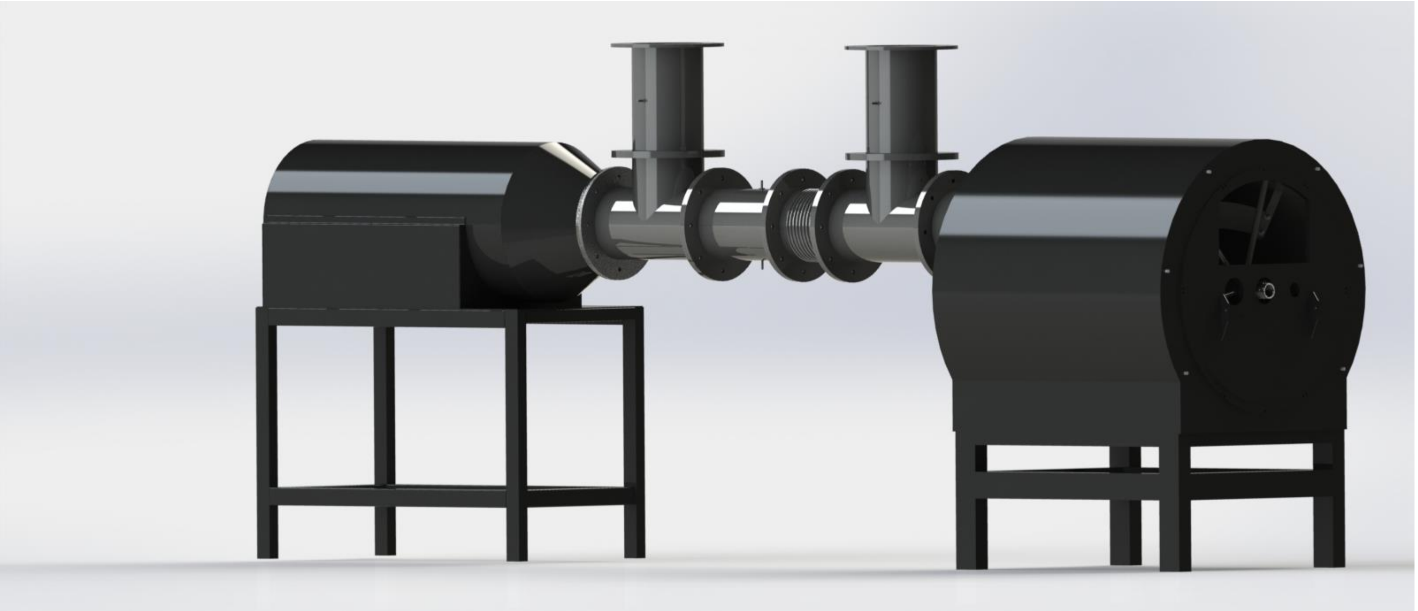
U.S. Roaster Corp

Spring Semester Design Report: 300 Kilogram Roaster



Brian Biggerstaff

Justin Ludwig

Jeff Biggerstaff

Jess Webb

Advisor: Dr. Tim Bowser

Table of Contents

1.0 Project Overview

1.1 Mission Statement

Our mission is to assist U.S. Roaster Corp in the design of a 300 kilogram coffee roaster by modifying a smaller roaster design.

1.2 Problem Statement

Our objective is to help design a fire tube and roaster drum for a new prototype 300 kilogram roaster.

1.3 Background

U.S. Roaster Corp is a company based in Oklahoma City, Oklahoma. U.S. Roaster Corp builds and remanufacturers coffee roasters. They offer a variety of sizes ranging from small scale roasters to large industrial roasters. U.S. Roaster Corp wishes to build a new large scale coffee roaster with a capacity of 300 kilogram. Currently, the largest roaster produced by U.S. Roaster Corp is a 150 kilogram roaster. They want to produce a larger roaster as requested by some customers. Furthermore, U.S. Roaster Corp currently faces some challenges with their current roasters. The process behind the roasting of coffee beans is quite simple but also very precise. For example, beans go through several stages at various temperatures and depending on the roast, temperatures need to be adjusted and maintained for precise periods of time. Beans rotate in a drum heated by a heating box providing hot air to the drum for a desired period of time anywhere from eight to thirteen minutes. Beans are then dispensed into a cooling pan with rotating arms and cool air blowing onto the beans to prevent further cooking. One challenge is the rubbing of the drum caused by metal expansion due to high temperatures. Another challenge, or desired change, is the location of their heat input and overall heating box design.

1.4 Impacts

The impacts of our project are limited to environmental and societal impacts. No global impacts are known at this time. U.S. Roaster Corp plans to recycle to the air to meet environmental requirements. Societal impacts are providing potential clients with a large scale industrial sized coffee roaster.

2.0 Scope of Work

U.S. Roaster Corp requested that the team assists them in design of a fire tube and roaster drum for a 300 kilogram roaster.

- Regularly met and discuss progress with our client.
- Conducted patent searches on roaster designs.
- Obtained a general knowledge of the coffee roasting process.
- Converted CAD drawings into Solid Works drawings.
- Researched different types of steel to withstand high temperatures.
- Investigated five alternative roaster designs.

2.1 Work Breakdown Structure

The two main components of the 300 kilogram roaster include the roaster drum and the heating tube. Having these two primary components, it was our team's goal to design these components including several secondary components. Using SolidWorks, the heating tube was designed along with the stand for the tube, the tube cradle, burner mounts, and the back plate for the tube, piping from the tube to the drum, piping tees, expansion joints, and a connecting cone. To complete the roaster drum; secondary parts were designed such as; the face plate, cover plates, drum flighting support rods, inner and outer wraps, and the drum stand. The two main components made up the design component of our project along with senior design class assignments. The work breakdown structure is found below in Figure 1.

Figure 1. Work breakdown structure.

3.0 Patent Search

The patent search revealed most patents applied to small scale designs but the team found three patents applicable to our design. The first patent, United States Patent US 7,003,897, which was a coffee roaster drum rocker arm roller bearing system. The inventors are James B. Lingle and Alexandru Scantee of 6500 S. Garfield, Bell Gardens, CA 90201. The patent application number is 10/998,097 and it was filed on November 29, 2004. The second patent found in the search was International Patent WO 2009/075893. This patent applied to recirculated airflow which our client mentioned might be a possibility for this design in the future. The applicant and inventor is Daniel

Sadamu Hyama of 564 North Virgil Ave. #14, Los Angeles, CA 90004. The filing date on this patent was December 8, 2008. The third and final patent discovered in the patent search was International Patent WO 03/011050. This patent applies to a filtered exhaust airflow may be a part of the project later. Daniel Sadamu Hyama is the applicant and inventor of 2940 Grace Lane, Costa Mesa, CA 92627. The filing date was July 30, 2002.

The only patent applies to our project is United States Patent US 7,003,897 which was one method of supporting the drum we considered but the team has moved past the idea. The other two patents apply to the recirculation of the air and exhausting filter. These aspects of the projects will be done by U.S. Roaster Corp.

4.0 Design Objectives

This report includes four alternative designs for a 300 kilogram coffee roaster with variations in materials used, heat flow location, process for turning the drum, and the drum dimensions. In order to meet U.S. Roaster Corp's expectations, the design team desires to meet the following criteria:

1.) Allow for at least 300 kilogram capacity based on 40% volumetric fill of coffee beans occupying a space of 22 lbs./ft^3

2.) Design needs to be durable to last for several years

3.) Drum needs to expand less than current design

4.) No spilling of product

5.) Quick cleanout of the drum to ensure that the coffee beans do not over roast

6.) Material of the drum needs to withstand at least 1000 °F for cleaning purposes

7.) Fire tube needs to be at least 100 ft^3 and no taller than 12 feet

8.) Make sure design is efficient and takes up as little space as possible

5.0 Technical Approach

5.1 Material Selection

Currently U.S. Roaster Corp uses 304 Stainless Steel for the design of the 150 kilogram roaster. There is an expansion issue with the use of 304 Stainless Steel due to the thermal properties. The unheated diameter of the 150 kilogram roaster is 37.75 inches and the unheated length is 47.25 inches. The drum experiences temperatures up to 1000°F during the coffee roasting process. Under this condition, the 150 kilogram roaster expands to a length of 47.68 inches and a diameter of 38.10 inches. The expansion causes drum clearance issues with other components of the roaster. The group was advised to look into 400 Series Stainless Steel. Table 1 provides a summary of material properties of different metals that were considered for the 300 kilogram roaster design.

Table 1. Summary of various material properties.

Metal Type	Property Notes
304 Stainless	Expands too much for the application. Current troubles with this expansion
RA 330	Similar properties to 304 Stainless
410 Stainless	Less resistant to corrosion than 430, used a lot in knives and kitchen utensils
422 Stainless	High temperature resistance up to 1200 degrees F, have not located a source
430 Stainless	Good heat resistance up to 1500 degrees F, typical in gas burners and oil refinery equipment
436 Stainless	High temperature applications such automotive exhaust applications
Inconel	Costly and very heavy, may be possible for the firebox

Based on the group's research and client preferences, the team decided to use either 430 Stainless Steel or 436 Stainless Steel depending on which material is available by a supplier. After checking with several different suppliers, the selection of 430 Stainless Steel was selected. Calculating the thermal expansion for 430 Stainless Steel, the new length of the 300 kilogram drum is 62.39 inches from an initial length of 62 inches and the new diameter is 52.32 inches from an initial diameter of 52 inches. Tables 2 and 3 below show the original dimensions of the 300 kilogram drum and the thermal expansion properties of the 300 kilogram drum. The linear thermal expansion equation is:

$$\textit{Equation 1:}\ \Delta l = L_0 \alpha \Delta T$$

Δl = change in length (in)
L_0 = initial length (in)
α = linear expansion coefficient (in/in°F)
ΔT = change in temperature (°F)

The diametrical thermal expansion equation is:

$$\textit{Equation 2:}\ \Delta d = \frac{(\pi d_0) + (\pi d_0 C_p \Delta T)}{\pi}$$

Δd = change in diameter (in)
d_0 = initial diameter (in)
C_p = temperature expansion coefficient (in/in°F)
ΔT = change in temperature (°F)

Table 2. Initial dimensions of the 300 kilogram drum.

300 kilogram Roaster Dimensions		
Diameter	52	in
Length	62	in

Table 3. Thermal expansion calculation of the 300 kilogram drum.

Metal Type	Cp	Length after heating (in)	Diameter after heating (in)
430 Stainless	6.30E-06	62.39	52.328

Our client wants less expansion from the material used on the roaster drum and 430 Stainless Steel provides an adequate solution.

5.2 Design Approach

The team has to consider the manufacturing capabilities of U.S. Roaster Corp in the design process. U.S. Roaster Corp prefers not to use complex shapes in the design process. Some designs have been verified by U.S. Roaster Corp to ensure that they have those capabilities.

5.3 Alternative Designs

U.S. Roaster Corp is a competitive manufacturer that is always advancing the quality of its products and expectations of its customers. It is because of that competitive drive that U.S. Roaster Corp has decided to build the largest coffee roaster to date. They have asked us to design the drum for a 300 kilogram roaster. In addition, they have also asked us to change the way the heating air is used in cooking the coffee beans. This involves designing a firebox to contain the heat and routing the air to the roasting drum in a different way. The method the team followed when addressing these problems is explained in the following design alternatives.

5.3.1 Alternative 1

Our first alternative design is based upon the already proven design which U.S. Roaster Corp. already has in production. This design takes the baseline design of the current 150 kilogram roaster and addresses the areas where durability is a problem, while also being designed to allow for roasting a batch of 300 kilograms. Even though a similar design is already in production, the team was faced with the complication of thermal expansion of the actual drum as the heat is applied. As the drum size is scaled up, the amount of thermal expansion increases. This causes complications of clearance tolerances between the rotating drum and stationary plates on each end of the drum. In order to counter this issue, our design will use 430 stainless steel. 430 stainless steel will allow for less thermal expansion than the current drum, which is being constructed from 304 stainless steel. Supporting calculations for this can be seen in Table 3.

By doing this, our client will be able to manufacture a drum that will have clearance tolerances small enough to ensure no product is lost during the roasting process while not inhibiting rotation. To address the problem of durability on the existing design, the air flow into the roaster was rerouted in a method which would allow for a more centralized heating method, as opposed to the old heating method where the heat was applied directly to the outside walls of the drum.

The new method uses our "vortex flow inlet." This inlet will allow for the heated air to enter the drum through the stationary rear plate. The air flow inlet will be angled so that as it enters the rotating drum, the air flow will meet with the rotating drum and its contents in a method which will result in the air making a vortex. As a result, there will be more evenly dispersed heat throughout the drum. The angled inlet directs into the drum in a clockwise rotation which is consistent with the drums rotation. This ensures that the heated air encounters less resistance than if it were to be inserted with the air flow being directed in a simple linear direction. The theoretical air flow pattern can be seen in Figures 1 and 2. As the air enters the drum it is complimented by the clockwise rotation of the drum as can be seen in Figure 2. By using this method, the air is more evenly dispersed throughout the entire drum than the conventional method of heating strictly the outer walls of the drum. The design will decrease the amount of heat applied during a regular roast to the outer walls of the drum which will increase durability and longevity of the roasting drum as well as improve roast quality.

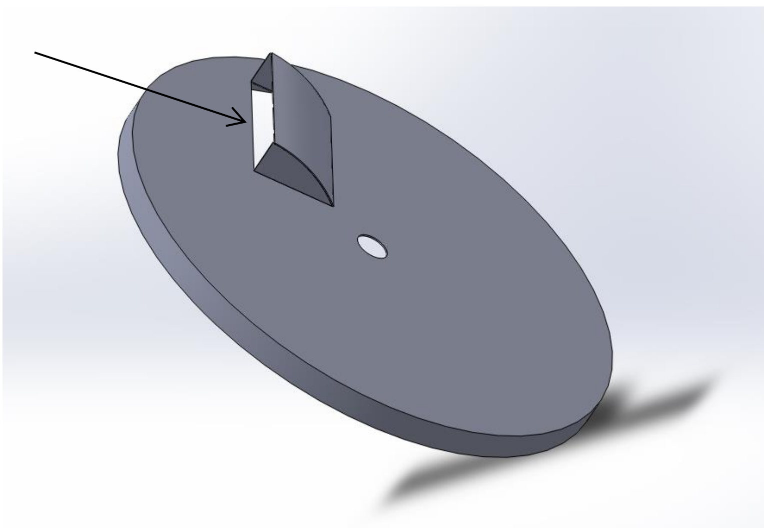


Figure 2. Vortex Flow Inlet design mounted to the rear stationary plate.

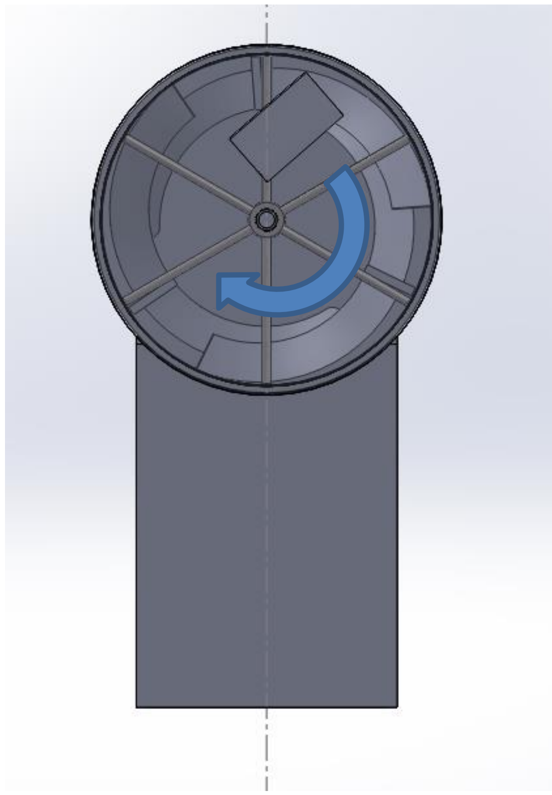


Figure 3. Theoretical airflow projection with use of Vortex Flow Inlet.

5.3.2 Alternative 2

Building upon the first alternative design, the team investigated a second design which eliminated the shaft support through the center of the drum. This design would be the same as design alternative 1, with only a change in the supporting structure. Instead of a rotating center support shaft, this design would be supported by a roller system as seen in Figure 3. By doing this the center support shaft is eliminated altogether. As a result of doing this, there is no worry in the effect the drum's expansion has on the drive mechanism, since the drum will be able to float on the rollers as it endures expansion.

However, this does not address the problem of linear expansion in the areas where rotating components meet with the stationary components. The rollers would be mounted onto a support stand and the drum's weight would rest on the rollers. The drum would be powered by an electric motor connected via chain and gear connected to an external shaft on the end of the drum similar to the way U.S. Roaster Corp powers their drums currently. This design seemed plausible for the support of the extra weight in the 300 kilogram roaster. However, after calculations, the team realized that a center shaft through the drum would in fact support the weight of a 300 kilogram roaster. Considering all the new changes associated with a roller design, the team decided to remain with the center shaft design solely for the previous experience and knowledge associated with that design.

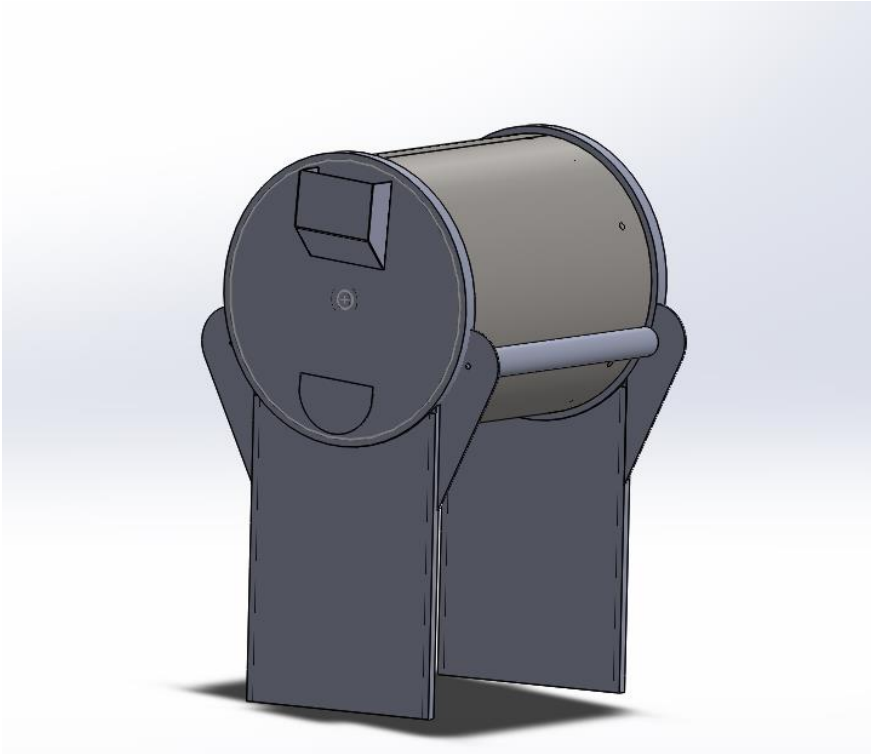


Figure 4. Alternative #2 featuring rollers to support the weight of the drum instead of center support shaft.

5.3.3 Alternative 3

For design alternative 3, a drastic change in approach was taken. Knowing that there would be a large amount of thermal expansion the team projected that it would be best to focus the heat at the center of the drum to ensure the walls of the drum were heated only to the point where the beans would roast. In this design the drum would be stationary. This addresses the issues the current design has with the expansion hindering the clearance tolerances where the rotating and stationary components meet. This design proposed running a solid shaft through the center of the drum. The shaft would rotate while the drum would remain stationary. On this shaft would be agitators with tines to stir the beans during the roasting process. Each of these agitators would house an individual heating element with sensor connected to a controller that would cycle power to the heating element depending on the temperature in that area of the drum. A design like this is considered too complex and high tech to create. Doing this would ensure a stable, even, roasting temperature for all of the beans.

Further analysis of this model showed many problems concerning the beans during the roasting process. One problem being the rotating agitators would be too rough and most likely damage the beans while in the drum. Another potential problem with this design was the inability to agitate the beans in a manner that would ensure all of the beans were continuously mixed. This would be a result due to using a stationary drum. Since this design has no previous research or experimentation it is expected to have many more problems that would arise as testing would take place. With all of these expected issues it was determined that this design was by far inferior to the current design.

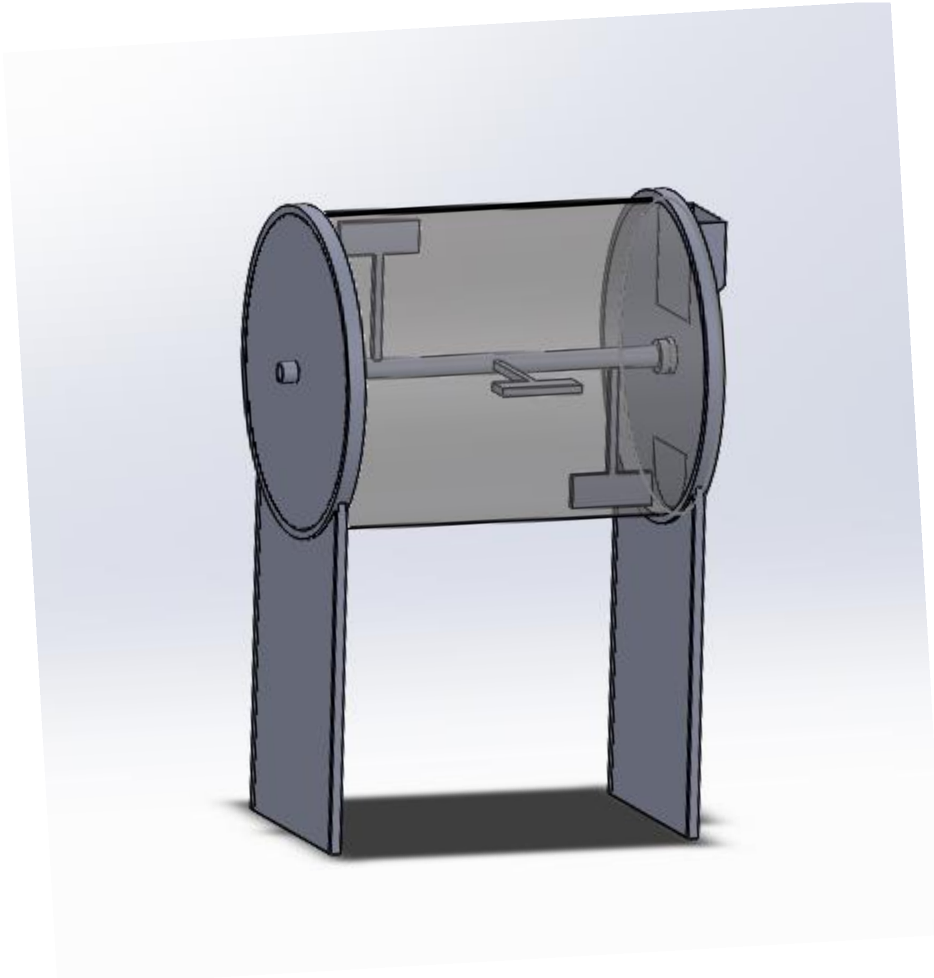


Figure 5. Alternative #3 using agitators featuring a stationary drum.

5.3.4 Alternative 4

Of all of the designs, design 4 is the most exotic and the most experimental. Instead of a rotating drum with applied heat, it consists of a vibrating conveyor belt through a tunnel with heat applied from all sides. A layer of beans would be applied onto the conveyor belt and then carried through the tunnel on the vibrating conveyor. The vibrations would ensure that the beans are moved around and cooked evenly. The length of the conveyor would be determined on the time exposed to heat that would be required to fully cook the beans. This idea would operate similarly to a pizza oven. By doing this a continuous flow of beans would be roasted and there would be less downtime resulting in a more efficient system. Due to how exotic this idea is, it would be best to design this continuous system on a small scale before attempting a large scale design. The team feels it could hold value in a future design when there is more available design and testing time.

Figure 6. Alternative #4 showing an example of a small conveyor style oven. Image Source: http://www.archiexpo.com/prod/middleby-marshall/commercial-conveyor-electric-pizza-ovens-51500-1036597.html

5.3.5 Alternative 5

After exploring pros and cons of designs 1 through 4 and talking with our client; the group decided to come up with a fifth design which better executed the project objective. For example, the final design alternative explored a new design for a fire tube which would be a horizontal, cylindrical tube. The heating tube will be elevated on a stand and piped in to the back of the drum via 6” pipe. The connecting pipe will include four dampers and an expansion joint. The roaster drum itself would be relatively similar to the design of U.S. Roaster Corp’s current drums and that of design alternative 1.

However, in design alternative 5, a hollow steel shaft will be connected to a spider assembly used to rotate the drum powered via a gear connection. The hollow shaft will be a mechanism for support as well as a transportation method for water to be dispersed onto the beans. The steel shaft will run the full length of the drum unlike the stub shaft design from design 1. A sprocket is connected to the shaft via a hub and it is powered by an electric motor and chain. The flighting inside the drum consists of nine total sections of flighting. The six sections mixing beans from the back of the drum to the front of the drum are 90 degrees in rotation. The three sections of flighting mixing beans from the front of the drum to the back of the drum are 180 degrees in rotation. Design alternative 5 will be a simple transition in manufacturing due to its similarity in design to drums U.S. Roaster Corps currently manufactures. Finally, design alternative 5 encompasses the client's desire for central heat flow through the drum and provides a method for cooling water to be dispersed through the hollow shaft onto the beans.

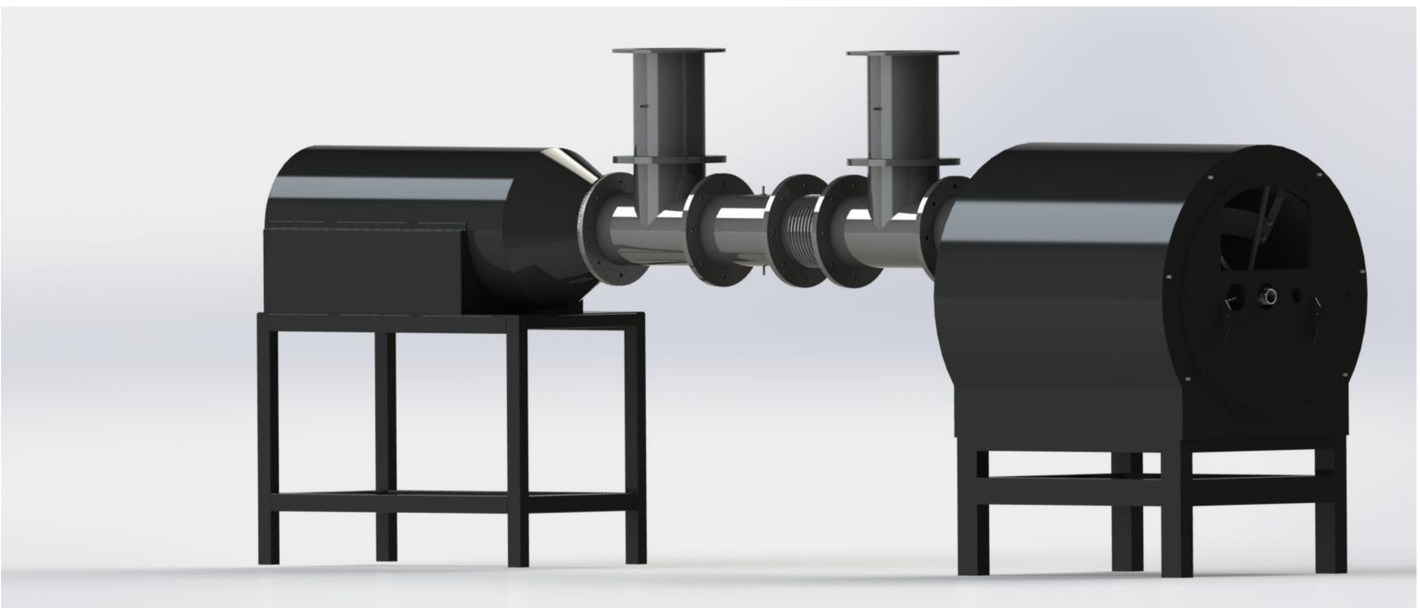


Figure 7. Alternative #5

5.3.6 Selected Alternative Justification

When trying to determine the best alternative, the team tried to choose the design that would be the best fit for U.S. Roaster Corp. The team felt the best design would be the one that was the most similar to the current design while still maintaining the high standard of quality associated with U.S. Roaster Corp Products. Therefore, the group selected alternative five as the desired alternative. The drum dimensions and rotational powering are simply scaled up versions of the current design. According to our engineering calculations, the volume of the drum needs to be at least 561 gallons with coffee beans occupying 22 lb/ft^3 at 40% fill to allow of expansion of the beans during the roasting process. The prototype dimensions of the roaster drum are 62 inches in length and 52 inches in diameter. The calculated volume of the roaster is 570 gallons thus exceeding the required 561 gallons. The position of the heating source and drum material are the greatest changes to the current design. There have been concerns about the structural stability of the scaled up version of the current design due to the added weight. Also, the center drive shaft is now hollow instead of solid to allow water to be applied to the roasted beans to help cool them during unloading. To address the shaft stress concerns, the following calculations were performed to ensure the stability of the alternative five.

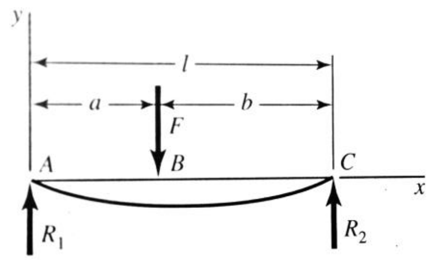


Figure 8. The free body diagram of the drive shaft for the 300 kilogram roaster.

$$\text{Equation 3: } Y_{AB} = \frac{FBX}{6EIL}(X^2 + B^2 - L^2)$$

Y_{AB} = the maximum vertical displacement of the shaft (in.)
F= Force applied (lbs.)
B= distance of force from the right side of the beam (in.)
X= distance from the left side of the beam (in.)
E = modulus of elasticity of the material (lbs/in^2)
I = moment of inertia of beam (in^4)
L = length of the beam (in)

$$\text{Equation 4: } \sigma = \frac{MY}{I}$$

σ = bending stress (KSI)
M = Maximum bending moment (Kip-in)
Y = distance from centroid to outer edge of beam (in.)
I = moment of inertia of beam (in^4)

Table 4. Summary of beam analysis results

Pipe Size (in.)	Schedule	Displacement (in.)	Stress (KSI)	Factor of Safety
2.5	80	0.264	14.81	2.43
3	80	0.132	9.03	3.98

Given a factor of safety of 1 indicates no failure will occur, both shaft sizes are physically capable of carrying the load of the drum and coffee beans during roasting. However, after discussing the results with US Roaster Corp, it was decided to use the 3 inch Schedule 80 pipe as the drive shaft. According to US Roaster Corp testing, coffee beans are capable of fitting into a gap of 0.1 in. Therefore, the drum displacement is important to the design as well as failure. The 3 inch pipe was selected for the drive shaft because it will help prevent leaking or grinding of coffee beans during roasting.

6.0 Prototype Fabrication

Due to the large size and complexity of this project, the prototype construction was split between U.S. Roaster Corp and the Biosystems and Agricultural Engineering Laboratory. Also, U.S. Roaster and the Biosystems and Agricultural Engineering Laboratory have different manufacturing capabilities and the capabilities of both locations factored into our decision to split the manufacturing duties. All of the parts were modeled in SolidWorks. Drawings were provided to the shop manager at the Biosystems and SolidWorks drawings were converted to AutoCAD drawings for U.S. Roaster Corp. The simpler parts such as stands and pieces for the fire tube were fabricated at the Biosystems and Agricultural Engineering Laboratory whereas, the more complex and larger parts were manufactured at U.S. Roaster Corp. A detailed drawing book can be seen in Appendix B. Various completed pieces can be found in Figures 8-17.

Figure 8. 300 Kilo Roaster Stand Fabrication Completion.

Figure 9. Completed Fire Tube Stand.

Figure 10. Cradle plus Fire Tube Assembly.

Figure 11. Completed 300 Kilo Upper and Lower Roaster Stand Assembly.

Figure 12. 300 Kilo Fire Tube Piping Completed.

Figure 13. Drum fabrication at US Roaster Corp.

Figure 14. Underneath view of the face plate fabrication at US Roaster Corp.

Figure 15. Up close view of the face plate showing grooves to hold the drum.

Figure 16. Face plate fabrication at US Roaster Corp.

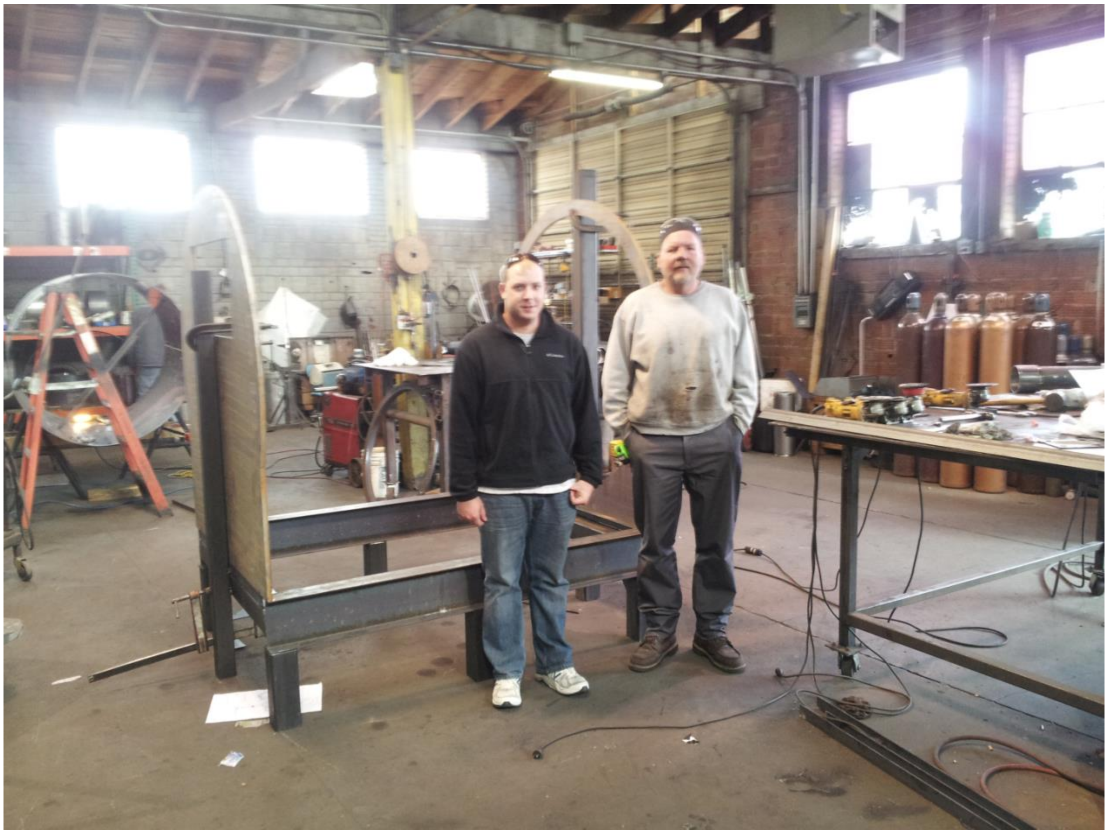


Figure 17. Human to machine size scaling.

7.0 Project Management

In order to meet expectations given to our team by U.S. Roaster Corp, our team had to practice a great deal of time management. From coordinating times to meet with four different schedules, to staying organized in our progression of work, time management was the key to our progression. The Gantt chart can be seen in Appendix A.

7.1 Budget:

U.S. Roaster Corp allotted a $50,000.00 - $100,000.00 budget for our design team. This budget allows for material costs such as, purchased stainless steel, insulation, and miscellaneous steel for the project. U.S. Roaster Corp manufactures their roasters and therefore, our team will not need to purchase materials on our own. Our team has chosen 430 series stainless steel. A detailed budget is listed below in Table 5.

Table 5. 300 Kilogram Coffee Roaster Projected Expenses

300 Kilo Roaster Costs							
Drum Assembly	Roaster Drum	Material	$ 3,025.00	Fire Tube Assembly	Fire Tube	Material	$ 4,775.00
		Labor	$ 5,700.00			Labor	$ 500.00
	Face Plates and Shields	Material	$ 5,000.00		Fire Tube Back Mount	Material	$ 197.50
		Labor	$ 1,710.00			Labor	$ 600.00
	Baffle	Material	$ 810.00		Burner Mount	Material	$ 25.00
		Labor	$ 500.00			Labor	$ 100.00
	Shroud and Wrap	Material	$ 1,530.00		Support Stand	Material	$ 224.32
		Labor	$ 500.00			Labor	$ 720.00
	Drum Stand	Material	$ 717.00		Fire Tube Stand	Material	$ 801.55
		Labor	$ 720.00			Labor	$ 480.00
	Support Rods	Material	$ 150.00		Fire Tube Piping	Materials	$42,000.00
		Labor	$ 60.00			Dampers	$ 850.00
	Spider Assembly	Material	$ 525.00			Expansion Joint	$ 1,490.00
		Labor	$ 2,500.00			Labor	$ 1,110.00
Miscellanous	Materials	Fasteners	$ 250.00		**Totals**	**Materials**	$60,030.37
	Labor	Final Assembly	$ 1,080.00			**Labor**	$16,280.00
						Purchased	$ 2,340.00
						Overall cost	**$78,650.37**

8.0 Conclusions and Recommendations

Upon receiving a problem statement of designing a 300 kilogram coffee roaster, our team has worked diligently to work towards an initial design for U.S. Roaster Corp. A mission statement was created as well as a scope of work and Gantt chart to track progress. A period of researching metal expansion properties was undertaken until 430 series stainless steel was selected. Furthermore, four alternative drum designs were investigated and a final design chosen from the four to meet client expectations. The chosen design was selected after several calculations regarding bending stress, fatigue life, and deflection on the shaft that supports and turns the drum. The selected design meets efficient heat inflow changes and was scaled up to twice the capacity of the current 150 kilogram roaster. Finally, the group has coordinated with U.S. Roaster Corp and the Biosystems and Agricultural Engineering to begin fabrication. Eventually the group plans on coordinating with U.S. Roaster Corp the start of the manufacturing process. The team looks forward to building of the prototype and testing.

8.1 Recommendations

The group has a few design recommendations for U.S. Roaster Corp. First, the group highly advises the use of weld nuts where possible to simplify the assembly and disassembly process. The supports for the fire tube could be moved from halfway up on the fire tube to further down on the sides closer to the bottom of the fire tube to help support the weight of the fire tube.

9.0 References

Budynas, R. G., and J. K. Nisbett. 2011. Shigley's Mechanical Engineering Design. 9th ed. New York, NY, USA: McGraw-Hill.

Dan Jolliff

Dr. Dan Thomas

Dr. Tim Bowser

Dr. Paul Weckler

Thermal Expansion Metals. Available at: http://www.engineeringtoolbox.com/thermal-expansion-metals-d_859.html. Accessed 2 October 2013.

300 Kilogram Coffee Roaster

Brian Biggerstaff

Jeff Biggerstaff

Justin Ludwig

Jess Webb

US Roaster Corp

- Owner Dan Joliff
- Serving the roasting industry for 33 years
- Located in Oklahoma City, Oklahoma
- Provide various companies with coffee roasters to complete their production plants
- Specialize in the fabrication of new coffee roasters and rebuilding old roasters

Objectives

- Design of a 300 kg coffee roaster drum
  - Roast 300 kg every 12 - 20 minutes
  - Drum 40% full
- Find Material with proper thermal expansion properties
- Design a fire tube, modify roaster drum, and change the location of the air flow input
- Ensure the final design is easy to manufacture at U.S. Roaster Corp’s facility

Scope of Work

- Regularly met and discussed progress with project affiliate
- Obtained a general knowledge of the process of coffee roasting
- Conducted patent research on roaster designs
- Researched different types of steel to withstand high temperatures
- Investigated 4 alternative roaster designs

Roasting Process

- Green coffee beans enter from the top via a hopper
- Beans enter drum and are spun at desired temperatures until "2nd crack phase"
- Once desired roast is reached, the beans are ejected into a cooling pan and mixed

Roasting Process

- Bean stages:
  - Green stage
  - Yellow Stage: **200 F – 250 F**
  - Light Brown Stage: **250 F – 300 F**
  - First Crack: **355 F – 400 F**
  - Second Crack: **Up to 440 F**

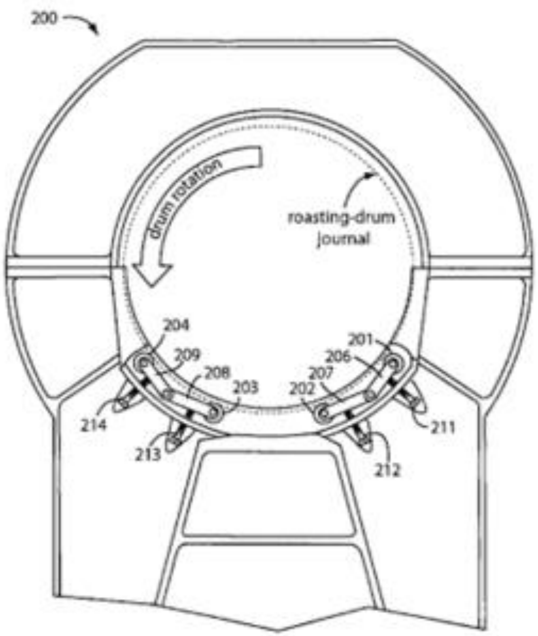
- Process time: **12 – 20 Minutes** depending on desired roast

Patent Searches

- Most patents applied to small scale designs
- International Patents WO 2009/075893, WO 03/011050
  - Recirculated Airflow, Filtered Exhaust Airflow
- United States Patent US 7,003,897
  - Coffee Roaster Drum with Rocker Arms

Patent Searches

- United States Patent US 7,003,897
  - Coffee Roaster Drum with Rocker Arms



Desired Modifications

- Change the location of heating source on the drum
  - Heat sets directly under the drum
- Using a different type of metal with lower thermal expansion properties
  - Drum expansion can cause rubbing or leaking
- Evaluate different support systems for the drum
  - Currently, a shaft supports the drum's weight
  - Roller system is considered

Materials Considered

- US Roaster Corp currently uses 304 stainless steel
- Our client advised us to look into 400 series stainless
  - Find the metal that is applicable to the process
  - Find a supplier
- Narrowed the metal to three choices
  - 422 Stainless
  - 430 Stainless
  - 436 Stainless

Linear Thermal Expansion

- $\Delta l = \ L_0 \alpha \Delta T$
  - $\Delta l = change\ in\ length\ (in)$
  - $L_0\ = initial\ length\ (in)$
  - $\alpha = linear\ expansion\ coefficient\ \left(\frac{in}{in}°\mathrm{F}\right)$
  - $\Delta T = change\ in\ temperature\ (°\mathrm{F})$

Radial Thermal Expansion

- $\Delta d = \frac{(\pi d_0)+(\pi d_0 C_p \Delta T)}{\pi}$
  - Δd = change in diameter (in)
  - d_0 = initial diameter (in)
  - C_p = temperature expansion ($\frac{\text{in}}{\text{in}}$ °F)
  - ΔT = change in temperature

300 Kilo Roaster Thermal Expansion

- Initial length = 62 in
- $\alpha, C_p = 6.30 \text{ x } 10^{-6} \left(\frac{in}{in} \text{°F}\right)$
- Initial diameter = 52 in
- $\Delta T = 1000 \text{ °F}$

Materials Considered

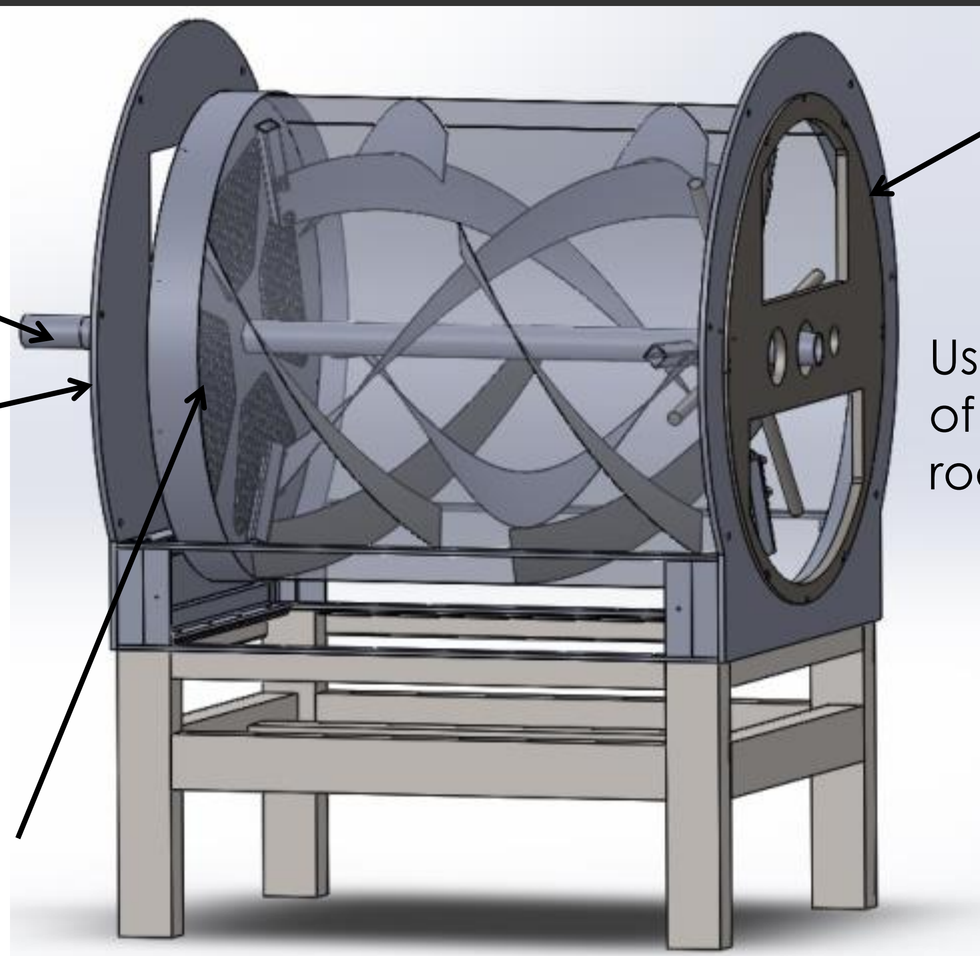
Metal Type	Cp	ΔL	ΔD
304 Stainless	9.20E-06	0.570	0.478
RA 330	9.30E-06	0.577	0.484
410 Stainless	6.50E-06	0.403	0.338
422 Stainless	6.20E-06	0.384	0.322
430 Stainless	6.30E-06	0.391	0.328
436 Stainless	6.10E-06	0.378	0.317
Inconel	7.80E-06	0.484	0.406

Design Alternative 1

Rotates about center shaft

Shaft supported by plates welded to upper frame

Heated air is directed into back of drum through screens



Grooved Face Plate allows for expansion

Use many aspects of current 150 kg roaster

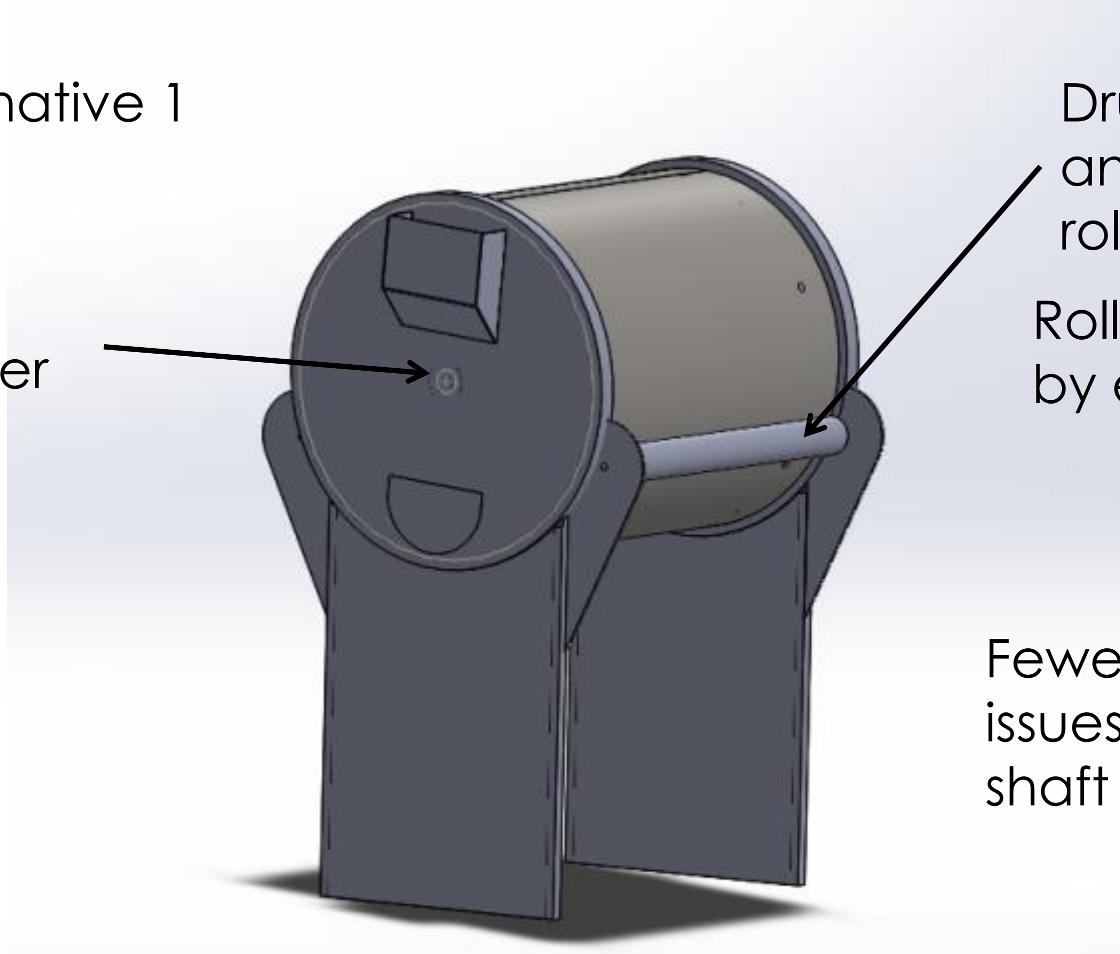
Design Alternative 1

- Pros
  - US Roaster Corp is already familiar with this design
  - Relatively simple
  - Proven on a smaller scale
- Cons
  - Stress on the shaft
  - Complications from drum expansion

Design Alternative 2

Similar to Alternative 1

Stub shafts replace center shaft



Drum supported and driven by rollers

Rollers powered by electric motor

Fewer expansion issues between shaft and drum

Design Alternative 2

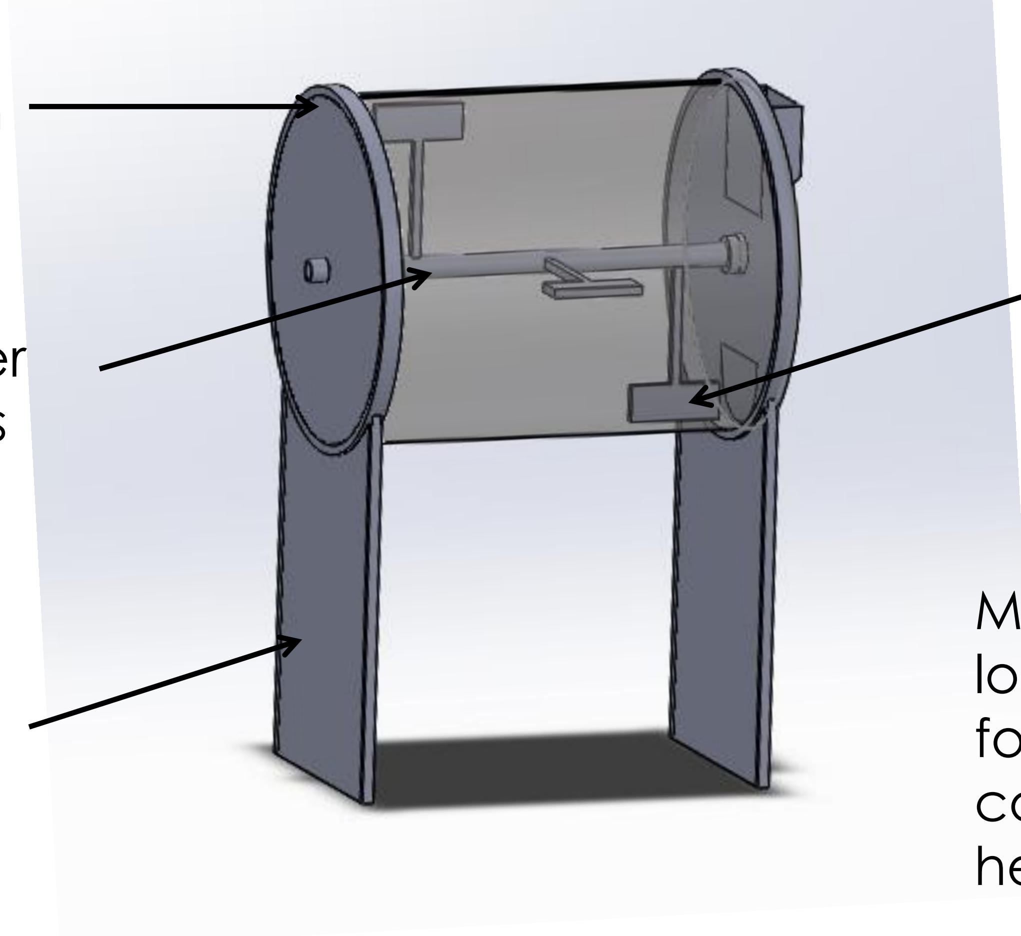
- Pros
  - Expansion
  - Simplicity
  - Addresses shaft loading issue
- Cons
  - Patents
  - Heating of rollers
  - Noise of rollers

Design Alternative 3

Stationary drum

Heat applied through center shaft and exits out agitator arms

Drum Weight supported by stand



Rotating agitators

Multiple heating locations allows for more controlled heating

Design Alternative 3

- Pros
  - Fewer issues with the drum expanding
  - Centralized heating
  - Even, controlled heating
  - No shaft loading issue
- Cons
  - The agitator will damage the beans
  - Complexity
  - Difficult to remove beans

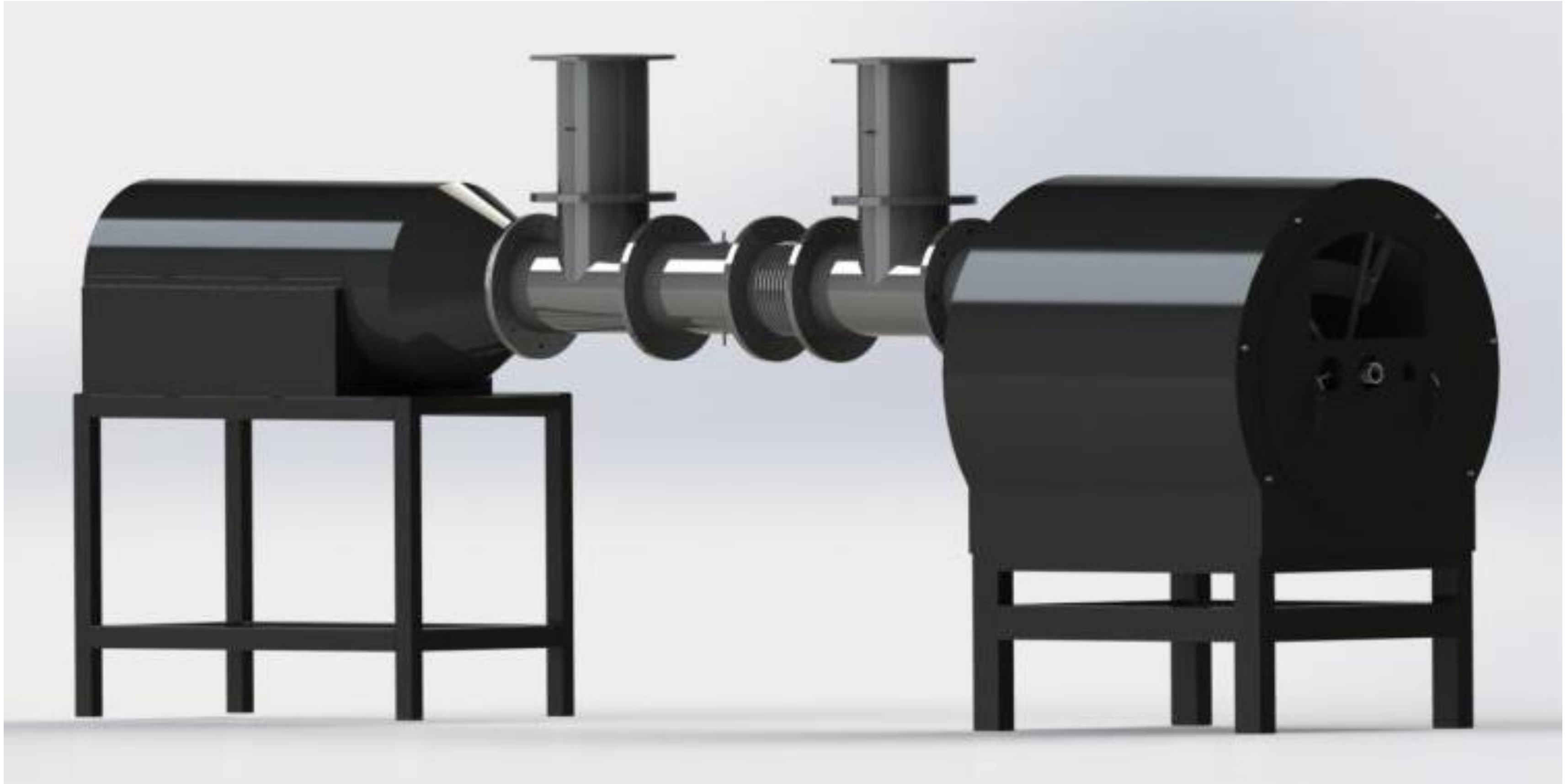
Design Alternative 4

- Conveyor Oven
- Burners underneath
- Constant flow
- Vibrating conveyor belt to equally heat beans
- Similar to a pizza oven

Design Alternative 4

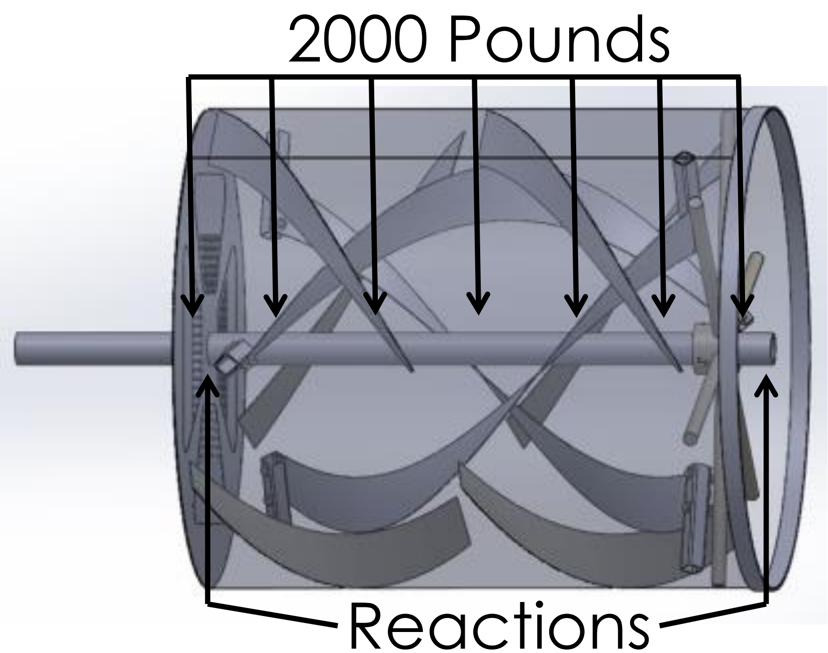
- Pros
  - Continuous flow of roasted coffee
  - No rotating drum so less worries about expansion
  - Capable of various roast sizes
- Cons
  - Design is too different and radical to implement
  - Would need to design on a small scale before large

Selected Design – Alternative 1



Design Justification

- Select Design Alternative #1
- Performed engineering calculations to verify design
  - Bending Stress
  - Deflection



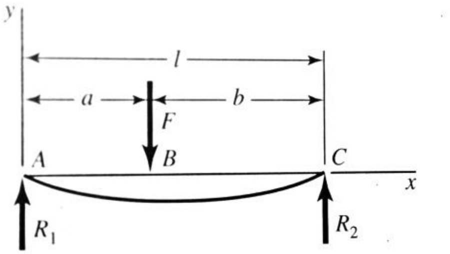
Design Justification

- Beam Stress Equation
  - $\sigma = \frac{MY}{I}$

- σ = bending stress (KSI)
- M = Maximum bending moment (Kip-in)
- Y = distance from centroid to outer edge of beam (in.)
- I = moment of inertia of beam (in^4)

Design Justification

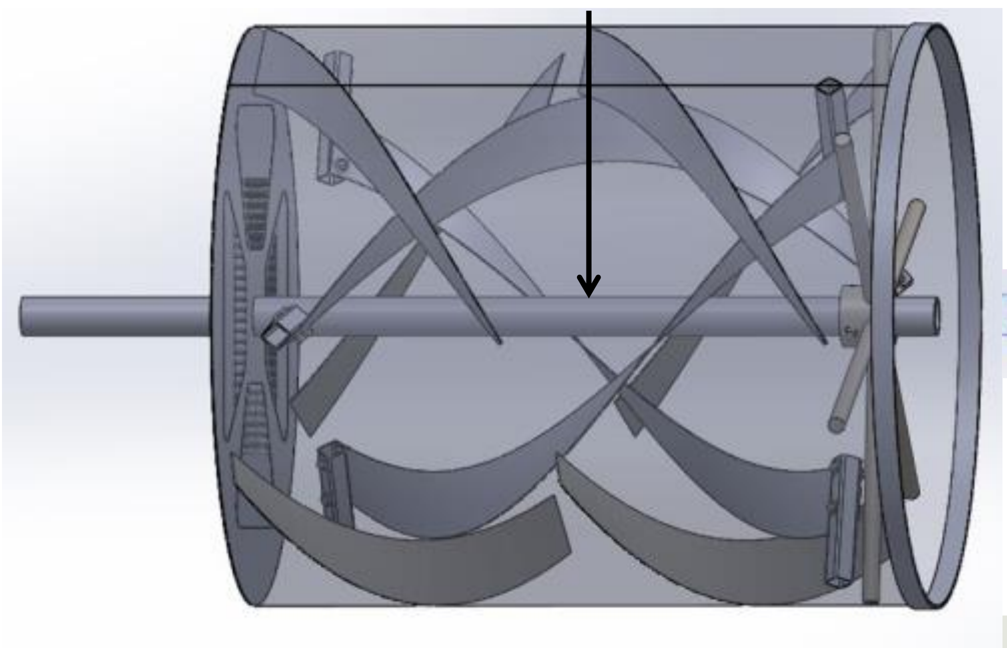
- Beam Deflection Equation
  - $Y_{AB} = \frac{FBX}{6EIL}(X^2 + B^2 - L^2)$



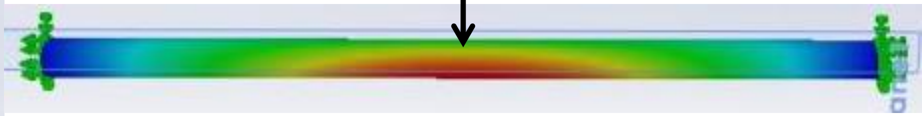
- Y_{AB} = the maximum vertical displacement of the shaft (in.)
- F= Force applied (lbs.)
- B= distance of force from the right side of the beam (in.)
- X= distance from the left side of the beam (in.)
- E = modulus of elasticity of the material (lbs/in^2)
- I = moment of inertia of beam (in^4)
- L = length of the beam (in)

Design Justification

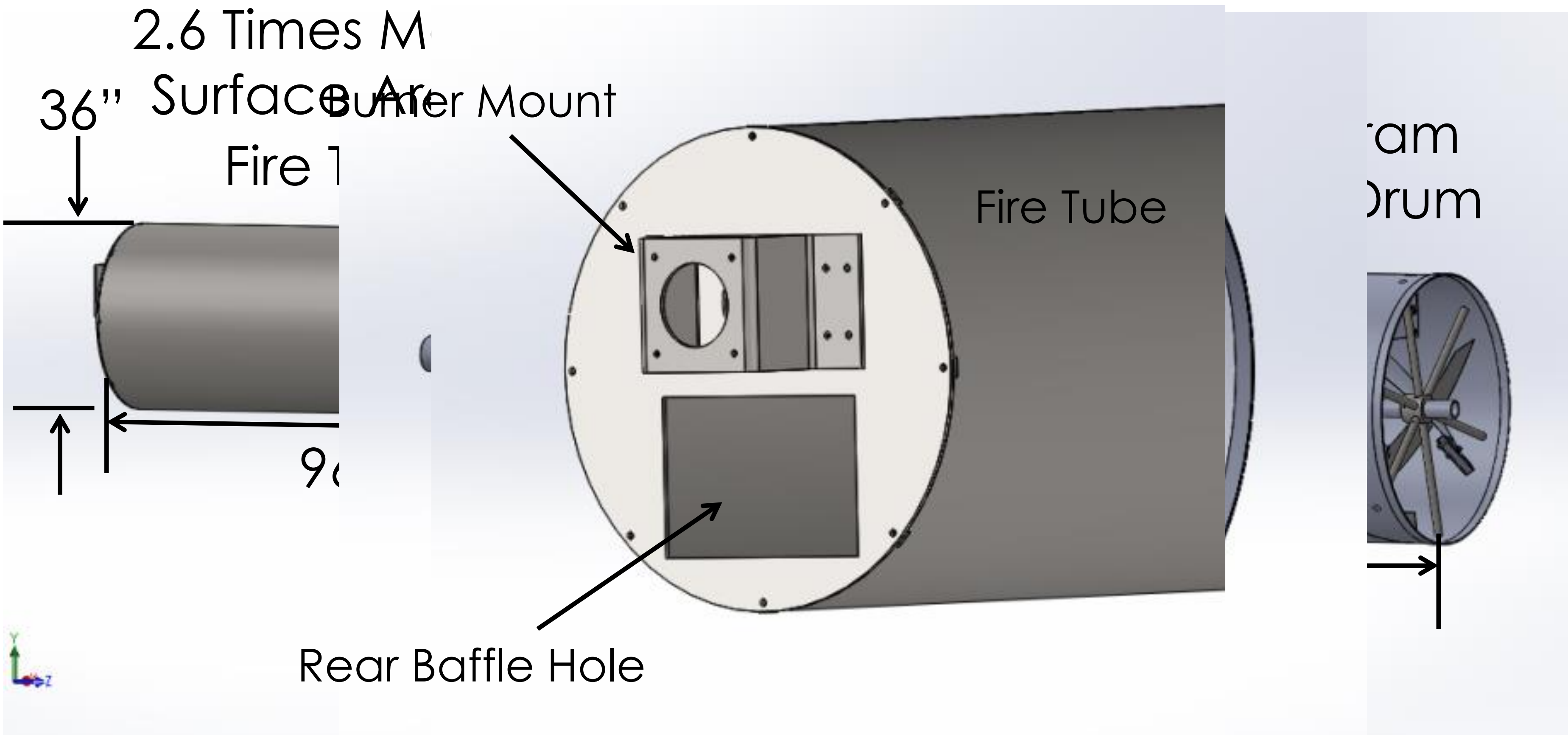
Pipe Size (in.)	Schedule	Displacement (in.)	Stress (KSI)	Factor of Safety
2.5	80	0.264	14.81	2.43
3	80	0.132	9.03	3.98



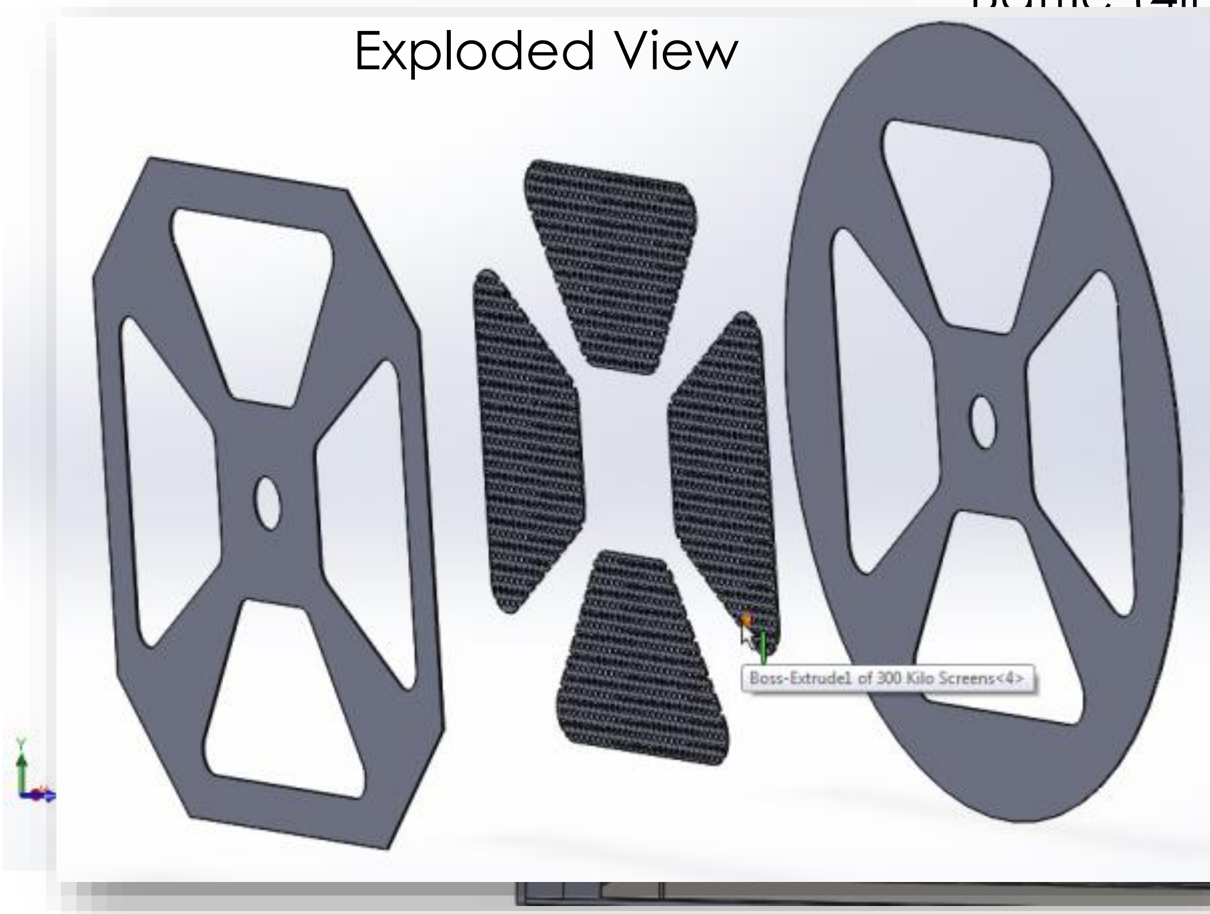
Max Displacement



Scope of Project



Stands, Shielding, and Face Plates

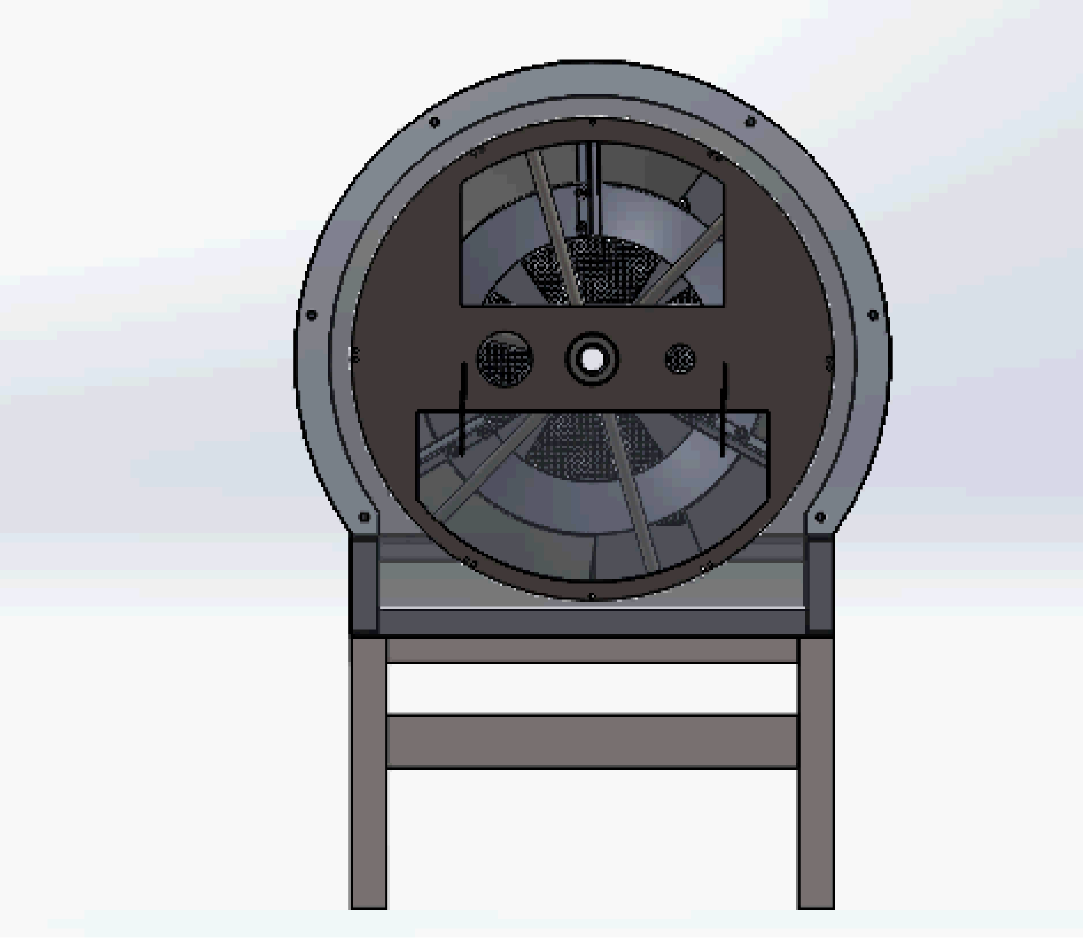


Baffle (4in. Fro

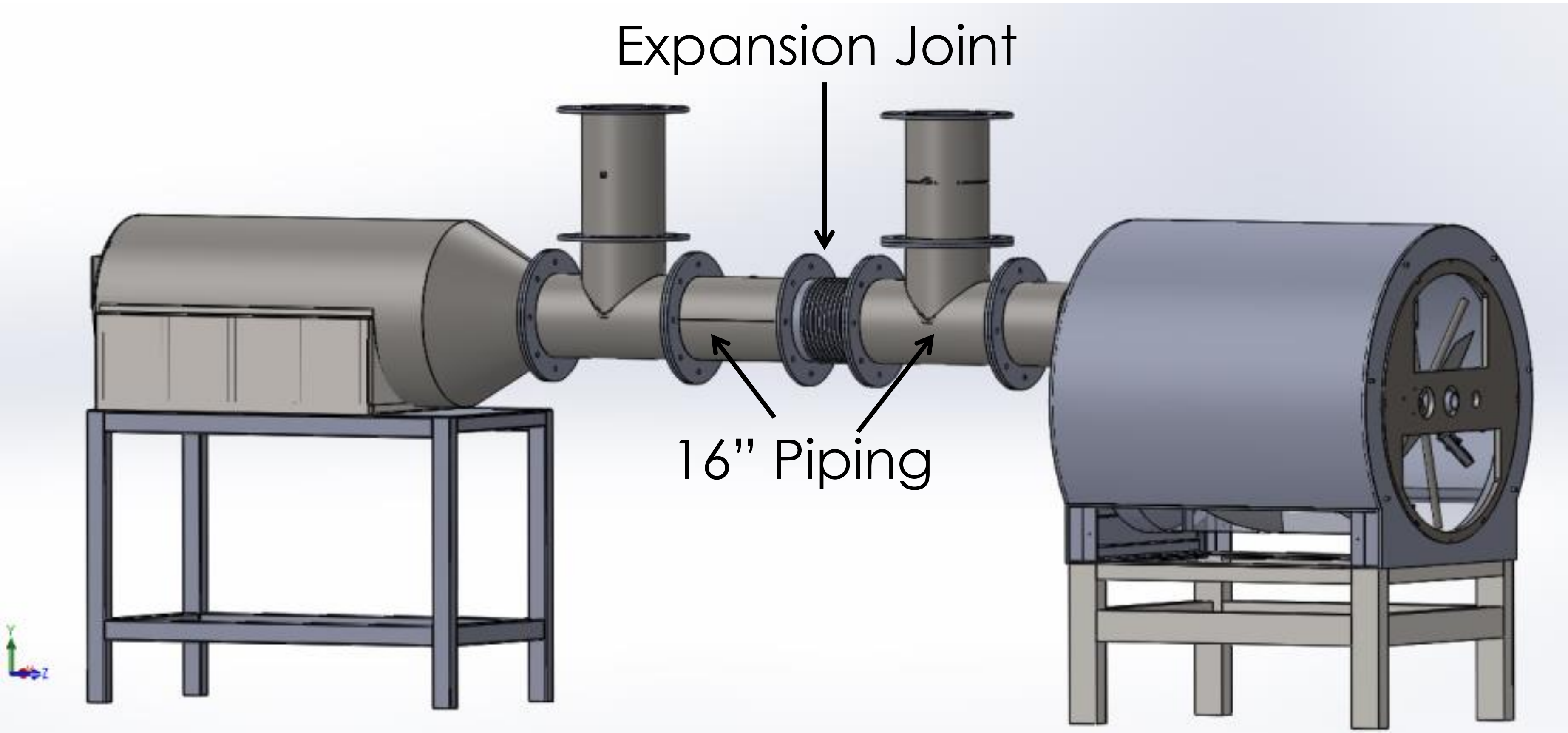
k Lift

Assembled View

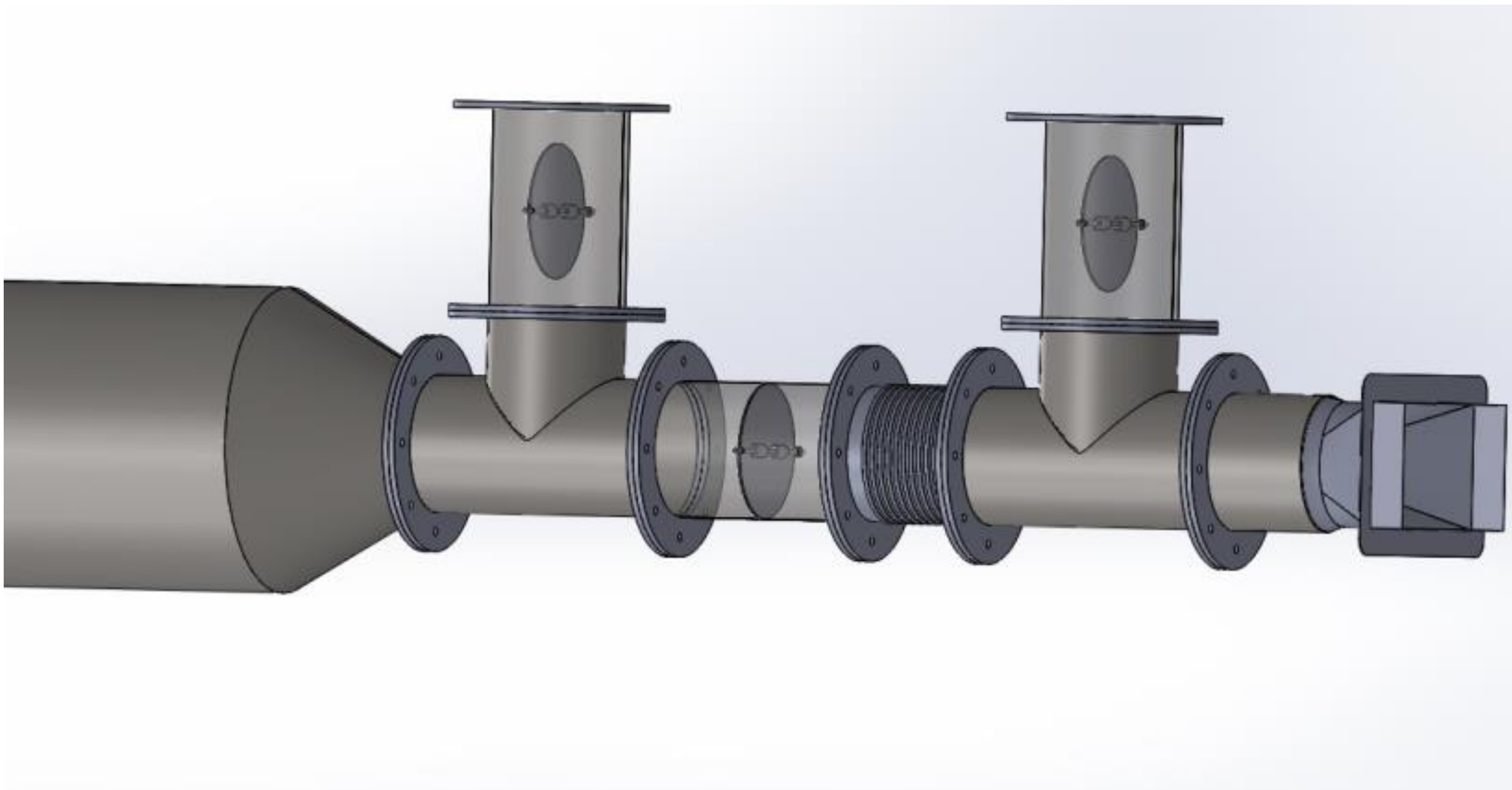
Drum Function



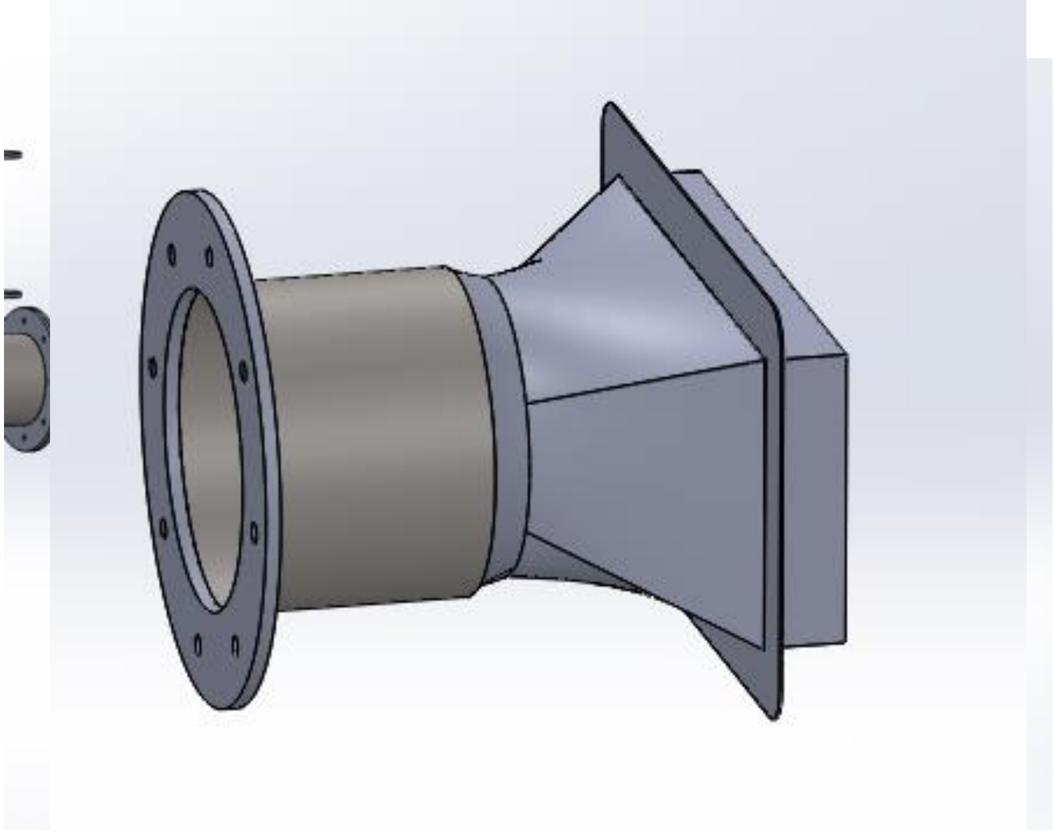
Fire Tube Plumbing



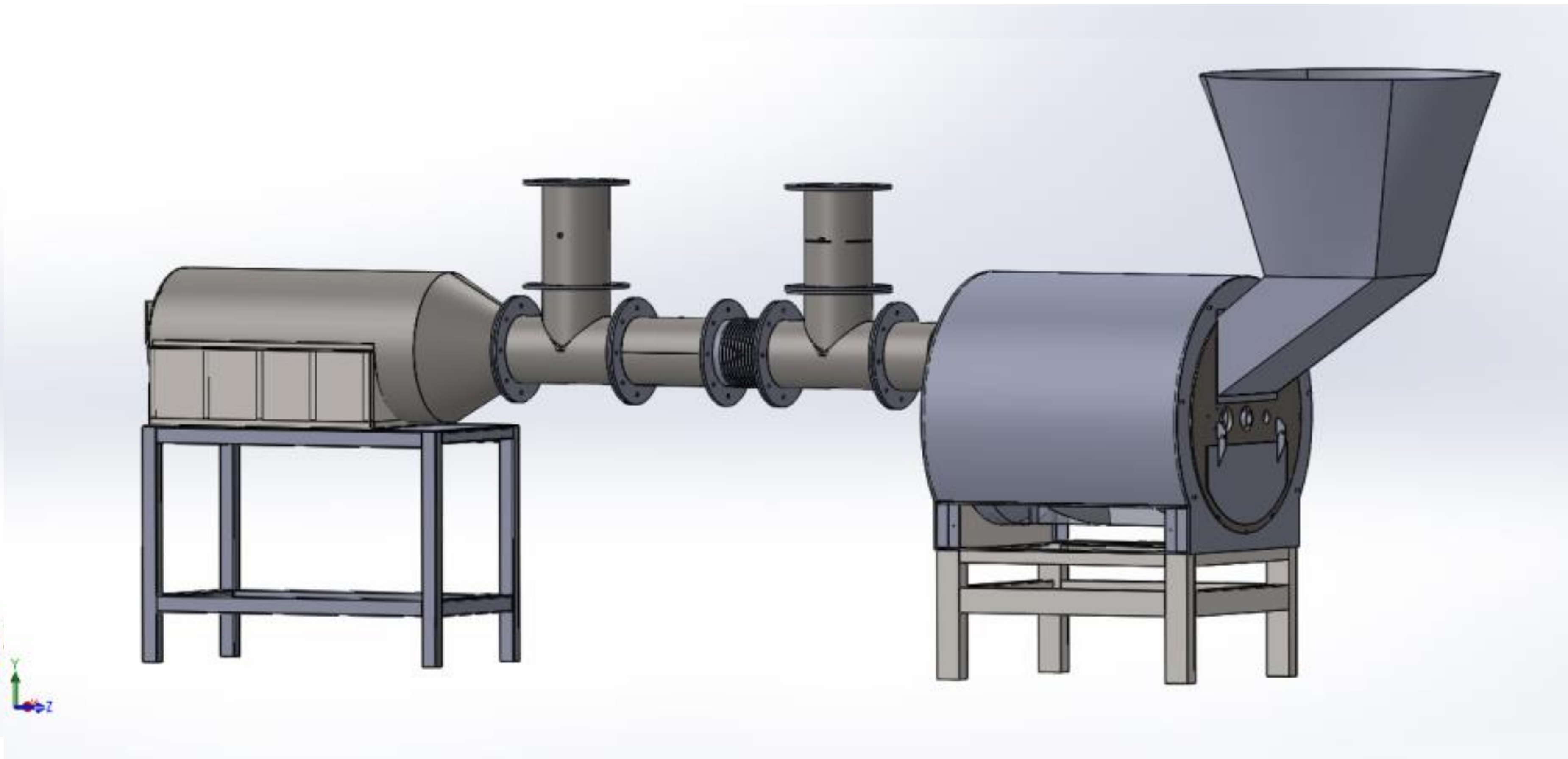
Fire Tube Plumbing



Fire Tube Plumbing



Future Work



Prototype Fabrication

Heating tube stand

Roaster stand

Prototype Fabrication

Prototype Fabrication

Drum Fabrication

Face Plate Fabrication

Drum Assembly Cost Analysis

Roaster Drum	Material	$ 3,025.00
	Labor	$ 5,700.00
Face Plates and Shields	Material	$ 5,000.00
	Labor	$ 1,710.00
Baffle	Material	$ 810.00
	Labor	$ 500.00
Shroud and Wrap	Material	$ 1,530.00
	Labor	$ 500.00
Drum Stand	Material	$ 717.00
	Labor	$ 720.00
Support Rods	Material	$ 150.00
	Labor	$ 60.00
Spider Assembly	Material	$ 525.00
	Labor	$ 2,500.00

Totals	
Material	**$ 11,757.00**
Labor	**$ 11,690.00**
Total	**$ 23,447.00**

Fire Tube Assembly Cost Analysis

Fire Tube	Material	$ 4,775.00
	Labor	$ 500.00
Fire Tube Back Mount	Material	$ 197.50
	Labor	$ 600.00
Burner Mount	Material	$ 25.00
	Labor	$ 100.00
Support Stand	Material	$ 224.32
	Labor	$ 720.00
Fire Tube Stand	Material	$ 801.55
	Labor	$ 480.00
Fire Tube Piping	Materials	$ 42,000.00
	Dampers	$ 850.00
	Expansion Joint	$ 1,490.00
	Labor	$ 1,110.00

Totals	
Material	**$ 49,513.37**
Labor	**$ 4,360.00**
Total	**$ 53,873.37**

Total Cost Analysis

Fire Tube Assembly	Material	$	11,757.00
	Labor	$	11,690.00
Drum Assembly	Material	$	49,513.37
	Labor	$	4,360.00
Miscellaneous	Material	$	250.00
	Labor	$	1,080.00

Totals

Material	**$**	**61,520.37**
Labor	**$**	**17,130.00**
Total	**$**	**78,650.37**

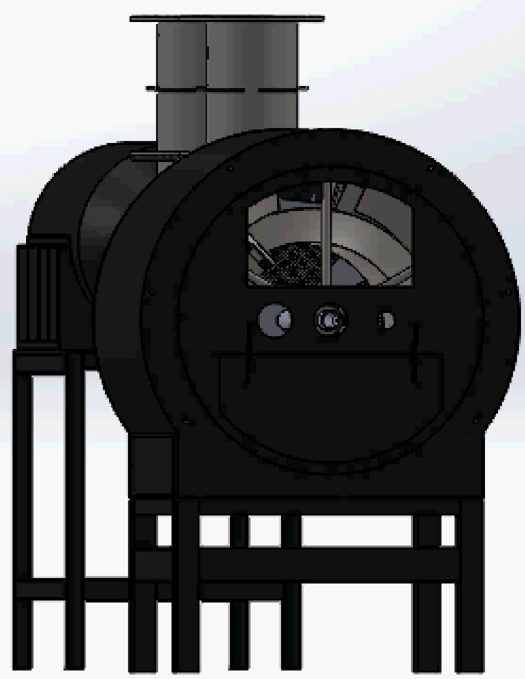
Conclusions

- The objectives were effectively completed
- US Roaster Corp is currently completing the remainder of our design
- Roaster and heating tube stands as well as the heating tube back plate were all manufactured at the Biosystems Design Lab
- Final assembly expected in July, 2014

Acknowledgements

- US Roaster Corp
  - Mr. Dan Jolliff
  - Mr. Joel Bomgren
  - Mr. Roger Scott
  - Mr. Richard Satter
- Dr. Tim Bowser
- Dr. Paul Weckler
- Dr. Dan Thomas
- BAE Shop
  - Mr. Wayne Kiner
  - Mr. Nick Semtner
  - Mr. Mike Fleming
  - Mr. Jason Walker

Questions?



U.S. Roaster Corp

Fall Semester Design Report: 300 Kilogram Roaster

Advisor: Dr. Tim Bowser

Brian Biggerstaff

Jeff Biggerstaff

Justin Ludwig

Jess Webb

Table of Contents

1.0 Project Overview

1.1 Mission Statement

Our mission is to assist U.S. Roaster Corp in the design of a 300 kilogram coffee roaster by modifying a smaller roaster design.

1.2 Problem Statement

Our objective is to help design a firebox and roaster drum for a new prototype 300 kilogram roaster.

1.3 Background

U.S. Roaster Corp is a company based in Oklahoma City, Oklahoma. U.S. Roaster Corp builds and remanufacturers coffee roasters. They offer a variety of sizes ranging from small scale roasters to large industrial roasters. U.S. Roaster Corp wishes to build a new large scale coffee roaster with a capacity of 300 kilogram. Currently, the largest roaster produced by U.S. Roaster Corp is a 150 kilogram roaster. They want to produce a larger roaster as requested by some customers. Furthermore, U.S. Roaster Corp currently faces some challenges with their current roasters. The process behind the roasting of coffee beans is quite simple but also very precise. For example, beans go through several stages at various temperatures and depending on the roast, temperatures need to be adjusted and maintained for precise periods of time. Beans rotate in a drum heated by a heating box providing hot air to the drum for a desired period of time anywhere from eight to thirteen minutes. Beans are then dispensed into a cooling pan with rotating arms and cool air blowing onto the beans to prevent further cooking. One challenge is the rubbing of the drum caused by metal expansion due to high temperatures. Another challenge, or desired change, is the location of their heat input and overall heating box design.

2.0 Scope of Work

U.S. Roaster Corp requested that the team assists them in design of a firebox and roaster drum for a 300 kilogram roaster.

- Regularly met and discuss progress with our client.
- Conducted patent searches on roaster designs.
- Obtained a general knowledge of the coffee roasting process.
- Converted CAD drawings into Solid Works drawings.
- Researched different types of steel to withstand high temperatures.
- Investigated four alternative roaster designs.

3.0 Patent Search

The patent search revealed most patents applied to small scale designs but the team found three patents applicable to our design. The first patent, United States Patent US 7,003,897, which was a coffee roaster drum rocker arm roller bearing system. The inventors are James B. Lingle and Alexandru Scantee of 6500 S. Garfield, Bell

Gardens, CA 90201. The patent application number is 10/998,097 and it was filed on November 29, 2004. The second patent found in the search was International Patent WO 2009/075893. This patent applied to recirculated airflow which our client mentioned might be a possibility for this design in the future. The applicant and inventor is Daniel Sadamu Hyama of 564 North Virgil Ave. #14, Los Angeles, CA 90004. The filing date on this patent was December 8, 2008. The third and final patent discovered in the patent search was International Patent WO 03/011050. This patent applies to a filtered exhaust airflow may be a part of the project later. Daniel Sadamu Hyama is the applicant and inventor of 2940 Grace Lane, Costa Mesa, CA 92627. The filing date was July 30, 2002.

4.0 Design Objectives

This report includes four alternative designs for a 300 kilogram coffee roaster with variations in materials used, heat flow location, process for turning the drum, and the drum dimensions. In order to meet U.S. Roaster Corp's expectations, the design team desires to meet the following criteria:

1.) Allow for at least 300 kilogram capacity based on 40% volumetric fill of coffee beans occupying a space of 22 lbs./ft^3

2.) Design needs to be durable to last for several years

3.) Drum needs to expand less than current design

4.) No spilling of product

5.) Quick cleanout of the drum to ensure that the coffee beans do not over roast

6.) Material of the drum needs to withstand at least 1000 °F for cleaning purposes

7.) Firebox needs to be at least 100 ft^3 and no taller than 12 feet

8.) Make sure design is efficient and takes up as little space as possible

5.0 Technical Approach

5.1 Material Selection

Currently U.S. Roaster Corp uses 304 Stainless Steel for the design of the 150 kilogram roaster. There is an expansion issue with the use of 304 Stainless Steel due to the thermal properties. The unheated diameter of the 150 kilogram roaster is 37.75 inches and the unheated length is 47.25 inches. The drum experiences temperatures up to 1000°F during the coffee roasting process. Under this condition, the 150 kilogram roaster expands to a length of 47.68 inches and a diameter of 38.10 inches. The expansion causes drum clearance issues with other components of the roaster. The group was advised to look into 400 Series Stainless Steel. Table 1 provides a summary of material properties of different metals that were considered for the 300 kilogram roaster design.

Table 1. Summary of various material properties.

Metal Type	Property Notes
304 Stainless	Expands too much for the application. Current troubles with this expansion
RA 330	Similar properties to 304 Stainless
410 Stainless	Less resistant to corrosion than 430, used a lot in knives and kitchen utensils
422 Stainless	High temperature resistance up to 1200 degrees F, have not located a source
430 Stainless	Good heat resistance up to 1500 degrees F, typical in gas burners and oil refinery equipment
436 Stainless	High temperature applications such automotive exhaust applications
Inconel	Costly and very heavy, may be possible for the firebox

Based on the group's research and client preferences, the team decided to use either 430 Stainless Steel or 436 Stainless Steel depending on which material is available by a supplier. After checking with several different suppliers, the selection of 430 Stainless Steel was selected. Calculating the thermal expansion for 430 Stainless Steel, the new length of the 300 kilogram drum is 62.39 inches from an initial length of 62 inches and the new diameter is 52.32 inches from an initial diameter of 52 inches. Tables 2 and 3 below show the original dimensions of the 300 kilogram drum and the thermal expansion properties of the 300 kilogram drum.

Table 2. Initial dimensions of the 300 kilogram drum.

300 kilogram Roaster Dimensions		
Diameter	52	in
Length	62	in

Table 3. Thermal expansion calculation of the 300 kilogram drum.

Metal Type	Cp	Length after heating (in)	Diameter after heating (in)
430 Stainless	6.30E-06	62.39	52.328

Our client wants less expansion from the material used on the roaster drum and 430 Stainless Steel provides an adequate solution.

5.2 Design Approach

The team has to consider the manufacturing capabilities of U.S. Roaster Corp in the design process. U.S. Roaster Corp prefers not to use complex shapes in the design process. Some designs have been verified by U.S. Roaster Corp to ensure that they have those capabilities.

5.3 Alternative Designs

U.S. Roaster Corp is a competitive manufacturer that is always advancing the quality of its products and expectations of its customers. It is because of that competitive drive that U.S. Roaster Corp has decided to build the largest coffee roaster to date. They have asked us to design the drum for a 300 kilogram roaster. In addition, they have also asked us to change the way the heating air is used in cooking the coffee beans. This involves designing a firebox to contain the heat and routing the air to the roasting drum in a different way. The method the team followed when addressing these problems is explained in the following design alternatives.

5.3.1 Alternative 1

Our first alternative design is based upon the already proven design which U.S. Roaster Corp. already has in production. This design takes the baseline design of the current 150 kilogram roaster and addresses the areas where durability is a problem, while also being designed to allow for roasting a batch of 300 kilograms. Even though a similar design is already in production, the team was faced with the complication of thermal expansion of the actual drum as the heat is applied. As the drum size is scaled up, the amount of thermal expansion increases. This causes complications of clearance tolerances between the rotating drum and stationary plates on each end of the drum. In order to counter this issue, our design will use 430 stainless steel. 430 stainless steel will allow for less thermal expansion than the current drum, which is being constructed from 304 stainless steel. Supporting calculations for this can be seen in Table 3. By doing this, our client will be able to manufacture a drum that will have clearance tolerances small enough to ensure no product is lost during the roasting process while not inhibiting rotation. To address the problem of durability on the existing design, the air flow into the roaster was rerouted in a method which would allow for a more centralized heating method, as opposed to the old heating method where the heat was applied directly to the outside walls of the drum. The new method uses our "vortex flow inlet." This inlet will allow for the heated air to enter the drum through the stationary rear plate. The air flow inlet will be angled so that as it enters the rotating drum, the air flow will meet with the rotating drum and its contents in a method which will result in the air making a vortex. As a result, there will be more evenly dispersed heat throughout the drum. The angled inlet directs into the drum in a clockwise rotation which is consistent with the drums rotation. This ensures that the heated air encounters less resistance than if it were to be inserted with the air flow being directed in a simple linear direction. The theoretical air flow pattern can be seen in Figures 1 and 2. As the air enters the drum it is complimented by the clockwise rotation of the drum as can be seen in Figure 2. By using this method, the air is more evenly dispersed throughout the entire drum than the conventional method of heating strictly the outer walls of the drum. The design will decrease the amount of heat applied during a regular roast to the outer walls of the drum which will increase durability and longevity of the roasting drum as well as improve roast quality.

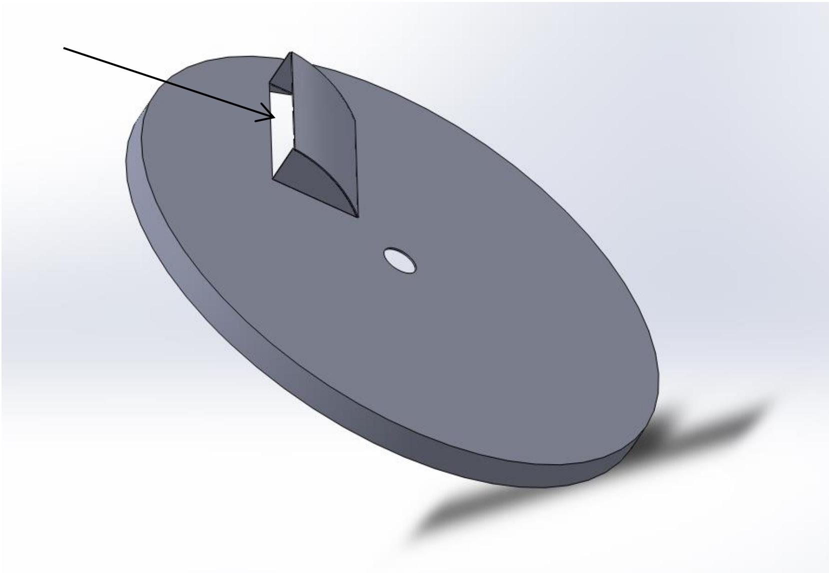


Figure 1. Vortex Flow Inlet design mounted to the rear stationary plate.

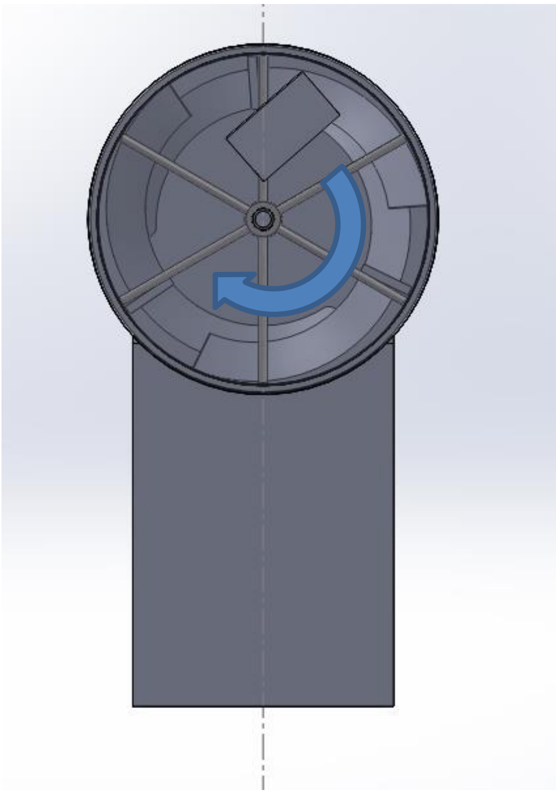


Figure 2. Theoretical airflow projection with use of Vortex Flow Inlet.

5.3.2 Alternative 2

Building upon the first alternative design, the team investigated a second design which eliminated the shaft support through the center of the drum. This design would be the same as design alternative 1, with only a change in the supporting structure. Instead of a rotating center support shaft, this design would be supported by a roller system as seen in Figure 3. By doing this the center support shaft is eliminated altogether. As a result of doing this, there is no worry in the effect the drum's expansion has on the drive mechanism, since the drum will be able to float on the rollers as it endures expansion. However, this does not address the problem of linear expansion in the areas where rotating components meet with the stationary components. The rollers would be mounted onto a support stand and the drum's weight would rest on the rollers. The drum would be powered by an electric motor connected via chain and gear connected to an external shaft on the end of the drum similar to the way U.S. Roaster Corp powers their drums currently. This design seemed plausible for the support of the extra weight in the 300 kilogram roaster. However, after calculations, the team realized that a center shaft through the drum would in fact support the weight of a 300 kilogram roaster. Considering all the new changes associated with a roller design, the team decided to remain with the center shaft design solely for the previous experience and knowledge associated with that design.

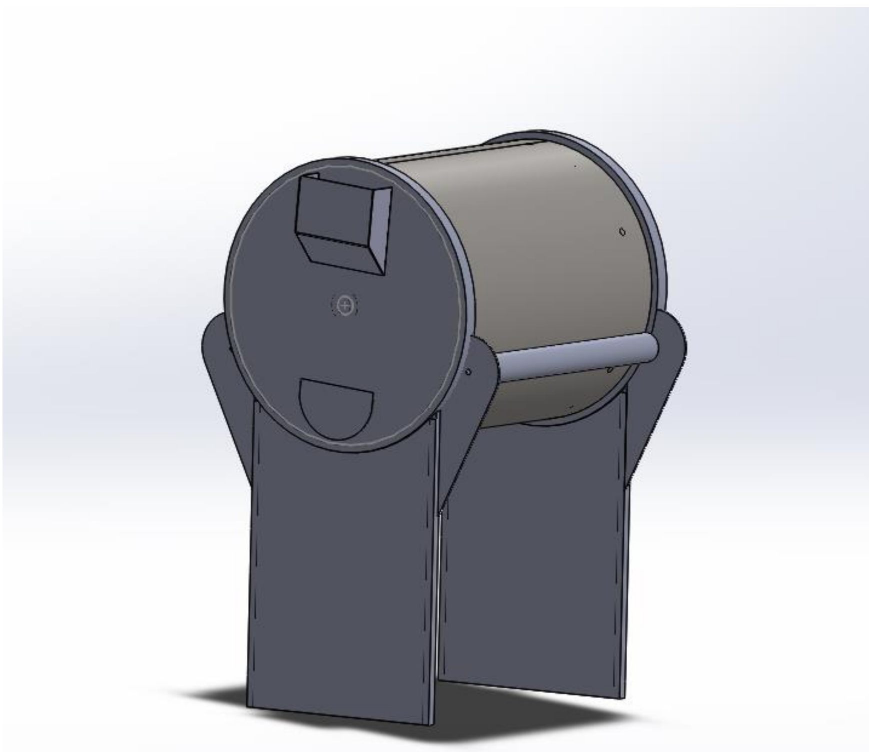


Figure 3. Alternative design concept 2 featuring rollers to support the weight of the drum instead of center support shaft.

5.3.3 Alternative 3

For design alternative 3, a drastic change in approach was taken. Knowing that there would be a large amount of thermal expansion the team projected that it would be best to focus the heat at the center of the drum to ensure the walls of the drum were heated only to the point where the beans would roast. In this design the drum would be stationary. This addresses the issues the current design has with the expansion hindering the clearance tolerances where the rotating and stationary components meet. This design proposed running a solid shaft through the center of the drum. The shaft would rotate while the drum would remain stationary. On this shaft would be agitators with tines to stir the beans during the roasting process. Each of these agitators would house an individual heating element with sensor connected to a controller that would cycle power to the heating element depending on the temperature in that area of the drum. Doing this would ensure a stable, even, roasting temperature for all of the beans. Further analysis of this model showed many problems concerning the beans during the roasting process. One problem being the rotating agitators would be too rough and most likely damage the beans while in the drum. Another potential problem with this design was the inability to agitate the beans in a manner that would ensure all of the beans were continuously mixed. This would be a result due to using a stationary drum. Since this design has no previous research or experimentation it is expected to have many more problems that would arise as testing would take place. With all of these expected issues it was determined that this design was by far inferior to the current design.

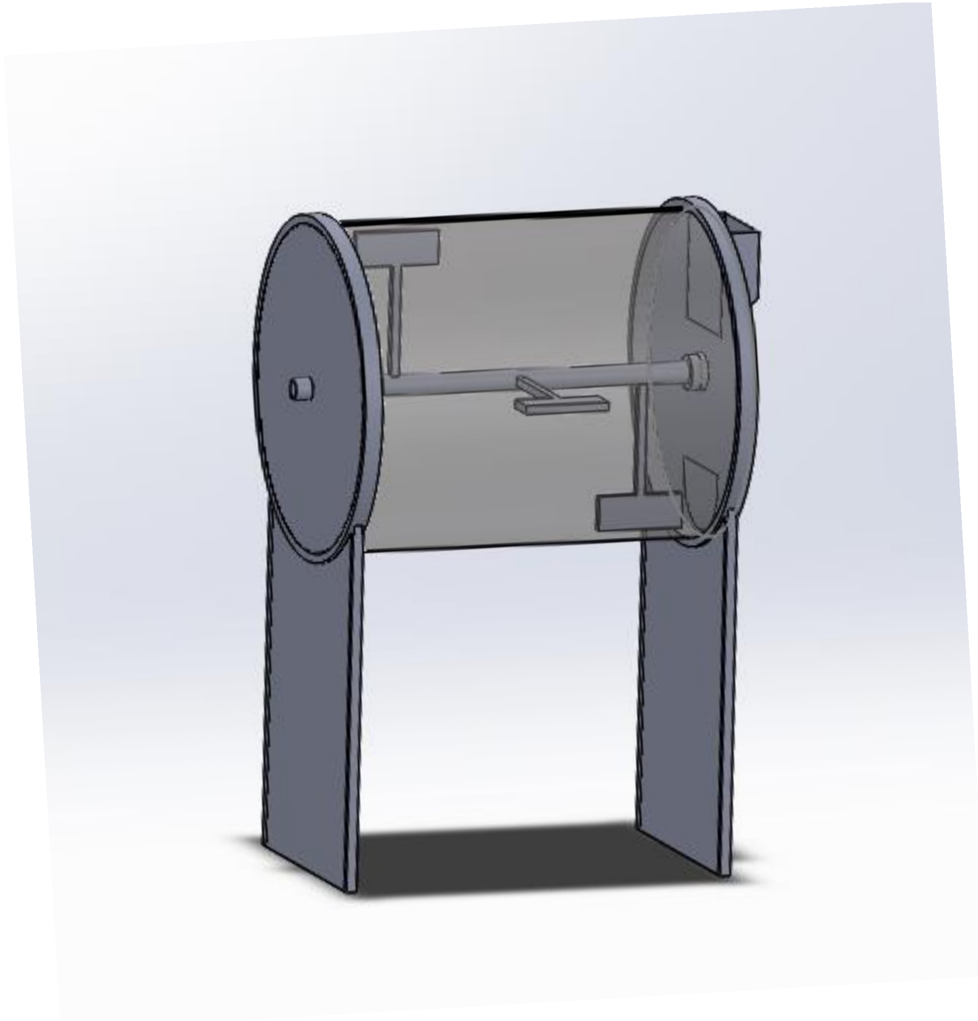


Figure 4. Alternative design concept 3 using agitators featuring a stationary drum.

5.3.4 Alternative 4

Of all of the designs, design 4 is the most exotic and the most experimental. Instead of a rotating drum with applied heat, it consists of a vibrating conveyor belt through a tunnel with heat applied from all sides. A layer of beans would be applied onto the conveyor belt and then carried through the tunnel on the vibrating conveyor. The vibrations would ensure that the beans are moved around and cooked evenly. The length of the conveyor would be determined on the time exposed to heat that would be required to fully cook the beans. This idea would operate similarly to a pizza oven. By doing this a continuous flow of beans would be roasted and there would be less downtime resulting in a more efficient system. Due to how exotic this idea is, it would be best to design this continuous system on a small scale before attempting a large scale design. The team feels it could hold value in a future design when there is more available design and testing time.

Figure 5. . Alternative design concept 4 showing an example of a small conveyor style oven.

.

5.3.5 Selected Alternative

When trying to determine the best alternative, the team tried to choose the design that would be the best fit for U.S. Roaster Corp. The team felt the best design would be the one that was the most similar to the current design while still maintaining the high standard of quality associated with U.S. Roaster Corp Products. Therefore, the group selected alternative 1 as the desired alternative. The drum dimensions and rotational powering are simply scaled up versions of the current design. There have been concerns about the structural stability of the scaled up version of the current design due to the added weight. To address these concerns, the following calculations have been performed and are shown in Tables 4 and 5. The fatigue factor of safety was calculated by using a modified-Goodman failure criteria (Budynas, 2011):

Equation 1: $$n_f = \frac{1}{\frac{\sigma_a}{S_e} + \frac{\sigma_m}{S_{ut}}}$$

The variables are: $n_f = safety\ fatigue\ factor, \sigma_a = amplitude\ component, \sigma_m = midrange\ component, S_e = endurance\ strength, and\ S_{ut} = ultimate\ strength$. The midrange and amplitude component are from the following equations:

$$\text{Equation 2}: \sigma_m = \frac{\sigma_{max} + \sigma_{min}}{2}\ and\ \sigma_a = \left|\frac{\sigma_{max} - \sigma_{min}}{2}\right|$$

with $\sigma_{max} = maximum\ stress\ and\ \sigma_{min} = minimum\ stress$. The endurance strength was calculated using the following equation:

$S_e = k_a k_b k_c k_d k_e k_f S_e'$ (Budynas, 2011) where $k_a = surface\ condition\ modification\ factor, k_b = size\ modification\ factor, k_c = load\ modification\ factor, k_d = temperature\ modification\ factor, k_e = reliability\ factor, S_e' = rotary - beam\ test\ specimen\ endurance\ limit\ and\ S_e = endurance\ limit\ at\ the\ critical\ location\ of\ a\ machine\ part\ in\ the\ geometery\ and\ condition\ of\ use.$ $S_e' = 0.5 S_{ut}$ for our application purposes.

The modification factors come from equations or tables (Budynas, 2011). The factors are as follows: $k_a = aS_{ut}^b,$ and $k_b = 0.91 d^{-.157}$ where $S_{ut} = ultimate\ strength, a\ and\ b\ Marin\ Surface\ Modification$

$Factors, and\ d = diameter$. The $k_{c,} k_d, and\ k_e$ factors come from various tables (Budynas, 2011). The k_f factor equals one for our purposes.

Table 4. Modified Goodman failure criteria safety factors.

Calculated Fatigue Safety Factors		
Force = 1500 lbs		
Pipe Size (inch)	Schedule	Safety Factor
2.5	40	33
2.5	80	22
3	40	32
3	80	44
Force = 2000 lbs		
Pipe Size (inch)	Schedule	Safety Factor
2.5	40	18
2.5	80	24
3	40	23
3	80	31

The safety factors listed in Table 4 show that the shaft will not fail due to fatigue. The shaft will have an infinite life. An infinite life means that the shaft will survive at least one million cycles. Deflection of the shaft was also calculated by using an equation for a cantilevered beam with an end load. The equation is:

$$\text{Equation 3}: y_{max} = \frac{-Fl^3}{3EI}$$

(Budynas, 2011) where $F = load, l = length, E = modulus\ of\ elasticity, and\ I = second\ moment\ of\ area\ about\ x\ axis$.

Table 5. Deflection calculations for the shaft.

Calculated Deflection		
Force = 1500 lbs		
Pipe Size (inch)	Schedule	Deflection (inches downwards)
2.5	40	0.019
2.5	80	0.016
3	40	0.001
3	80	0.008
Force = 2000 lbs		
Pipe Size (inch)	Schedule	Deflection (inches downwards)
2.5	40	0.026
2.5	80	0.021
3	40	0.013
3	80	0.010

The maximum bending moment was also calculated by using an equation from *Shigley's Mechanical Engineering Design* (Budynas, 2011). The equation is:

Equation 4: $\sigma = \frac{Mc}{I}$ where $M = moment, c = the\ distance\ from\ the\ central\ axis, and\ I = moment\ of\ interia\ about\ the\ neutral\ axis$.

Table 6 shows the maximum bending moment for the shaft. The moment was calculated by the load being a distance of thirty-one inches from the end of the shaft.

Table 6. Maximum bending moment for the shaft.

Calculated Deflection		
Force = 1500 lbs		
Pipe Size (inch)	Schedule	Bending (lb/in)
2.5	40	43,976
2.5	80	34,814
3	40	27,034
3	80	20,919
Force = 2000 lbs		
Pipe Size (inch)	Schedule	Bending (lb/in)
2.5	40	58,635
2.5	80	46,419
3	40	36,047
3	80	27,892

6.0 Firebox

The design of the firebox was subcontracted to a freshman project team composed of Zachary Hall, Tyler Heape, Benjamin Jenkins, and Hailie Snyder. The group was tasked to determine the most efficient design for heating air flow. The firebox had to be able to withstand 2000°F with 5000 cubic feet per minute of air flowing out to the roasting drum. Also, the firebox had a necessary volume of 100 ft^3. The freshman team researched fireboxes and found a design that featured a shelf with an opening to create an expansion chamber within the firebox. In order to test the design idea, they used the SolidWorks flow simulation to determine if the shelf would improve the outlet temperature. The two designs tested in SolidWorks can be seen in Figure 6.

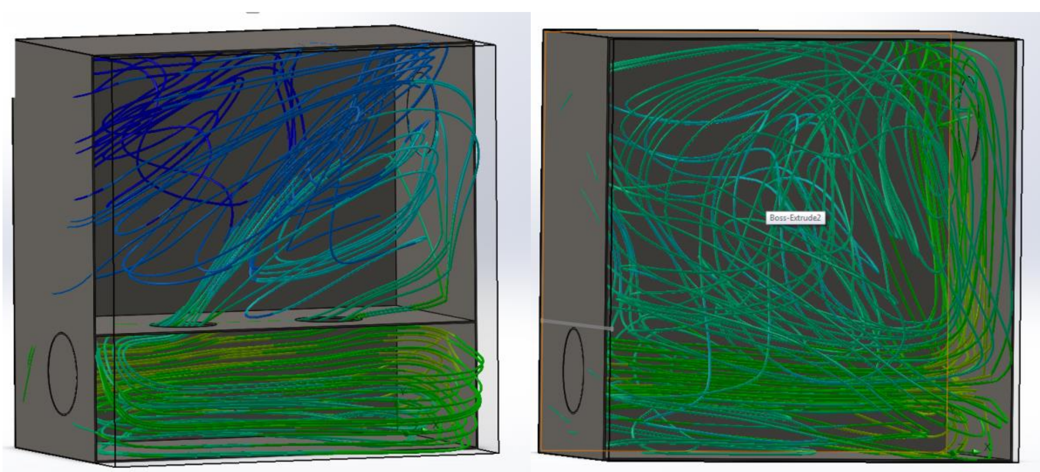


Figure 6. The two firebox designs, one with a shelf and one without, tested by the freshmen project team.

The team researched insulation materials and found K-23 Fire Bricks to be an adequate insulating material. The estimated thermal conductivity (.24 $W*m^{-1}*K^{-1}$) along with the melting temperature (2750°F) of K-23 were used in the SolidWorks simulation. The outlet temperature from the two designs can be seen in Table 7.

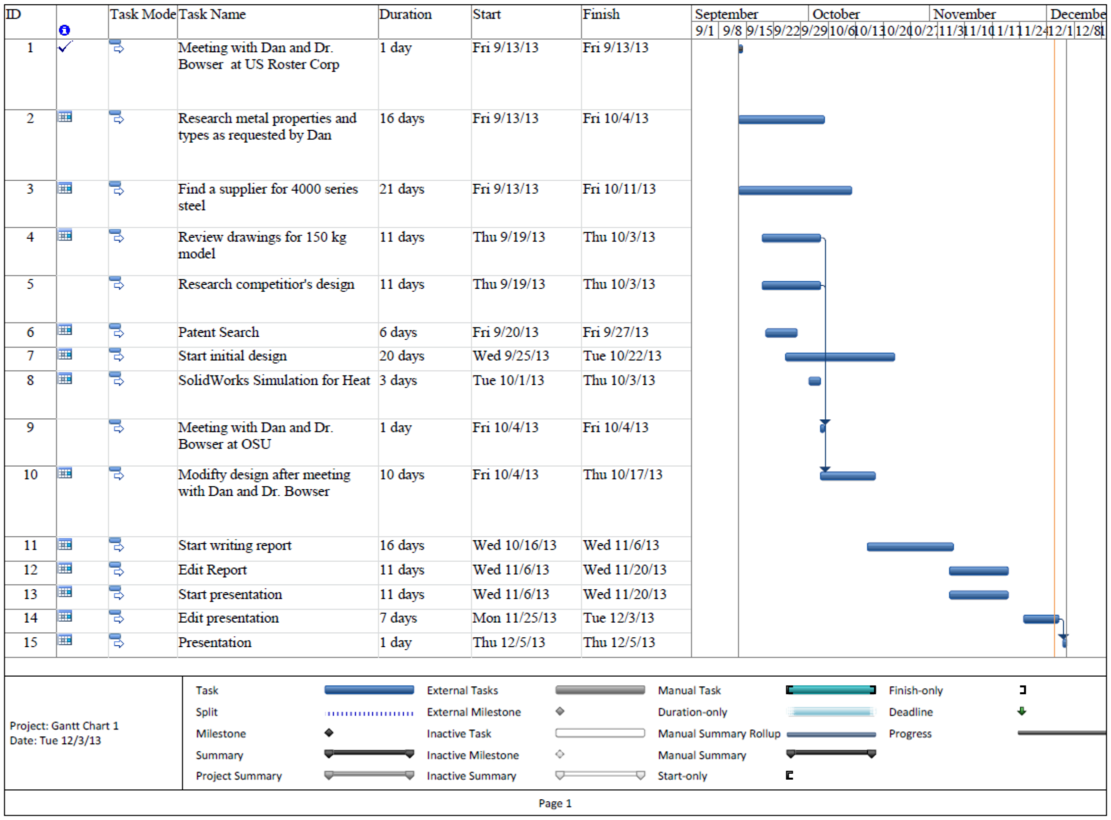
Table 7. The outlet temperature from the two firebox designs.

Design Type	Temperature (°F)
With Shelf	827.11
Without Shelf	1868.34

The team decided to use the fire box design without the shelf. The shelf restricts the flow of heat causing the majority of the heat to be trapped below the shelf. The design without the shelf adequately allows the heat to be evenly distributed throughout the fire box.

7.0 Project Management

In order to meet expectations given to our team by U.S. Roaster Corp, our team had to practice a great deal of time management. From coordinating times to meet with four different schedules, to staying organized in our progression of work, time management was key in our progression. To help with time management our group created the following Gantt chart in order to stay focused on tasks within a certain time frame:



ID	Task Mode	Task Name	Duration	Start	Finish
1		Meeting with Dan and Dr. Bowser at US Roster Corp	1 day	Fri 9/13/13	Fri 9/13/13
2		Research metal properties and types as requested by Dan	16 days	Fri 9/13/13	Fri 10/4/13
3		Find a supplier for 4000 series steel	21 days	Fri 9/13/13	Fri 10/11/13
4		Review drawings for 150 kg model	11 days	Thu 9/19/13	Thu 10/3/13
5		Research competitor's design	11 days	Thu 9/19/13	Thu 10/3/13
6		Patent Search	6 days	Fri 9/20/13	Fri 9/27/13
7		Start initial design	20 days	Wed 9/25/13	Tue 10/22/13
8		SolidWorks Simulation for Heat	3 days	Tue 10/1/13	Thu 10/3/13
9		Meeting with Dan and Dr. Bowser at OSU	1 day	Fri 10/4/13	Fri 10/4/13
10		Modifty design after meeting with Dan and Dr. Bowser	10 days	Fri 10/4/13	Thu 10/17/13
11		Start writing report	16 days	Wed 10/16/13	Wed 11/6/13
12		Edit Report	11 days	Wed 11/6/13	Wed 11/20/13
13		Start presentation	11 days	Wed 11/6/13	Wed 11/20/13
14		Edit presentation	7 days	Mon 11/25/13	Tue 12/3/13
15		Presentation	1 day	Thu 12/5/13	Thu 12/5/13

Figure 7. Project Gantt Chart.

7.1 Budget:

U.S. Roaster Corp allotted a $50,000.00 - $100,000.00 budget for our design team. This budget allows for material costs such as, purchased stainless steel, insulation, and miscellaneous steel for a fire box frame and piping. U.S. Roaster Corp manufactures their roasters and therefore, our team will not need to purchase materials on our own. Our team has chosen 430 series stainless steel and the team is currently obtaining quotes from several companies on pricing. A detailed budget which tracks individual pricings of all purchases will be added to a final report in the future once purchases are actually made.

7.2 Future Work

Looking forward into the spring semester the team will continue to work on the design of the 300 kilogram coffee roaster. Beginning in January the team will have a meeting with Dan Jolliff, owner of U.S. Roaster Corp to finalize our design. If all of the requirements are met, and Mr. Jolliff is content with our product, construction will begin. The construction of this prototype roaster will be performed by U.S. Roaster Corp at their manufacturing facility over an estimated period of 2-3 months. Following completion of construction, the team will begin testing the products expansion and durability properties. Any issues with the design will be addressed. If enough time is provided, the team has considered to further test their design. This would be done by varying the drums inner flighting dimensions to optimize the drums mixing and emptying capabilities.

8.0 Conclusion

Upon receiving a problem statement of designing a 300 kilogram coffee roaster, our team has worked diligently to work towards an initial design for U.S. Roaster Corp. A mission statement was created as well as a scope of work and Gantt chart to track progress. A period of researching metal expansion properties was undertaken until 430 series stainless steel was selected. Furthermore, four alternative drum designs were investigated and a final design chosen from the four to meet client expectations. The chosen design was selected after several calculations regarding bending stress, fatigue life, and deflection on the shaft that supports and turns the drum. The selected design meets efficient heat inflow changes and was scaled up to twice the capacity of the current 150 kilogram roaster. Finally, the group plans to begin finalizing the selected design with U.S. Roaster Corp and begin the testing phase of the design. Eventually the group plans on coordinating with U.S. Roaster Corp the start of the manufacturing process. The team looks forward to building of the prototype and testing.

9.0 References

Budynas, R. G., and J. K. Nisbett. 2011. Shigley's Mechanical Engineering Design. 9th ed. New York, NY, USA: McGraw-Hill.

Dan Jolliff

Dr. Dan Thomas

Dr. Tim Bowser

Dr. Paul Weckler

Thermal Expansion Metals. Available at: http://www.engineeringtoolbox.com/thermal-expansion-metals-d_859.html. Accessed 2 October 2013.

U.S. Roaster CORP.

300 KG Roaster Design

Brian Biggerstaff

Jeff Biggerstaff

Justin Ludwig

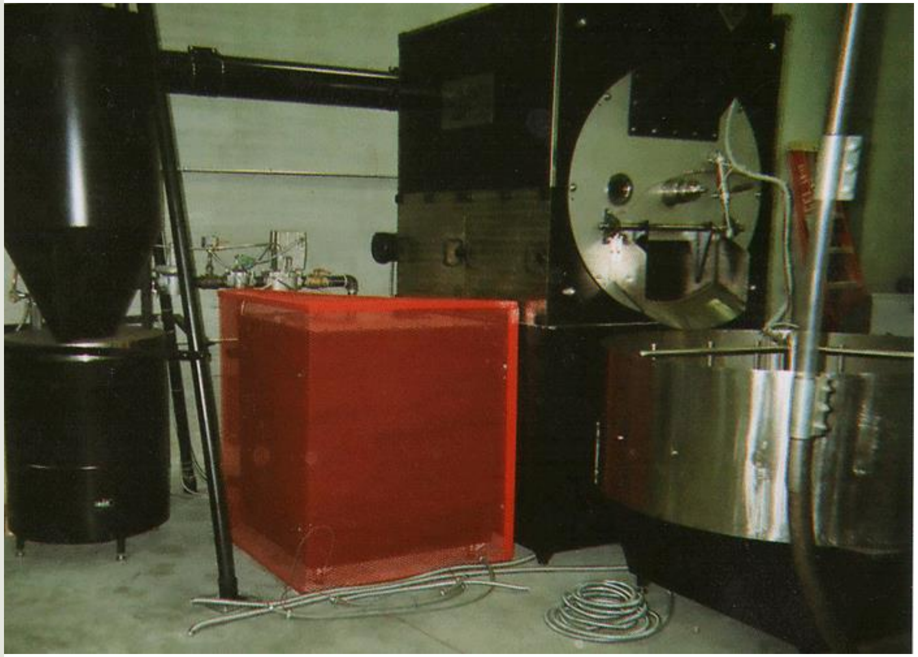
Jess Webb

Mission Statement / Objectives

- To assist U.S. Roaster Corp.in the design of a 300 kg coffee roaster by modifying the current smaller roaster designs
- Finalize materials for the new drum and heating box that meet client expectations
- Choose a material for the drum that allows minimal expansion to prevent rubbing on the edges of casting

Roasting Process

- Green beans enter from the top via funnel
- Beans enter drum and are spun at desired temperatures until "2nd crack phase"
- Once desired roast is reached, the beans are ejected into a cooling pan and mixed
- http://www.youtube.com/watch?feature=player_detailpage&v=BUhpg9RbafM



Roasting Process Cont.

- Bean stages:
  - Green stage
  - Yellow Stage: **200 F – 250 F**
  - Light Brown Stage: **250 F – 300 F**
  - First Crack: **355 F – 400 F**
  - Second Crack: **Up to 500 F**

- Process time: **8 – 13 Minutes** depending on desired roast

Desired Modifications

- Using a different type of metal with lower thermal expansion properties
  - Currently, the drum's expansion causes rubbing against the casting wall and also creates a gap where beans can fall out
- Change the location of heating source on the drum
  - Currently, heat sets directly under the drum causing temperature control issues
- Using a different system for the support of the drum
  - Currently, a shaft supports the drum's weight. With the upscale and addition of weight, a roller support system system is desired

Scope of Work

- Regularly meet and discuss progress with project affiliate
- Patent research on roaster designs
- Obtained a general knowledge of the process of coffee roasting
- Researched different types of steel to withstand high temperatures
- Investigated 4 alternate roaster designs

Patent Searches

- Most patents applied to small scale designs
- United States Patent US 7,003,897
  - Coffee Roaster Drum with Rocker Arms
- International Patents WO 2009/075893, WO 03/011050
  - Recirculated Airflow, Filtered Exhaust Airflow

Alternatives Considered

- Materials Considered
- Roaster Designs Considered

Materials Considered

- US Roaster Corp currently uses 304 stainless steel
- Our client advised us to look into 400 series stainless
  - Find the metal that is applicable to the process
  - Find a supplier
- Narrowed the metal to three choices
  - 422 Stainless
  - 430 Stainless
  - 436 Stainless

Materials Considered

Metal Type	Property Notes
304 Stainless	Expands too much for the application. Dan has had trouble with this expansion
RA 330	Similar properties to 304 Stainless
410 Stainless	Less resistant to corrosion than 430, used a lot in knives and kitchen utensils
422 Stainless	High temperature resistance up to 1200 degrees F, have not located a source
430 Stainless	Good heat resistance up to 1500 degrees F, typical in gas burners and oil refinery equipment
436 Stainless	High temperature applications such automotive exhaust applications
Inconel	Costly and very heavy, may be possible for the firebox

Materials Considered

Metal Type	150 Kg ΔD (in)	300 Kg ΔD (in)
304 Stainless	0.347	0.478
RA 330	0.351	0.484
410 Stainless	0.245	0.338
422 Stainless	0.234	0.322
430 Stainless	0.238	0.328
436 Stainless	0.230	0.317
Inconel	0.294	0.406

Design Alternative 1

- Use the current 150 kg roaster design scaled up to a 300 kg design
- Rotate drum about a shaft traveling through the center of the drum
- Change heated air flow to go through the center of the drum instead of heating the outside

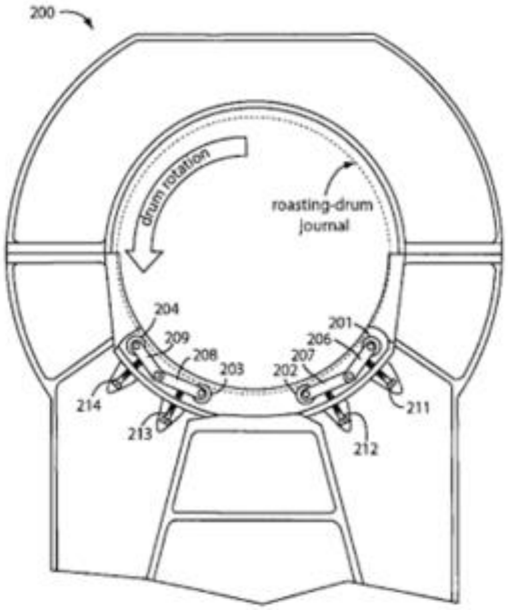
Design Alternative 1

- Pros
  - US Roaster Corp is already familiar with this design
  - Relatively simple
  - Proven
- Cons
  - Fatigue on the shaft
  - Complications from drum expansion

Design Alternative 2

- Similar to Design Alternative 1
- Drum rests on rollers instead of having a shaft through the middle
- Drum rotation is driven by rollers

Design Alternative 2



Design Alternative 2

- Pros
  - Expansion
  - Simplicity
  - Addresses shaft loading issue
- Cons
  - Patents
  - Heating of rollers

Design Alternative 3

- Stationary drum rotating agitators
- Apply hot air through the agitators
  - Multiple heating elements for each agitator arm
  - Multiple locations for applied heat
  - Allows for more control of heat

Design Alternative 3

- Pros
  - Fewer issues with the drum expanding
  - Centralized heating
  - Even, controlled heating
- Cons
  - The agitator will damage the beans
  - Complexity

Design Alternative 4

- Conveyor Oven
- Burners underneath
- Constant flow
- Vibrating conveyor belt to equally heat beans
- Similar to a pizza oven

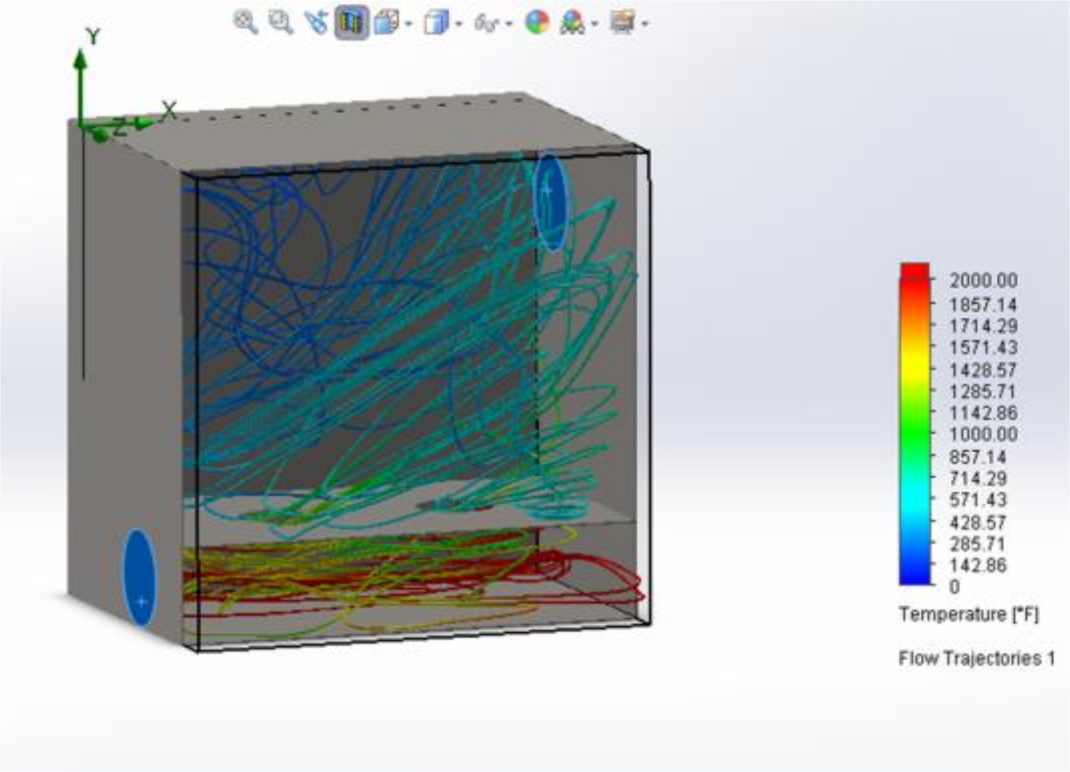
Design Alternative 4

- Pros
  - Constant flow of roasted coffee
  - No rotating drum so less worries about expansion
- Cons
  - Design is too different and radical to implement
  - Would need to design on a small scale before large

Freshman Project

- Responsible for designing the firebox
  - Guidance for overall design and expansion calculations
  - SolidWorks simulations for analyzing design
- Researching insulation materials
  - Have to be safe for high temperatures, up to 2000 °F
  - Long lasting and durable

Freshman Project



Conclusions

- Selection of Alternatives
  - Design #1 or Design #2
  - 430 or 436 Stainless Steel
- Future Work
  - Finalize and draw selected design alternative
  - Finalize metal selection based on client preference
  - Finish working with the Freshman group on firebox design
  - Test for drum expansion, air flow, and mixing optimization

Questions?