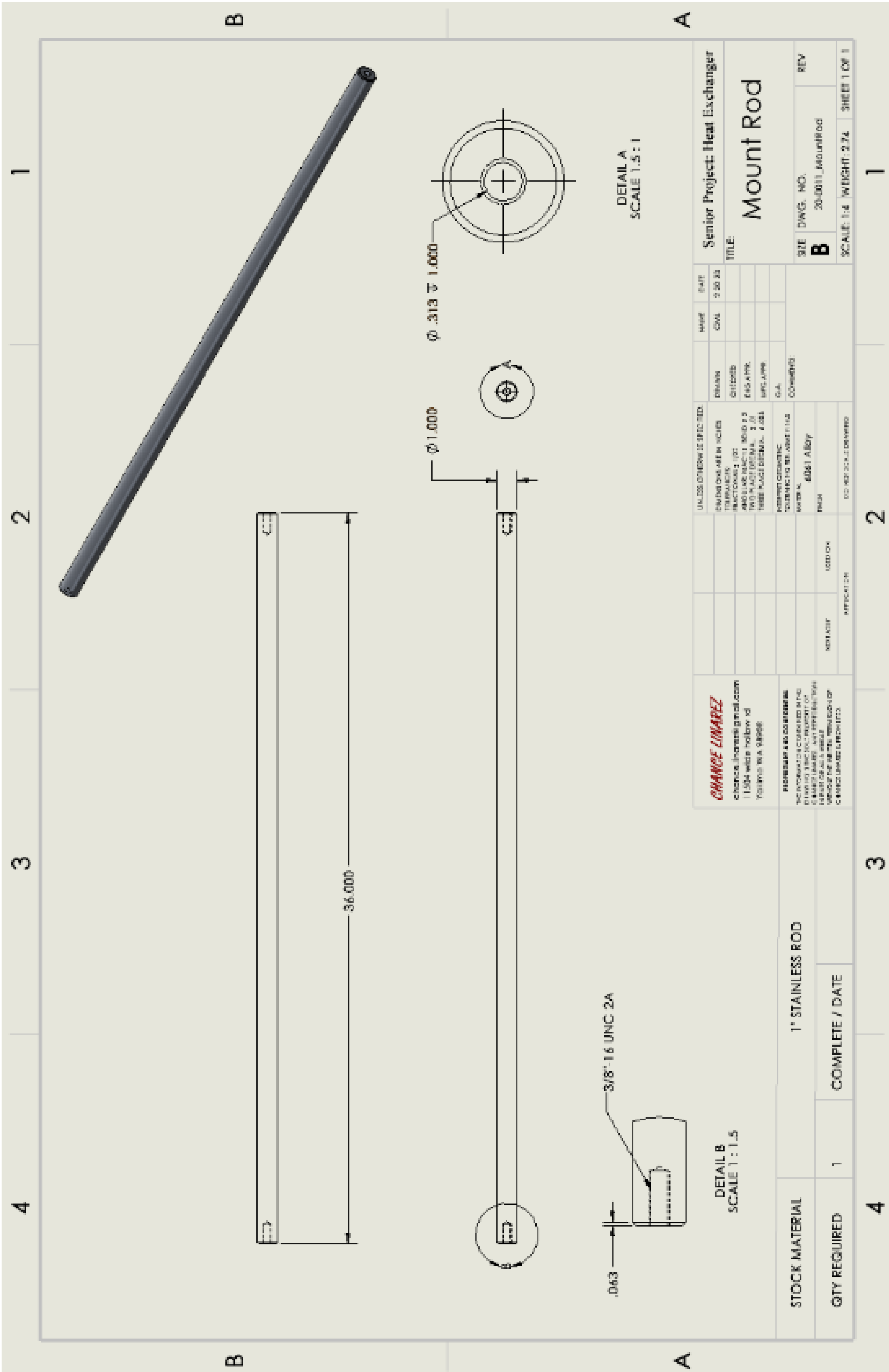
B-5 – Water Manifold Pipe Part 3



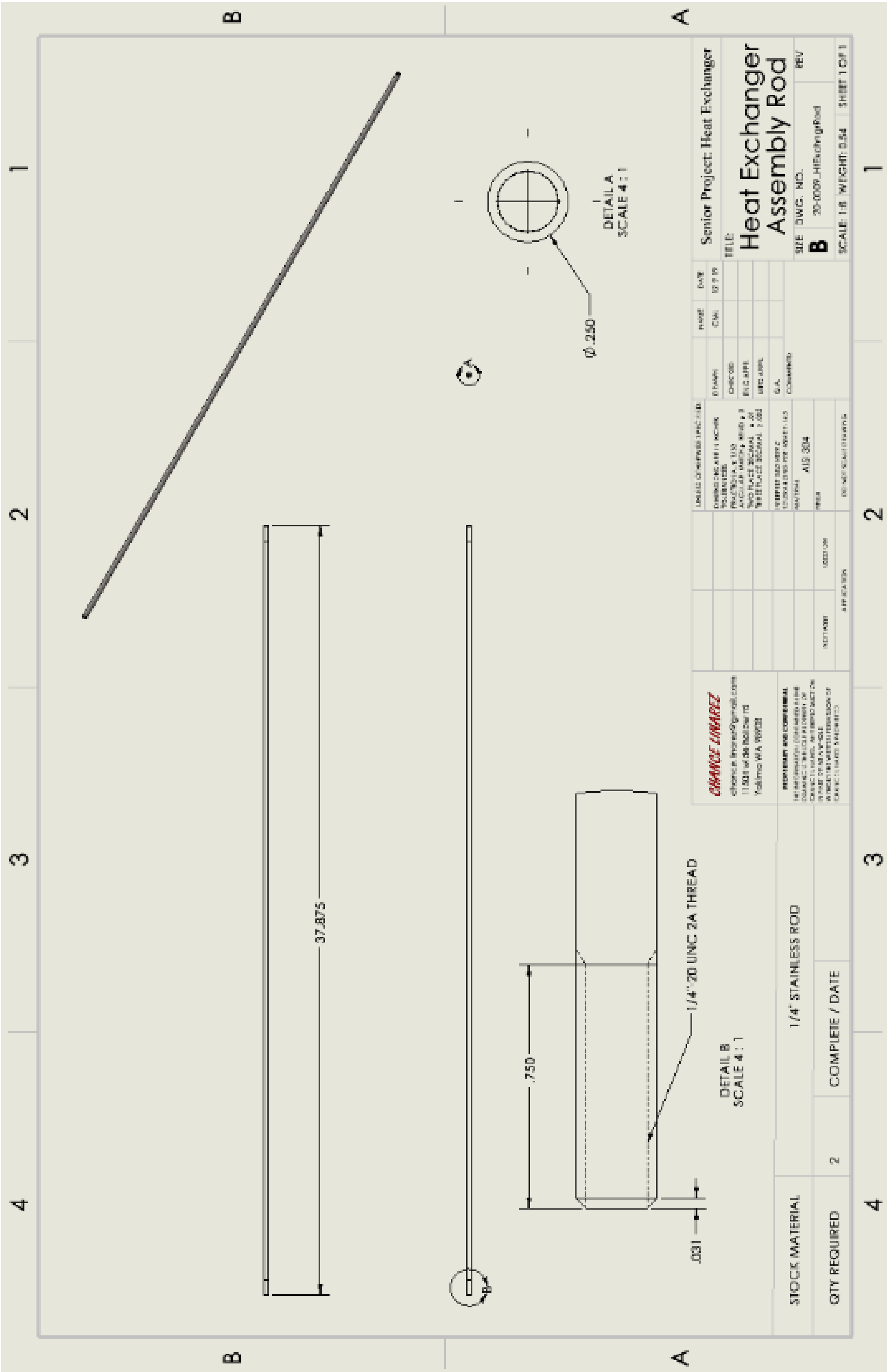
B-6 – Heat Exchanger Mount Part



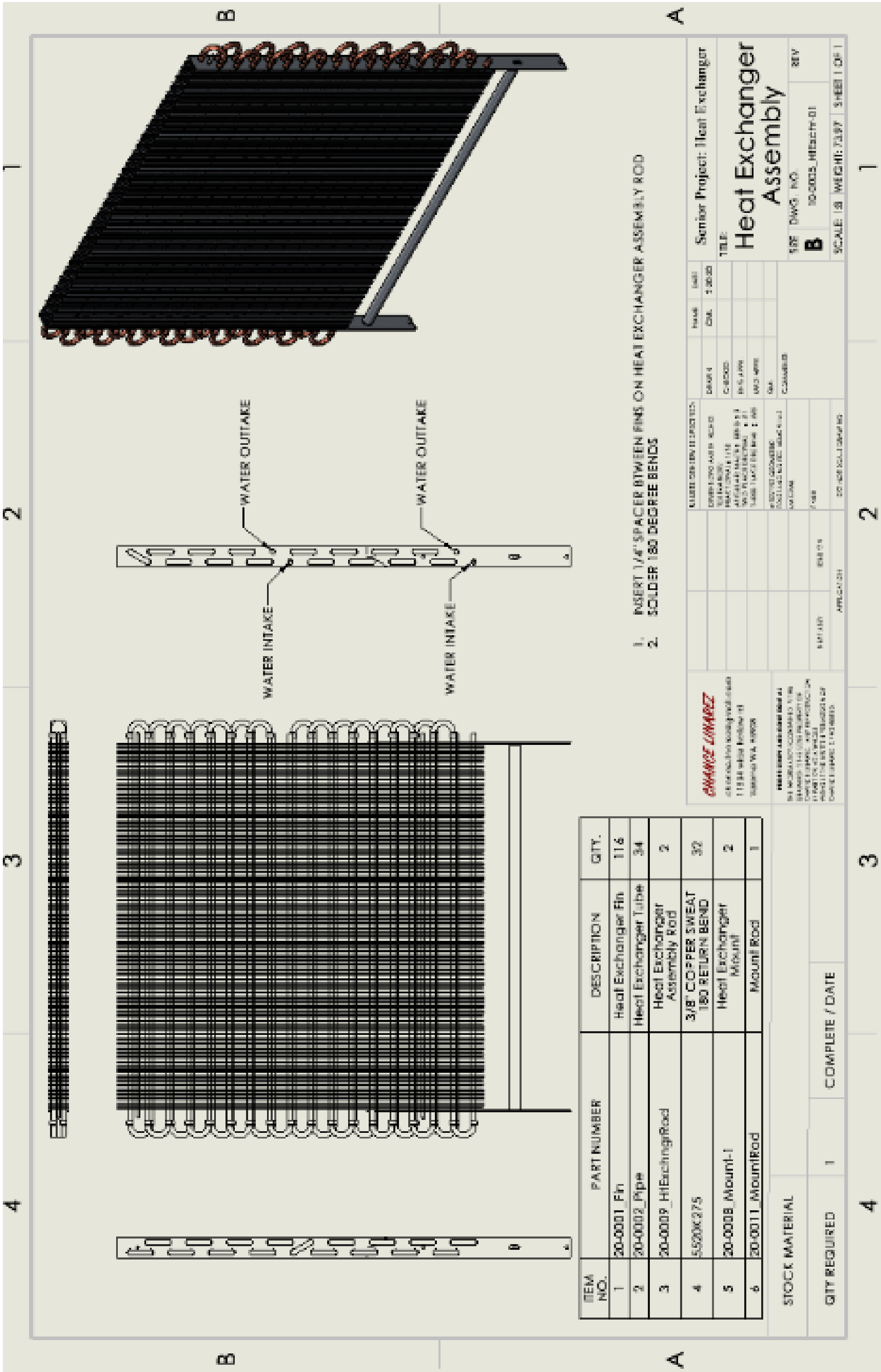
B-7 – Mount Rod Part



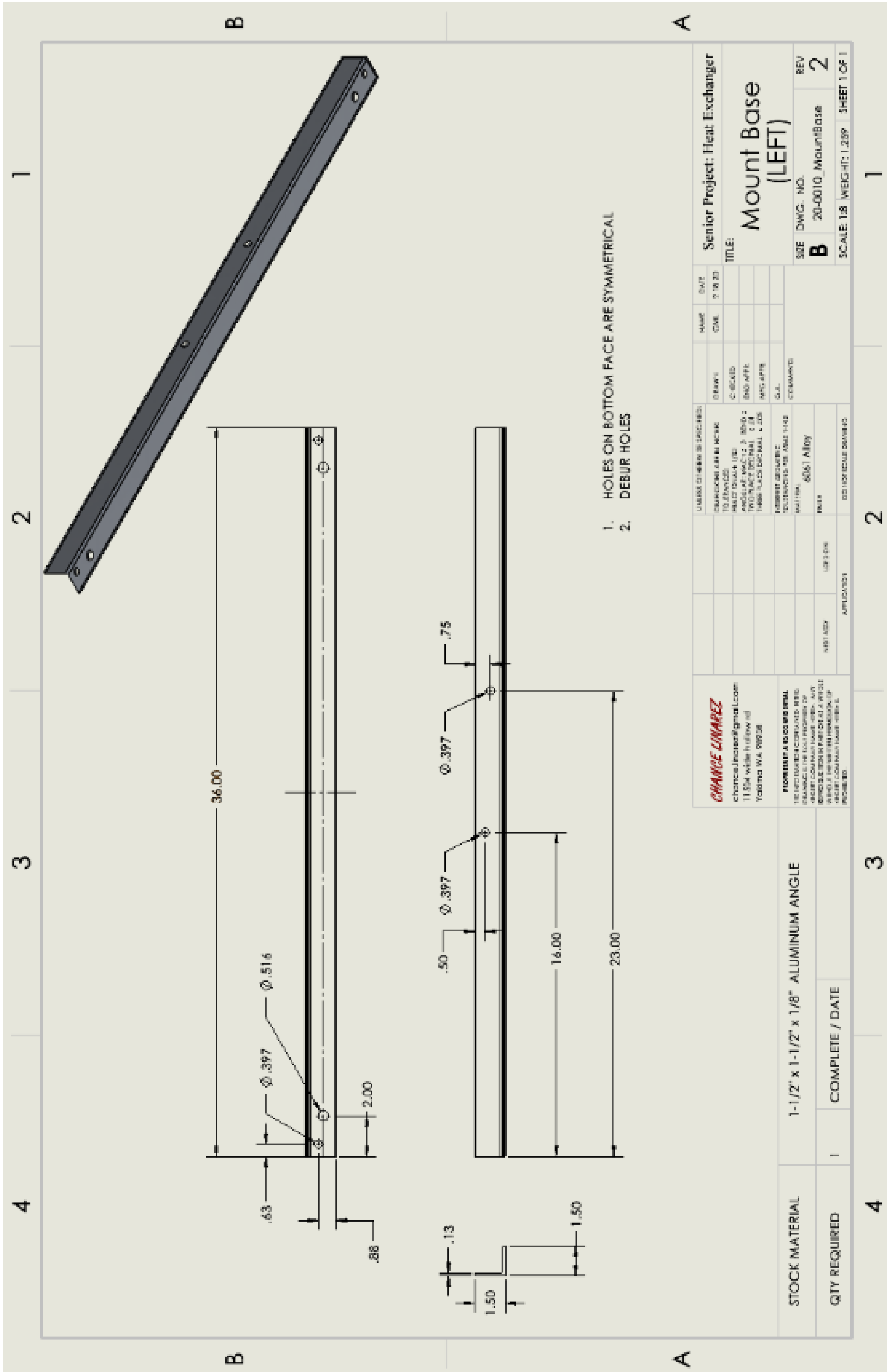
B-8 – Heat Exchanger Assembly Rod



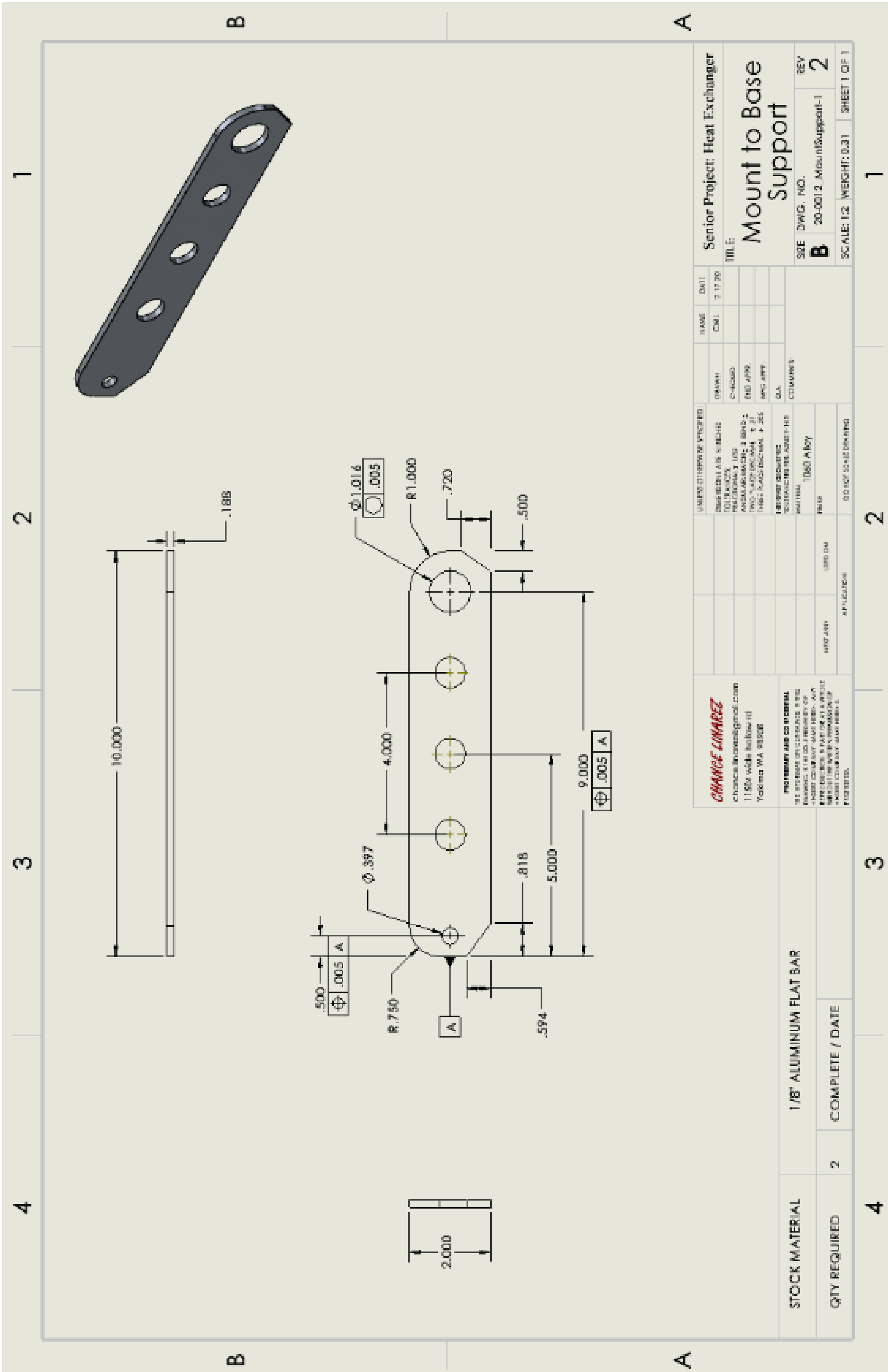
B-9 – Heat Exchanger Assembly



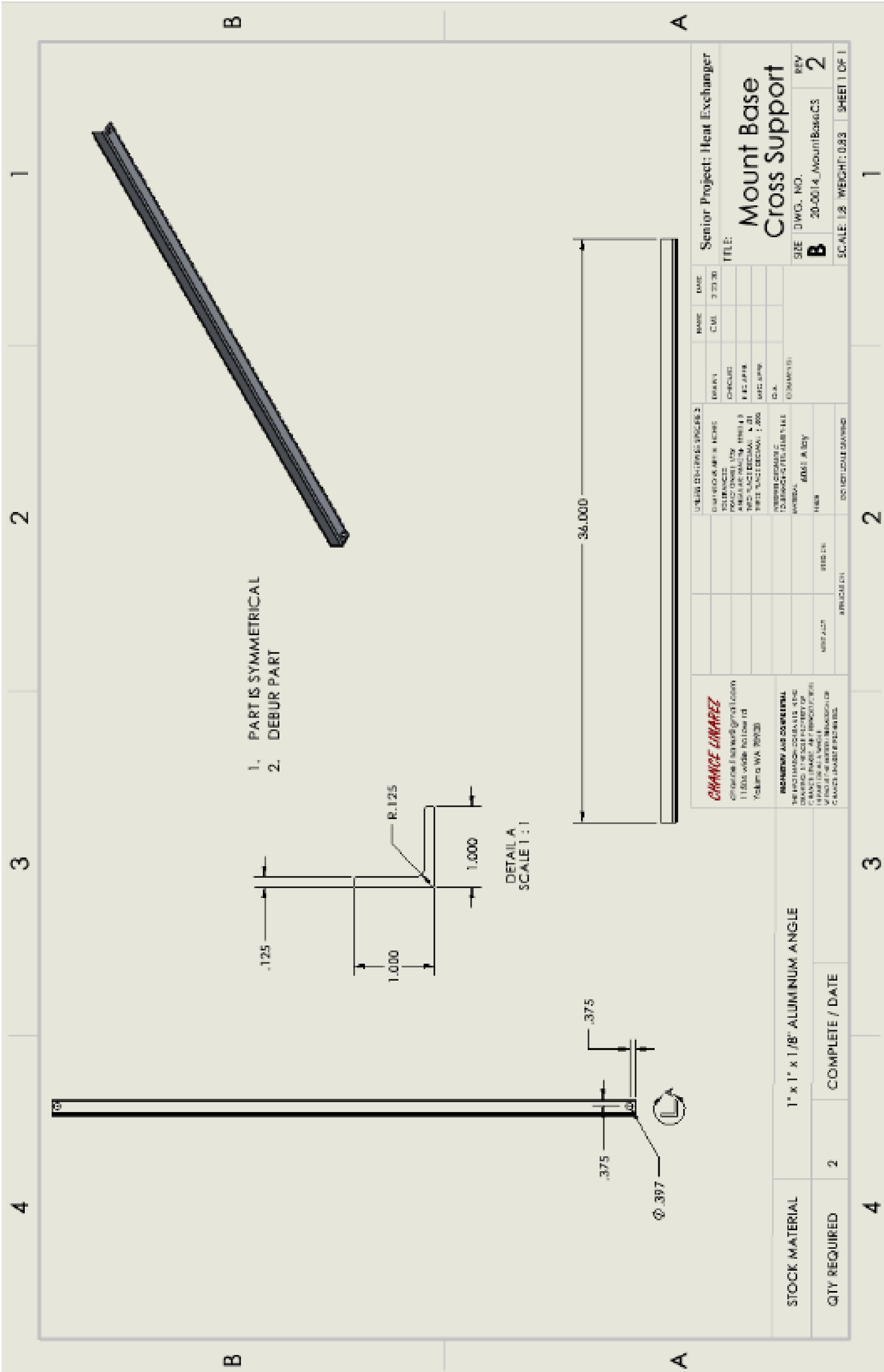
B-10 – Heat Exchanger Mount Base Part (Left)



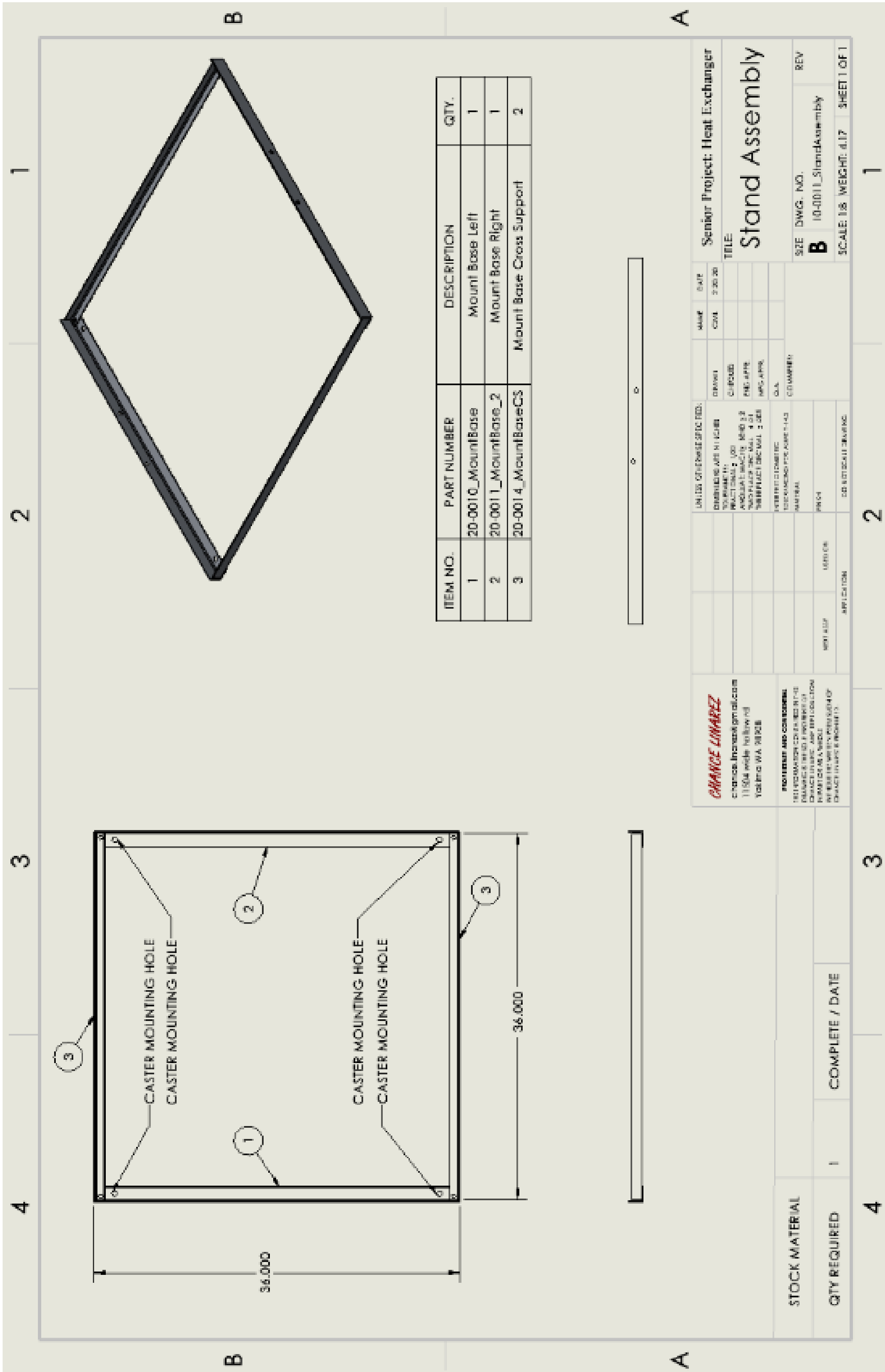
B-11 – Heat Exchanger Mount to Base Support Part



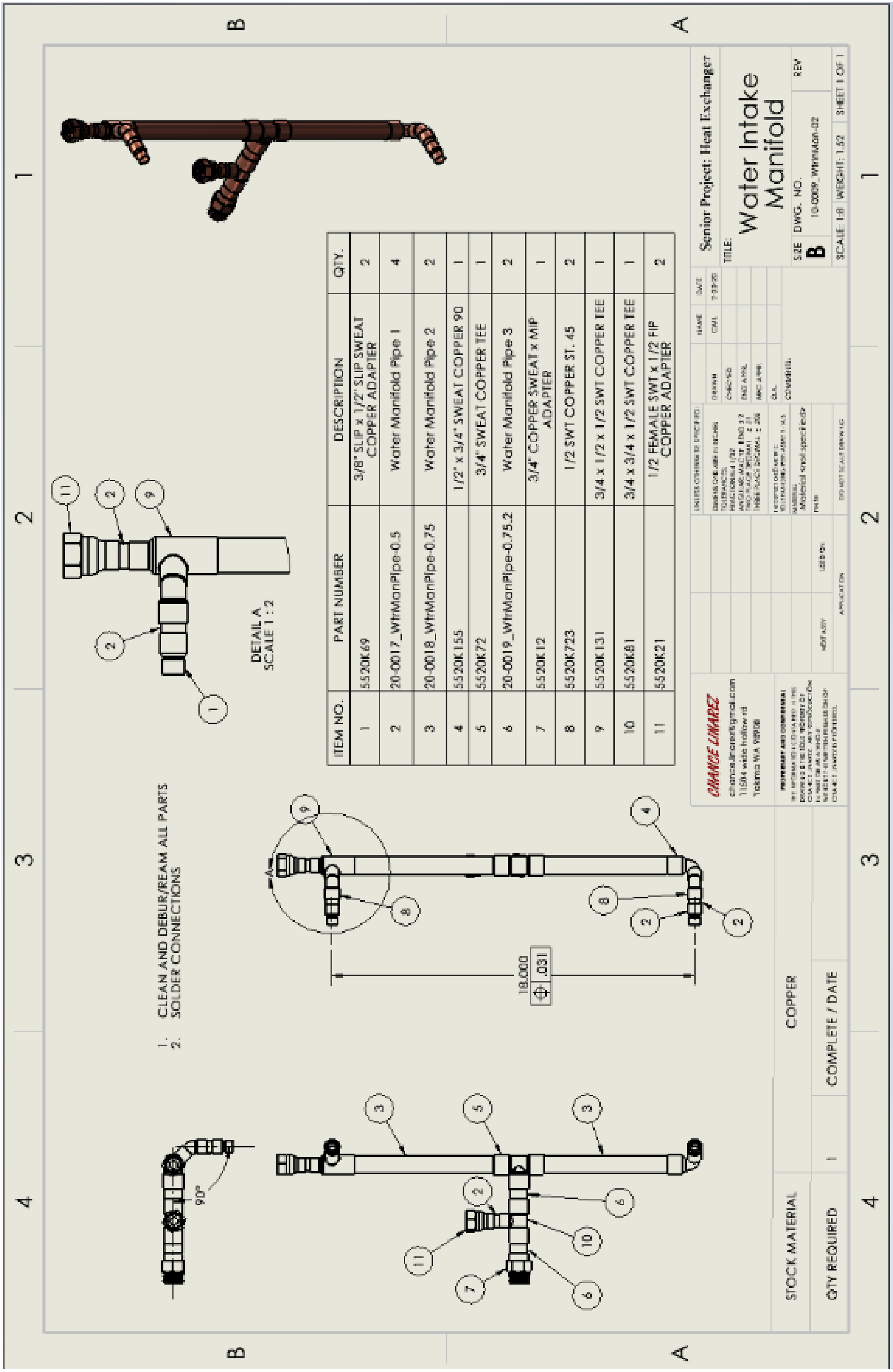
B-12 – Base Cross Support Part



B-13 – Mount Base and Caster Plate Assembly

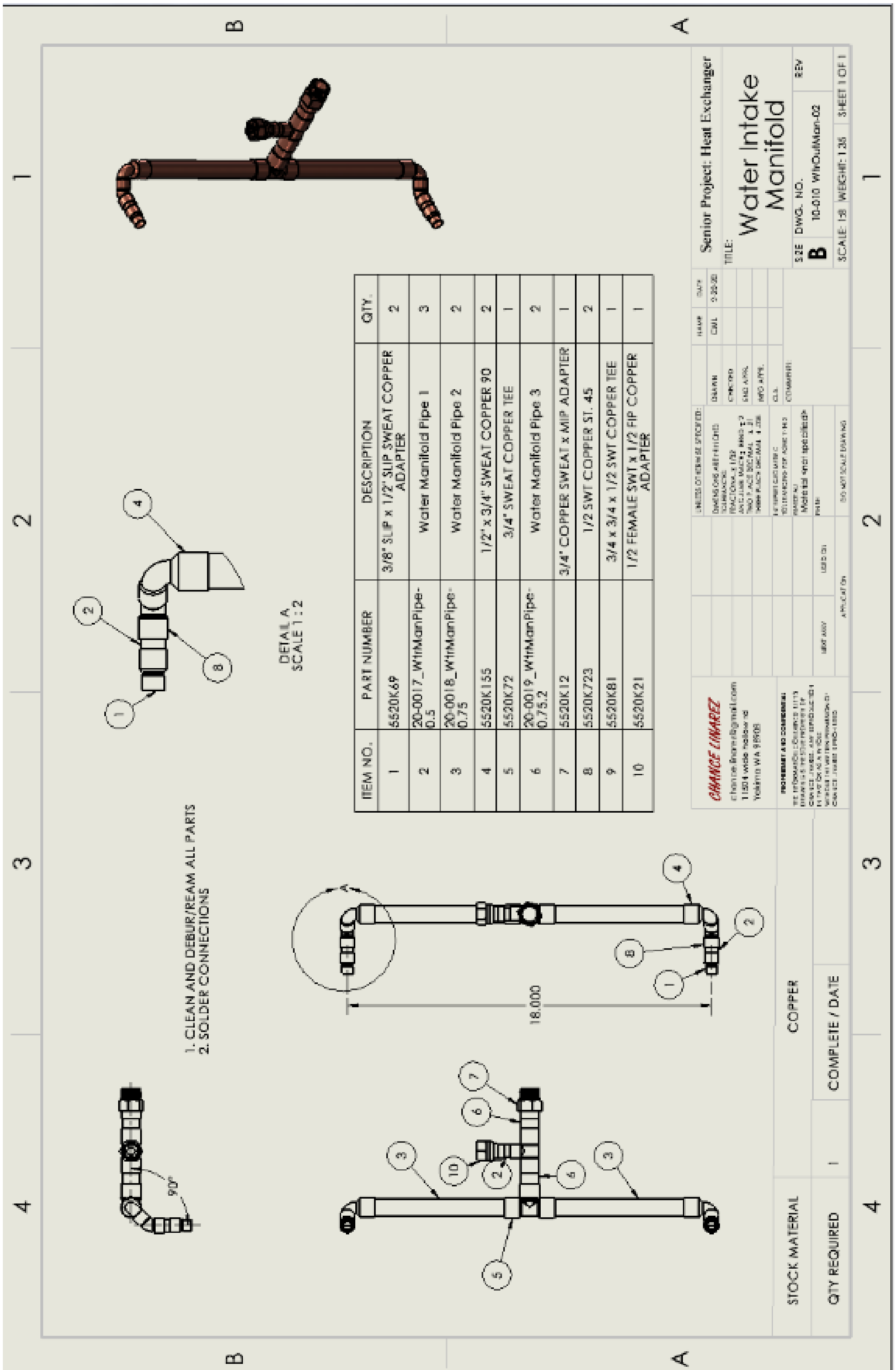


B-14 – Water Intake Manifold Assembly

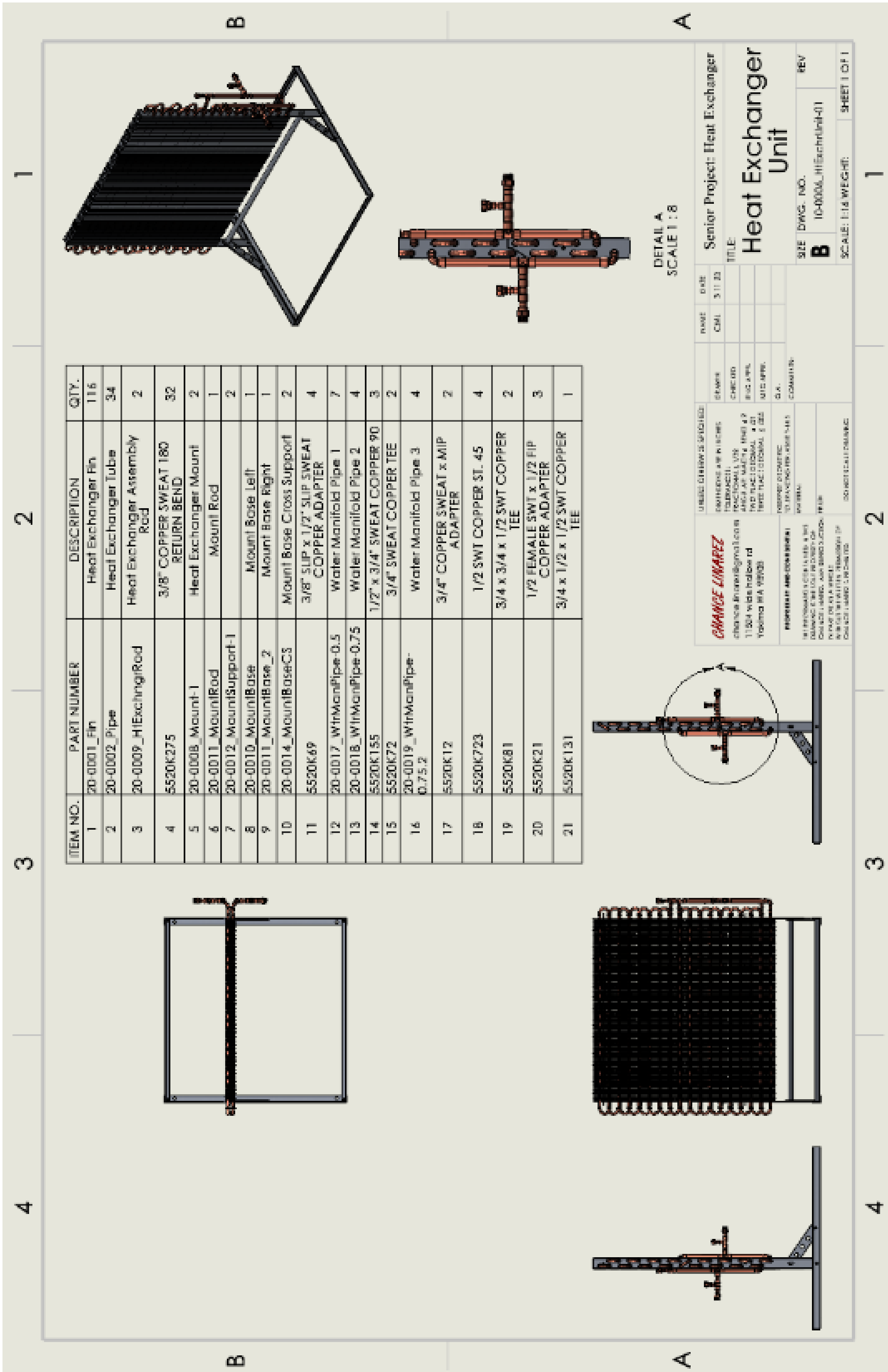


ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	5520K69	3/8" SLIP x 1/2" SLIP SWEAT COPPER ADAPTER	2
2	20-0017_WtrManPipe-0.5	Water Manifold Pipe 1	4
3	20-0018_WtrManPipe-0.75	Water Manifold Pipe 2	2
4	5520K155	1/2" x 3/4" SWEAT COPPER 90	1
5	5520K72	3/4" SWEAT COPPER TEE	1
6	20-0019_WtrManPipe-0.75.2	Water Manifold Pipe 3	2
7	5520K12	3/4" COPPER SWEAT x MIP ADAPTER	1
8	5520K723	1/2 SWT COPPER ST. 45	2
9	5520K131	3/4 x 1/2 x 1/2 SWT COPPER TEE	1
10	5520K81	3/4 x 3/4 x 1/2 SWT COPPER TEE	1
11	5520K21	1/2 FEMALE SWT x 1/2 FIP COPPER ADAPTER	2

B-15 – Water Outtake Manifold Assembly



B-16 – Heat Exchanger Unit Assembly



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	20-0001_Fin	Heat Exchanger Fin	116
2	20-0002_Pipe	Heat Exchanger Tube	34
3	20-0009_HtExchngrRod	Heat Exchanger Assembly Rod	2
4	5520K275	3/8" COPPER SWEAT 180 RETURN BEND	32
5	20-0008_Mount-1	Heat Exchanger Mount	2
6	20-0011_MountRod	Mount Rod	1
7	20-0012_MountSupport-1		2
8	20-0010_MountBase	Mount Base Left	1
9	20-0011_MountBase_2	Mount Base Right	1
10	20-0014_MountBaseCS	Mount Base Cross Support	2
11	5520K69	3/8" SLIP x 1/2" SLIP SWEAT COPPER ADAPTER	4
12	20-0017_WtrManPipe-0.5	Water Manifold Pipe 1	7
13	20-0018_WtrManPipe-0.75	Water Manifold Pipe 2	4
14	5520K155	1/2" x 3/4" SWEAT COPPER 90	3
15	5520K72	3/4" SWEAT COPPER TEE	2
16	20-0019_WtrManPipe-0.75.2	Water Manifold Pipe 3	4
17	5520K12	3/4" COPPER SWEAT x MIP ADAPTER	2
18	5520K723	1/2 SWT COPPER ST. 45	4
19	5520K81	3/4 x 3/4 x 1/2 SWT COPPER TEE	2
20	5520K21	1/2 FEMALE SWT x 1/2 FIP COPPER ADAPTER	3
21	5520K131	3/4 x 1/2 x 1/2 SWT COPPER TEE	1

APPENDIX C

Parts List

Item ID	Item Description	Item Source	Model/SN
1	16ga 1060 AL sheet (48x120)	McMaster-Carr	
2	3/8" Copper 180 female connector	McMaster-Carr	5520K275
3	3/8" Copper Pipe Type M (10' stick)	Grainger	
4	Aluminum flat bar	Ace	
5	1-1/2"x1-1/2"x 1/8" Aluminum angle	Ace	
6	1" x 1" x 1/8" aluminum angle	Ace	
7	Casters	McMaster-Carr	2835T35
8	Pump	McMaster-Carr	
9	Fin Spacers	McMaster-Carr	94729A215
10	1/4" Aluminum rod	Ace	
11	Fan	Grainger	

APPENDIX D
Budget

	Budget for Senior Project							
	Heat Exchanger							
								0.08
tem ID	Item Description	Item Source	Model/SN	Price/Cost $	QTY or Hours	Subtotal $	Tax $	TOTAL $
1	16ga 1060 AL sheet (48x120)	McMaster-Carr		55.47	3	166.41	13.65	180.06
2	3/8" Copper 180 female connector	McMaster-Carr	5520K275	3.73	30	111.9	9.18	121.08
3	3/8" Copper Pipe Type M (10' stick)	Grainger		15.4	11	169.4	13.89	183.29
4	Aluminum flat bar	Ace		16	2	32	2.62	34.62
5	1-1/2"x1-1/2"x 1/8" Aluminum angle	Ace		20	2	40	3.28	43.28
6	1" x 1" x 1/8" aluminum angle	Ace		14	2	28	2.30	30.30
7	Casters	McMaster-Carr	2835T35	2.99	4	11.96	0.98	12.94
8	Pump	McMaster-Carr		249.99	1	249.99	20.50	270.49
9	Fin Spacers	McMaster-Carr	94729A215	6.78	15	101.7	8.34	110.04
10	1/4" Aluminum rod	Ace		12	2	24	1.97	25.97
11	Fan	Grainger		170	1	170	13.94	183.94
	hose adapter fittings	Ace		5.99	1	5.99	0.49	6.48
	hose end fitting	Ace		4.99	1	4.99	0.41	5.40
	test equipment			80	1	80	6.56	86.56
	Est. Total $	**PROJECT TOTAL $**						
	1116.34	1294.44						

APPENDIX E

Schedule

SCHEDULE FOR SENIOR PROJECT:

Started on Time

Started Late

Note: March x Finals

Note: June x Presentation

Note: June y-z Spr Finals

PROJECT TITLE: Heat Exchanger

Principal Investigator.: Chance Linarez

x' marks that Task was being worked on during that week.

TASK: ID	Description	Duration Est. (hrs)	Actual (hrs)	%Com	S	October	November	Dec	January	February	March	April	May	June
1	Proposal*													
1a	Outline	2	1.5			x x								
1b	Intro	1	1			x x								
1c	Methods	1	1			x	x x							
1d	Analysis	6	12			x x x x	x x x x							
1e	Discussion	2	1				x x x	x						
1f	Parts and Budget	2	1				x x x x	x						
1g	Drawings	18	20			x x x	x x x x	x x	x					
1h	Schedule	2	1.2				x x x	x						
1i	Summary & Appx	2	1			x x	x x x x	x						
	subtotal:	36	39.7											
2	Analyses													
2a	Heat Trans	12	12			x x	x x x x	x						
2b	Stress Anal	1	1				x							
2c	Power Anal	1	0											
2d	Kinematic	1	0											
2e	Tolerance	1	0											
	subtotal:	16	13											
3	Documentation													
3a	20-0001_Fin	2	3.1			x	x							
3b	20-0002_Pipe	0.5	0.8			x								
3c	20-0003_LongPipe	2	0.3			x	x x							
3d	20-0003_ShortPipe	1	0.3				x x							
3e	20-0004_LongPipe	2	0.3				x x							
3f	20-0005_LongPipe	1	0.3				x x x	x x	x x					
3g	20-0006_ManTopPipe	1	0.3				x x x	x x	x x					
3h	20-0007_ManBtmPipe	1	0.3				x x							
3i	20-0008_Mount	2	2.5				x x							
3j	20-0009_HtExchangrRod	2	1				x							
3k	20-0010_MountBase	1	2				x							
3l	20-0011_MountRod	1	0.8				x x x							
3m	20-0012_MountSupport	1	0.8				x x							
3n	20-0013_CasterPlate	1	0.3				x							
3o	20-0014MountBaseCS	1	0.3				x x							
3p	10-0002_FinTubeFittings	1	1				x x							
3q	10-0003_WtrInMan	1	1.3				x							
3r	10-0004_WtrOutMan	1	0.8				x x							
3s	10-0006_HtExchrUnit	2	1				x x							
3t	10-0007MntBasCstrPlt	1	0.8				x x							
3u	20-0016_ShroudSideMnt	1	0.5						x					
3v														
3w														
3x														
3y														
3z														
3l	ANSIY14.5 Compl	5	3					x x	x					
3m	Make Object Files	2	1				x x							
	subtotal:	33.5	22.8											

TASK: ID	Description	Est. (hrs)	Actual (hrs)	%Com	S	October	November	Dec	January	February	March	April	May	June
4	Proposal Mods													
4a	Project Schedule	2	2						x x					
4b	Project Parts	4	2						x x					
4c	Design Review	2	1						x x					
	subtotal:	8	5											

TASK: ID	Description	Est. (hrs)	Actual (hrs)	%Com	S	October	November	Dec	January	February	March	April	May	June
7	Part Construction													
7a	20-0001	14	10							x				
7b	20-0002	6	0.9						x	x				
7c	20-0008	2	1.2							x x				
7d	20-0009	1	0.6							x				
7e	20-0010 R&L	1	1							x				
7f	20-0012	1	1							x				
7g	20-0014	1	0.2							x				
7h	20-0016	3	0.6						x					
7i	20-0017	2	0.5							x				
7j	20-0018	3	0.5							x				
7k	20-0019	1	0.5							x				
7l														
7m														
7n														
7o														
	subtotal:	35	17											

TASK: ID	Description	Est. (hrs)	Actual (hrs)	%Com	S	October	November	Dec	January	February	March	April	May	June
9	Device Construct													
9a	Assemble Fin and Tubes	4	7							x x	x			
9b	Assemble Manifolds	2	1.5							x				
9c	Assemble Ht. Exchanger	6	9							x	x x			
9d	Assemble Stand	2	0.1							x				
9e	Take Dev Pictures	0.5	0.1							x x				
9f	Update Website	1	3						x					
	subtotal:	15.5	20.7											
10	Device Evaluation													
10a	List Parameters	1	0.5									x		
10b	Design Test&Scope	8	2									x		
10c	Obtain resources	2	1									x		
10d	Make test sheets	2	1							x		x x		
10e	Plan analyses	2	0.5											
10f	Instrument Robot													
10g	Test Plan*	1	4									x x	x	
10h	Perform Evaluation	2	5.8									x	x x	
10i	Take Testing Pics	0.5	0.3									x		
10h	Update Website	2												
	subtotal:	20.5	15.1											

TASK: ID	Description	Est. (hrs)	Actual (hrs)	%Com	S	October	November	Dec	January	February	March	April	May	June
11	495 Deliverables													
11a	Get Report Guide	0.5	0.2								x			
11b	Make Rep Outline	1	1										x	
11c	Write Report	4	9						x x x x	x x x	x x	x x	x x x	x
11d	Make Slide Outline	1	4.8									x x x	x x	
11e	Create Presentation	5	5.5									x x x x	x x x	
11f	Make CD Deliv. List	1												
11e	Write 495 CD parts	1												
11f	Update Website	2	3.2									x x	x x	x
11g	Project CD*													
	subtotal:	15.5	23.7											
	Total Est. Hours=	180	157				=Total Actual Hrs							
Labor$	100	18000												

Note: Deliverables*

- Draft Proposal
- Analyses Mod
- Document Mods
- Final Proposal
- Part Construction
- Device Construct
- Device Evaluation
- 495 Deliverables

APPENDIX F

Expertise in setting up DXF files for the water jet will was used from members at Precision Industrial Equipment.

Methods of machining parts was guided by members of Precision Industrial Equipment.

Methods of soldering and assembly was guided by Anthony Linarez.

Appendix G

Testing Report:

The heat exchanger must keep 2000 gallons of water below 100 degrees Fahrenheit, maintain cooling in 40 to 100-degree Fahrenheit environments, be able to operate 12 hours a day. The main parameter of interest is to find the heat transfer rate of the heat exchanger. Calculations predict that it will have a heat transfer rate of 11.76 kW. Data will be collected with thermocouples and various other equipment. Tests on other aspects of the heat exchanger will be done as well like withstanding pressure, being deemed portable, and testing the stand construction to see if it can withstand continuous weight and use. Testing the heat exchanger will take an estimated 20.5 hours. The testing schedule can be seen in the Gantt chart at the end of this report.

Tests to be conducted include:

1. Rate of Heat Transfer
2. Pressure Test
3. Transportability
4. Stand Deflection

Test Report: Method/Approach:

Resources required for this test are a 100-gallon tank, a circulating pump, heat source (wood stove or large propane burner), Microsoft excel, flow meter, thermocouple, pressure gauge, measuring tape.

Test 1

Data will be collected using built in thermometers in the manifolds of the heat exchanger and a thermocouple will be used to measure air temperature leaving surface of heat exchanger, water temperature and ambient air temperature.

The heat exchanger will be tested by placing a temperature probe in the water intake manifold and a temperature probe in the water outtake manifold. This will show how much heat is being taken out of the water by the heat exchanger. The hot water source will be a tank of water that is heated to 120-150 degrees Fahrenheit and the cooled water will be returned to the tank so a rate can be determined of how long it took the heat exchanger to cool X amount gallons of water to a desired temperature. To heat the water to a much higher temperature, the tank will sit on a propane burner. The goal will be to have the water enter the heat exchanger at a temperature higher than 120 degrees Fahrenheit. Data described in the next section will be collected to determine the rating of the heat exchanger in kW or Btu/hr.

Operational limitations of testing this device will be tank size, a 100-gallon water tank will be used. The accuracy of temperature taken will be ± 1.5° Fahrenheit. Data will be recorded on paper and the data will be used in calculating heat transfer rate and overall heat transfer coefficient. The results will be put into Microsoft excel to graph temperature vs time and present the data taken.

Test 2

To test pressure the heat exchanger should be able to withstand, the manifolds will be capped off and a pressure gauge with an air valve will be applied. The heat exchanger will be pressurized to 100 psi using an air compressor and left standing. If pressure holds without dropping for 30 min the test will be a success.

Test 3

To test heat exchanger movability, it will be moved across various surfaces such as smooth cement floor, asphalt, and gravel. The heat exchanger should be able to withstand those types of rolling surfaces when be used in the workplace.

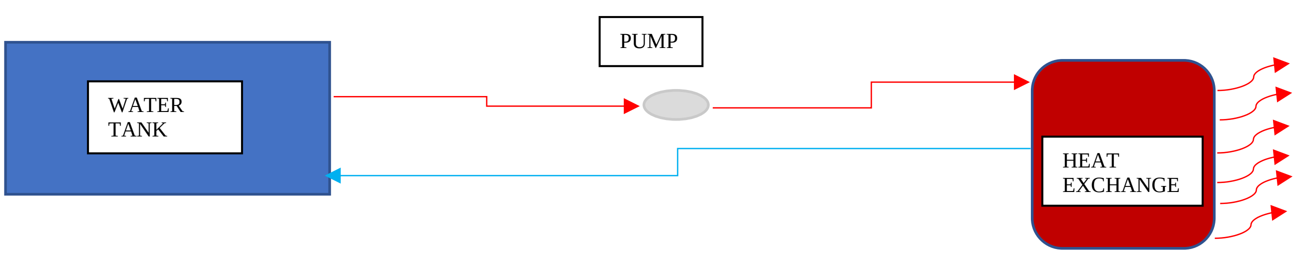
Test 4

To test stand deflection, the heat exchanger will be put on a flat smooth surface such as cement. All the weight will be taken off the heat exchanger stand and a measurement will be taken from the ground to the bottom of the stand angle at the location where the mount part assembles to the stand angle part. Then more components of the heat exchanger will be added such as fan, pump, and water. After each component is added deflection will be measured and recorded.

Test Report: Test Procedures:

Test 1

Figure 1: Test setup



The testing of the heat exchanger will be done midday at home shop. Testing and setup will likely take 8 hours to complete.

Specific actions of test:

(All the following **test 1** procedures MUST be done on the same day so ambient air is close to the same temperature for each procedure)

1. Set up equipment as seen in figure 1 and 2.
2. Fill tank with water and begin heating using propane burner.
3. Measure and record ambient air temperature.
4. Begin step 5 once tank water stabilizes at a temperature between 120-200 degrees Fahrenheit.
5. Start fan on heat exchanger and turn pump on.
6. Measure and record water flow rate and air volume flow rate.
7. Measure and record tank water temperature.
8. Repeat step 6 every 5 minutes.

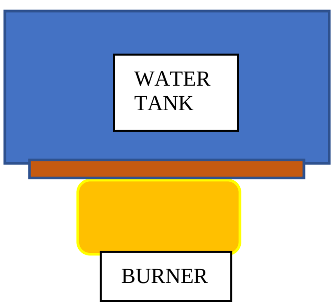


Figure 2: Heating water

Heating the water using a propane burner can be dangerous due to the water and hot copper can cause serios burns. Tank water will be a risk when hot as well. Tank should be on a flat surface to prevent from any tipping or splashing. Gloves and safety glasses are required to perform this test.

Test 2

1. Install ¾" NPT cap onto water outtake manifold
2. Install pressure test gauge onto water inlet manifold
3. Use air compressor and pressurize the heat exchanger until gauge reads 100 psi.
4. Wait for 30 minutes
5. Check gauge pressure
6. If gauge pressure shows 100 psi, test complete.
7. If gauge pressure has dropped, use spray bottle with water and soap and spray fitting connections until leak is found.
8. Once leak is found, repair and return to step 3.

Test 3

1. Clear a 20 x 10 ft area of floor space on concrete
2. Roll unit back and forth to test if casters roll/pivot
3. If the heat exchanger unit feels rigid proceed to step 5
4. If heat exchanger does not roll or pivot, replace casters and return to step 2.
5. Roll heat exchanger across gravel
6. Be sure to check bolts in stand along with casters to confirm bolts have not loosened and casters do not come loose.
7. Replace and tighten bolts as necessary and return to step 5
8. Inspect mount and stand for any bends or deformation.
9. If stand deformation occurs, inspect part to see if a new design or part is necessary.
10. If no bends or deformation, test complete.

Test 4

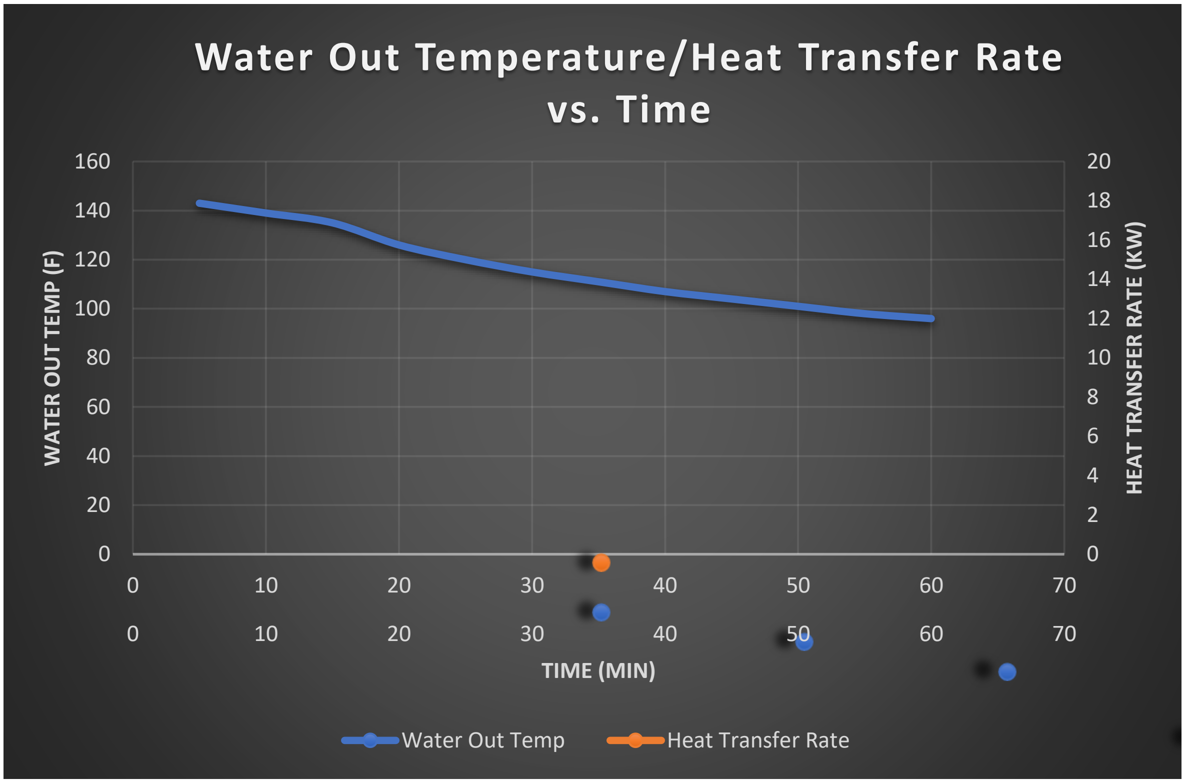
1. Place heat exchanger on level rigid surface. Concrete will work well.
2. Remove fan, pump, and drain all water from heat exchanger.
3. Measure distance from floor to bottom of heat exchanger stand next to where the mount assembles to the stand. This is close to center of stand where deflection will be the greatest.
4. Assemble fan to heat exchanger and record stand deflection.
5. Install pump and hoses back onto heat exchanger and record stand deflection
6. Fill heat exchanger with water and record stand deflection.
7. Compare predicted deflection with actual. If stand deflection is over 0.125”, stand redesign is recommended.

Test Report: Deliverables:

Test 1:

The above procedures will provide a test that will deliver data on how well and how much faster the heat exchanger cools a given amount of water as a replacement for of letting the water cool to the surrounding air. The test will be considered a success if the heat exchanger has a heat transfer rate of 20kW.

Predictions of test 1 were the heat exchanger should have a heat transfer rate of 24kW in the given conditions. The actual heat transfer rate that was calculated from raw data was a maximum of 18.7kW. This is close to 20kW but failed to meet the required heat transfer rate. The heat exchanger failed to meet the required heat transfer rate because all calculations and design choices were assuming an ideal heat exchanger and this heat exchanger has construction flaws that impact its performance and reduce its rating.



Test 2:

The pressure test was a success after repairing a small leak that was found on one of the 180-degree copper fittings. It was predicted that the heat exchanger would hold 100 psi, but after pressurizing to 100 psi a leak was detected. Once repaired the heat exchanger held 100 psi for over 30 minutes. This test provides a physical performance parameter of the heat exchanger. It can be recorded that max working pressure is 100 psi. although the fittings and soldered connections are rated for a pressure of 250 psi, the unit was not tested at pressure that high.

Test 3:

Transportability of the heat exchanger unit was an important test to ensure the device would not break or fall apart when used in the field. There were no issues when performing this test.

Test 4:

Stand deflection provides analysis of how much the angle part of the stand deflects. This part supports all the weight of the heat exchanger and is essential it does to deform to the point of failure. Calculated predictions showed that the angle would deflect 0.116 inches. This amount of deflection would remain ok if deflection did not exceed this. This test needed to show a deflection of no more than 0.125 inches to be considered a success. Actual deflection of angle part came to be 0.095 inches. This test proved the stand to be a success.

Useful equations:

$Q_{dot} = m_{dot}C_p(T_{in} - T_{out})$

Page 994 in *Fundamentals of Thermal-Fluid Sciences* Textbook

*Properties of water used from appendices of *Fundamentals of Thermal-Fluid Sciences*

$Y_{max} = \frac{-PL^3}{48EI}$

Page 801 in *Machine Elements of Mechanical Design*

Appendix G1 - Procedure checklist

Required Items	**In possession (yes/no)**
Water tank	Yes
3-5 gpm pump	Yes
Heat exchanger	Yes
Water flow meter	Yes
Air flow meter	Yes
Thermocouple	Yes
Propane and propane burner	Yes
All required PPE	Yes
Data collection sheets	Yes
Measuring tape, caliper, or ruler	Yes

Appendix G2 - Data Forms

Ambient Air Temperature	
Flow Rate of Water	
Flow Rate of Air	

TEST: Tank Water Temperature (°F)	Air Leaving Heat Exchanger Surface (°F)	Water Intake Temperature (°F)	Water Out Temperature (°F)	Pass/No pass
5 min 143				
10 min				
15 min				
20 min				
25 min				
30 min				
35 min				
40 min				
45 min				
50 min				
55 min				
60 min				

Appendix G2.1

Approximated weight	Initial Distance (in)	Measured Distance (in)	Deflection (in)	Pass/No Pass
Stand (0lb)				
Heat exchanger (80lb)				
Fan and Pump (100lb)				
Water (110lb)				

Appendix G3 – Raw data

Test 1 Raw Data

Ambient Air Temperature (°F)	68
Flow Rate of Water (GPM)	6
Flow Rate of Air (CFM)	1200

TEST: Tank Water Temperature (°F)	Air Leaving Heat Exchanger Surface (°F)	Water Intake Temperature (°F)	Water Out Temperature (°F)	Rate of heat transfer (kW)	Pass/No pass
5 min 143	82	143	123	18.7	No Pass
10 min 139	85	139	121		
15 min 135	85	135	118		
20 min 126	76	126	110	14kW	No Pass
25 min 120	75	120	106		
30 min 115	74	115	104		
35 min 111	73	111	101		
40 min 107	71	107	99	7.8kW	No Pass
45 min 104	70	104	96		
50 min 101	71	101	93		
55 min 98	74	98	91		
60 min 96	71	96	89	7.8kW	No Pass

Appendix G3.1

Test 2 Raw Data

Approximated weight	Initial Distance (in)	Measured Distance (in)	Deflection (in)	Pass/No Pass
Stand (0lb)	4.389	4.389	0	Pass
Heat exchanger (80lb)	4.389	4.297	0.078	Pass
Fan and Pump (100lb)	4.389	4.288	0.087	Pass
Water (110lb)	4.389	4.280	0.095	Pass

Appendix G4 – Evaluation sheets

Test 1

3-0237 — 200 SHEETS — 5 SQUARES
3-0137 — 200 SHEETS — FILLER

GIVEN: SURROUNDING AIR : 68°F = 20°C
RAW DATA FROM TEST
TANK WATER INITIALLY AT 66°C + MAINTAINING
AIR VOLUME FLOW RATE = 1200 CFM
WATER FLOW RATE AT PUMP = 6 GPM $= 378.54 \times 10^{-6}\ m^3/s$

FIND: RATE OF HEAT TRANSFER OF HEAT EXCHANGER AT 5min, 20 MIN, 40min + 60 min.

ASSUME: ALL HEAT IS LOST FROM TANK WATER TO HEAT EXCHANGER
FLUID PROPERTIES ARE CONSTANT
STEADY OPERATING CONDITIONS EXIST
NEGLECT ANY CHANGES IN KINETIC + POTENTIAL ENERGIES IN FLUID STREAMS.

METHOD: $\dot{Q} = \dot{m} C_p (T_{in} - T_{out})$

SOLUTION: ~~[illegible]~~ $\dot{m} = \rho \dot{V}$

WATER @ 143°F ≈ 62°C ≈ 60°C

$\rho = 983.3\ kg/m^3$

$\dot{m} = 983.3 \frac{kg}{m^3} \left(378.54 \times 10^{-6} \frac{m^3}{s}\right) = 0.372\ kg/s$

At 5min: Water in = 62°C WATER OUT = 50°C Cp of water @ 55°C = 4.183 KJ/kgK

$\dot{Q} = 0.372 \frac{kg}{s} \left(4.183 \frac{KJ}{kgK}\right)(62°c - 50°c)$

~~$\dot{Q}$ = [illegible] 18672.8 KJ/s ≈ 18.7~~

$\dot{Q} = 18.67\ KJ/s \approx$ **18.7 KW**

AT 20min: WATER IN = 126°F = 52°C WATER OUT = 110°F = 43°C Cp @ 50°c = 4.181 KJ/kgK

$\dot{Q} = .372\ kg/s\ (4.181\ KJ/kgK)(52 - 43°c)$

$\dot{Q}$ = **14.0 KW**

Appendix G4.1

MET 489c | 4-20-20 | 2/2

AT 40 min : WATER IN = 107° F, 42°C; WATER OUT = 99° F, 37°C; C_p @ 40°C = 4.179 kJ/kgK

$\dot{Q} = 0.372\ kg/s\ (4.181\ kJ/kgK)(41 - 37°C)$

[illegible] $\dot{Q} = 7.8\ kW$

AT 60 min : WATER IN = 96° F, 36° C; WATER OUT = 89° F, 31°C; C_p @ 35° C 4.178 kJ/kg K

$\dot{Q} = 0.372\ kg/s\ (4.178\ kJ/kgk)(36°C - 31°C)$

$\dot{Q} = 7.8\ kW$

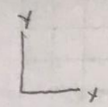
Appendix G4.2

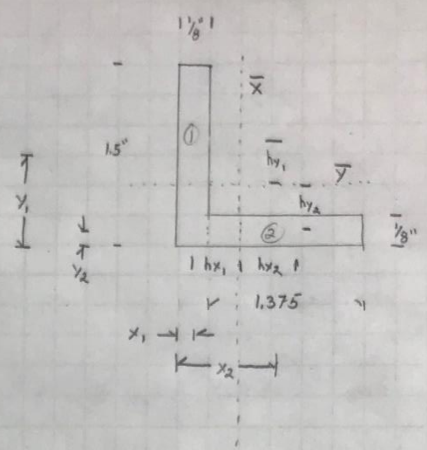
Test 4

3/5

11-18-19

$\frac{1}{8}" \times 1.5" \times 1.5"$ Angle





Areas

$A_1 = (1.5)(.125) = .1875 in^2$

$A_2 = (1.375)(.125) = .172 in^2$

Centroidal Distances

$X_1 = 0.125(\frac{1}{2}) = 0.0625 in$

$X_2 = 1.375(\frac{1}{2}) = 0.6875 in$

$Y_1 = 1.5(\frac{1}{2}) = 0.75 in$

$Y_2 = .125(\frac{1}{2}) = 0.0625 in$

Centroid

$$\bar{X} = \frac{A_1X_1 + A_2X_2}{A_1 + A_2} = \frac{0.1875(.0625) + .172(.6875)}{.1875 + .172} = 0.362 in$$

$$\bar{Y} = \frac{A_1Y_1 + A_2Y_2}{A_1 + A_2} = \frac{.1875(.75) + .172(.0625)}{.1875 + .172} = 0.421 in$$

Moment of Inertia

$h_{y_1} = Y_1 - \bar{Y} = 0.75 in - .421 in = .329 in$

$h_{y_2} = \bar{Y} - Y_2 = .421 in - .0625 in = .359 in$

$$I_{1xx} = \frac{1}{12} b_1 L_1^3 + A_1 h_{y_1}^2 = \frac{1}{12}(.125)(1.5^3) + .1875(.329^2) = .0555 in^4$$

$$I_{2xx} = \frac{1}{12} b_2 L_2^3 + A_2 h_{y_2}^2 = \frac{1}{12}(1.375)(.125^3) + .172(.359^2) = .0224 in^4$$

$$I_{xx} = I_{1xx} + I_{2xx} = 0.0555 in^4 + 0.0224 in^4 = .0779 in^4$$

Deflection

$$Y_{max} = \frac{-PL^3}{48EI} = \frac{-110 lb (48 in)^3}{48(28 \times 10^6 \frac{lb}{in^2})(.0779 in^4)} = \boxed{-0.116 in}$$

Not Good

Use thicker angle

APPENDIX H

Chance Linarez

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(509)-494-9705
chance.linarez@gmail.com

Objective: To complete required college classes to major in Mechanical Engineering Technology from Central Washington University, and find a career in mechanical engineering.

Experience:

Precision Industrial Equipment

June 2019- Present

Worked as an Engineering Intern. Machined various parts for food processing equipment, running a water jet, and assisted in assembly and installation.

Central Washington University

October 2018- June 2019

Work for University housing. Replacing furniture and appliances in dorms and apartments on campus.

RossCo Plumbing Co

2014- September 2018

Worked under the supervision of a Journeyman plumber in residential and commercial job sites.

Yakima Valley College

Ecology Youth Corps

Education:

West Valley High School

Graduated and received diploma in 2015. Maintained a 3.4 GPA throughout high school.

Yakima Valley Community College

First enrolled in fall of 2015. Received AA Direct-transfer-agreement to Central Washington University.

Central Washington University

First enrolled in fall Of 2017. Working towards completing my degree in mechanical engineering technology. Have maintained above a 3.6 GPA throughout college.

Achievements: -Passed SolidWorks CSWA Exam. (2018)

-Placed 7th in Washington State High School Agricultural Mechanics Competition. (2014)

Skills: -Experience with SolidWorks, Cad, and Microsoft office. Able to use solid works proficiently for basic part designs. Work very well with others.

-Knowledge of basic machine shop machines, tools, and procedures. Able to use lathe, mill, drill press.

-Knowledge of welding shop tools and safety. Able to use MIG welder, stick welder, and oxy-acetylene.

-Experience in mechanical problem solving and repair, such as engines and machines.

-Experience in jobsite safety. For example, working around lifts, equipment, and other trades.

Activities: Skiing, Welding, work on cars, enjoy fixing things, dirt bikes, street bikes, gym and physical activity.

References Upon Request

APPENDIX J

JOB HAZARD ANALYSIS

Prepared by: Chance Linarez	Reviewed by: Approved by:

Location of Task:	Precision Industrial Equipment
Required Equipment / Training for Task:	Water Jet, TIG welder, Grinder, Band Saw. Training how to setup water jet as well as welding experience, use of band saw and familiar with hand tools related to grinding and welding. PPE including eye protection, ear protection, gloves, welding mask, and appropriate shoes for welding.
Reference Materials as appropriate:	Omax 80x Water Jet Cutting Machine manual

Personal Protective Equipment (PPE) Required
(Check the box for required PPE and list any additional/specific PPE to be used in “Controls” section)

Gloves	Dust Mask	Eye Protection	Welding Mask	Appropriate Footwear	Hearing Protection	Protective Clothing
☒	☐	☒	☒	☒	☒	☒

Use of any respiratory protective device beyond a filtering facepiece respirator (dust mask) is voluntary by the user.

Pictures (if applicable)	TASK DESCRIPTION	HAZARDS	CONTROLS
USING AN ANGLE GRINDER			
	1. Check cord integrity.	Hand cut from cut wires.	Wear leather gloves. Inspect slowly.
	2. Check conditions of grinding wheel and appropriate RPM.	(None foreseen)	
	3. Check grinding wheel tightness.	Hand injury from inadvertent starting	Do not plug in the machine until inspection is complete.

	4. Verify the guard is tight and appropriate for the job.	Foot injury from dropping the tool	Rest the tool on the bench. Wear steel-toed shoes.
	5. Verify the appropriate handle location.	Foot injury from dropping the tool	(See controls for Task 4.)
	6. Inspect trigger for physical damage and proper operation.	(None foreseen)	
	7. Make sure the materials being ground are adequately secured and positioned correctly.	Injuries associated with the work propelled by the grinder and/or landing on you	Verify the work is adequately secured by trying to dislodge it with a gloved hand (the work weight may secure it enough). Wear steel-toed shoes.
	8. Plug-in the grinder.	Eye and skin damage from projectiles.	Check the trigger switch to insure it is off.
	9. Begin grinding.	Eye injuries from projectiles and sparks	Wear safety glasses/goggles and a face shield.
		Skin damage from sparks and projectiles	Wear leather gloves, long sleeved shirt, long pants, or leather welding guards.
		Hearing loss	Wear ear plugs.
		Ergonomic considerations.	Change position from time to time. Wear vibration resistant gloves.
		Inhalation of toxic or irritant fume or particulate	Wear the appropriate respirator based on the content of the metal and its coatings. Contact EH&S (2-3073) for evaluation and exposure assessment. Use local or dilution ventilation to direct or collect fumes and/or particulate
OPERATING A WATER JET CUTTING MACHINE			
	Check workpiece is secure on cutting table.	Cutting fingers and hands	Avoid touching slats.
	2. Check jet nozzle will not hit any clamps.	Cutting fingers and hands	Avoid touching slats.
	3. Adjust jet to 0.060 inches above workpiece	Pinching fingers or hands	Avoid pinch points between jet and workpiece
	4. Start water jet.	Cutting fingers and hands	Keep fingers and hands away from jet.
		Injuries from flying debris	Wear safety glasses or face shield.
OPERATING A MILLING MACHINE			

	Milling fins and drilling holes in fins	Injury to hands from milling blades	Never disconnect safety shields from milling blades.
		Hearing damage from noise of machine operation	Wear hearing protection, such as ear plugs, if operating machine for periods extending more than 10 minutes.
		Possible eye injury from wire stitches thrown out by milling blade	Wear safety glasses during operation.
		Crushing finger hazard from book clamp	Do not hold book at spine when activating book clamp. Hold book at the face.
OPERATING A BAND SAW			
	Check condition of blade.	Cutting fingers and hands	Avoid contact with blade teeth.
	2. Align materials flat on table.	Pinching fingers or hands	Keep fingers and hands away from pinch points.
	3. Adjust guard to no more than ¼ inch above top of material.	Pinching fingers or hands	Avoid pinch points between guard and housing and between guard and material.
	4. Start blower and saw.	Cutting fingers and hands	Keep fingers and hands away from blade. Use push bar for smaller materials.
		Injuries from flying sawdust	Wear safety glasses or face shield.
USING TIG AND MIG WELDER			
	1. Close off welding area.	Flashing	Close welding curtain to shield outsiders from flashing.
	2. Prepare for tig welding.	Inhalation of fumes	Turn on exhaust fan and timer.
		Flashing	Wear welding hood.
		Sparks	Wear welding jacket, apron, gloves, work shoes.
		Slag splatter	Wear welding jacket, apron, gloves, work shoes.
	3. Turn on power and unwrap wire.	Tripping	Take care to keep wire untangled and free from under feet.
	4. Insert tungsten welding rod in handle.	Pinch to fingers	Keep fingers away from pinch points.

	5. Strike arc.	Flashing, sparks, slag splatter	Wear welding hood, welding jacket, apron, gloves, work shoes.
	6. Allow material to cool on workbench.	Burn to hands or fingers	Wear glove. Chalk mark welded area "Hot"
	7. Remove remainder of arc welding rod (if any) from handle, set aside on workbench to cool.	Burn to hands or fingers	Chalk mark welded area "Hot"
	8. Wrap wire.	Tripping	Take care to keep wire untangled and free from under feet.
	9. Use chipping hammer to remove excess slag.	Eye damage by flying debris from hammer strikes	Wear safety glasses.
		Injuring fingers with hammer	Use caution to avoid striking fingers or hands with hammer.