

RoastRig One

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Executive Summary

RoastRig is an advanced drum profile roaster designed to elevate the art of coffee roasting by enabling precise control over roasting profile. Profile roasting involves carefully crafting each phase of the roasting process to unlock the unique flavors and aromas inherent in each coffee bean. Unlike previous roasters that suffer from poor visibility and user-unfriendliness, RoastRig offers enhanced visibility through a 6-inch diameter viewport, allowing roasters to monitor the process closely. It's superior bean agitation ensures optimal movement within the roasting drum, promoting even heat distribution through effective convection and conduction. This results in a consistent roast, giving each bean uniform exposure to heat, essential for developing desired flavor profiles. Additionally, strategically placed thermocouples provide accurate temperature monitoring at critical points during the roast, allowing professionals to fine-tune their techniques with precision. With these innovations, RoastRig empowers professional roasters to achieve greater consistency and depth in their craft, unlocking the full potential of their coffee offerings.

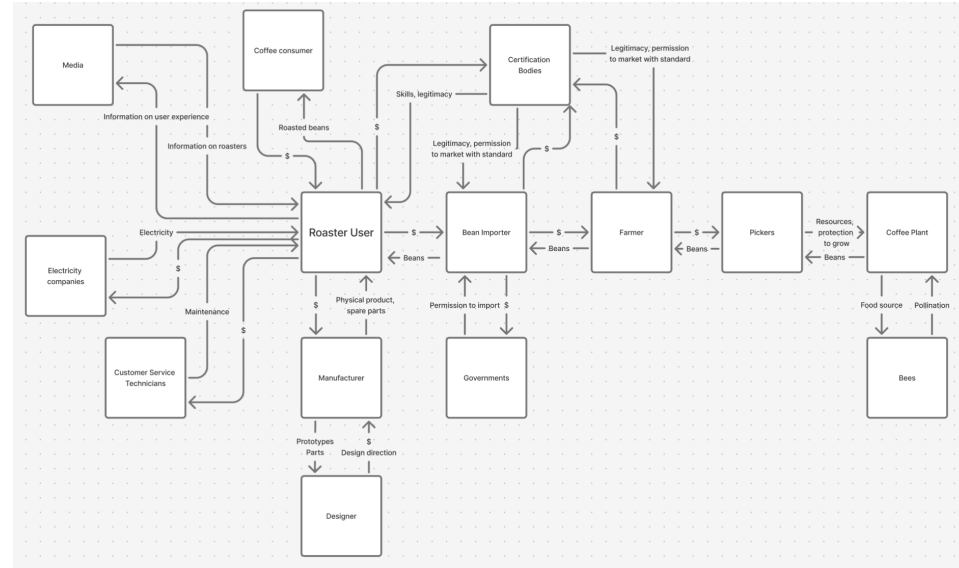
The image captures the RoastRig drum profile roaster, showcasing its modern design and functionality. It features a large visibility window for monitoring the roasting process, a bean entry door for easy loading, and a removable door that houses the visibility window for bean exit. Additionally, the roaster tilts for seamless bean exit and includes an integrated exhaust for efficient smoke and heat management, highlighting its user-friendly design for professional coffee roasting.



ME217 Tools

Voice of the Customer (VoC)

- The analysis highlighted that professional roasters prioritize not only the quality and consistency of their roast profiles but also the ease with which they can adjust variables such as temperature and time. This insight guided our approach to the CVCA tool by emphasizing the importance of creating a product that enhances control while also streamlining the roasting process.
- From the CVCA chart, we learned that the most significant value of our Profile Roaster lies in its ability to provide precise data analytics and monitoring capabilities. Roasters expressed a clear need for real-time feedback on each roast batch, enabling them to replicate successful profiles and swiftly address any issues that arise during the roasting process.
- The CVCA tool underscored the importance of user experience and support for our professional roasters. Their feedback has pushed us to prioritize intuitive controls and detailed training resources, ensuring they can maximize the capabilities of the Profile Roaster without a steep learning curve. This understanding has inspired us to incorporate a robust educational component into our offering, including online tutorials and troubleshooting guides.



Dimensions of Engagement

Useability–Surface

- Users engage with the roaster to load and unload beans using their hands to open and close the bean entry/exit door.
- Users operate the roaster using buttons or sliding mechanisms to control parameters like temperature, rotation speed, and time.
- Users monitor the roasting process via a viewport window to see bean color and movement to adjust temperature, drum speed, and other key metrics.

Scenario-Depth

- The roaster drum engages with the beans throughout the roasting process, from green to final roast.
- The roaster drum is part of a drivetrain that interacts with a heat gun source.
- The bean entry lever door and the latch on the bean exit door of the roaster drum are operated by the user's hands for loading and unloading beans.

Core-Network

- The coffee roaster creates a feedback loop among roasters and engineers to refine roasting techniques and improve bean quality.
- The coffee roaster facilitates collaboration between roasters, engineers, and researchers to develop best practices, standards, and metrics for optimal roasting processes.

Dimensions of Engagements Grid			
	Surface: buttons, sliding mechanisms, dials, sensor temperature displays	Depth: heating system, electric drill driven rotating drum, bean entry/exit door	Core: Create a good mechanism to roast coffee beans
Useability: Opening bean entrance/exit door, pressing heater on button, adjusting motor speed			
Scenario: Insert beans, turn heat and motor on to roast beans, take beans out and cool			
Network: Provide information feedback loop on how to roast good beans			

Quality Function Deployment House 1

Customer Requirement (VOC)	Customer Weights (1-5)	Engineering Metrics				
		Measurement Precision	Temperature & Drum Speed Control	Drum Viewing Visibility	Heat Source Adjustability (Location, Air Speed)	Device/Drum Size
Visible bean churning	5	1	1	9	1	3
		5	5	45	5	15
Ease of use	3	1	1	3	3	9
		3	3	9	9	27
Repeatability of roast results	5	9	9	3	9	3
		45	45	15	45	15
Emulates different roasters	4	9	9	1	9	3
		36	36	4	36	12
Accurate air, drum, and bean temperature measurements	4	9	9	1	9	3
		36	36	4	36	12
Air Flow Adjustable	3	9	3	1	9	1
		27	9	3	27	3
	Raw Score	152	134	80	158	84
	Relative Weight	25.00%	22.04%	13.16%	25.99%	13.82%

Quality Function Deployment House 1

Customer Requirements

The key customer requirements for this project focus on achieving better visibility of bean agitation profiles, user-friendliness, repeatability of roast results, and the capability to emulate various roasting profiles.

Customer Weights

- Visible bean churning
- Ease of use
- Repeatability of roast results
- Emulation of different roasters
- Accurate air, drum, and bean temperature measurements
- Adjustability of airflow

Engineering Metrics

- Measurement precision
- Temperature & drum speed control
- Drum viewing visibility
- Heat source adjustability (location, air speed)
- Device/drum size

Raw Score

The highest raw score is attributed to visible bean churning (158) and repeatability of roast results (152), which are essential in evaluating roasting consistency and quality. Ease of use (80) and accurate temperature measurements (84) also contribute significantly but are of secondary importance compared to the primary requirements.

Relative Weights

Visible bean churning carries the highest relative weight (25.99%) due to its critical role in showcasing the roasting process. Ease of use (13.82%) and repeatability of roast results (13.16%) are also essential metrics that directly impact user satisfaction and operational effectiveness. Accurate temperature measurements and airflow adjustability follow closely and are crucial for achieving optimal roasting outcomes.

Conclusion

The QFD analysis reveals that visible bean churning, ease of use, and repeatability of roast results are the key attributes of the Profile Roaster. These elements are critical for customer satisfaction and product quality. The design and engineering decisions have successfully prioritized these metrics, ensuring a reliable and user-friendly roasting experience that meets customer expectations.

Quality Function Deployment House 2

		Piece Part Characteristics						
Engineering Metrics	Weights (from QFD1)	Roaster Drum	Sensors	Motor/Drive Train	Heating Element	Digital Display	Control Dials	Chassis & Window
Measurement Precision	0.25	1	9	9	9	1	1	1
		0.25	2.25	2.25	2.25	0.25	0.25	0.25
Temperature & Drum Speed Control	0.22	3	9	9	9	3	3	1
		0.66	1.98	1.98	1.98	0.66	0.66	0.22
Drum Viewing Visibility	0.13	9	1	1	1	1	1	9
		1.18	0.13	0.13	0.13	0.13	0.13	1.18
Heat Source Adjustability (Location, Air Speed)	0.26	1	9	1	9	3	3	9
		0.26	2.34	0.26	2.34	0.78	0.78	2.34
Device/Drum Size	0.14	9	3	9	3	1	1	9
		1.24	0.41	1.24	0.41	0.14	0.14	1.24
	Raw Score	3.60	7.12	5.87	7.12	1.96	1.96	5.24
	Relative Weight	10.95%	21.66%	17.86%	21.66%	5.97%	5.97%	15.94%

Quality Function Deployment House 2

Engineering Metrics (carried from QFD1)

- Measurement precision
- Temperature & drum speed control
- Drum viewing visibility
- Heat source adjustability (location, air speed)
- Device/drum size

QFD1 Relative Weights (carried from QFD1)

- Heat source adjustability (26%) is vital for maintaining optimal roasting conditions.
- Temperature & drum speed control (22%) supports effective roasting by allowing precise adjustments.
- Drum viewing visibility (13%) enhances user engagement and monitoring during roasting.
- Device/drum size (14%) impacts usability and integration within existing setups.

Parts

- Roaster Drum
- Sensors
- Motor/Drive Train
- Heating Element
- Digital Display
- Control Dials
- Chassis & Window

Raw Score

The Sensors and Heating Element each received a raw score of 7.12, underscoring their critical importance in providing accurate measurements and effective heat management. The Motor/Drive Train followed with a score of 5.87, reflecting its essential role in the roaster's operation. The Chassis and Window scored 5.24, indicating their significance in user interaction. The Roaster Drum achieved a score of 3.60, while both the Digital Display and Control Dials received a score of 1.96, highlighting their supportive roles in the overall design.

Relative Weight

The Sensors and Heating Element both have the highest relative weight at 21.66%, highlighting their critical importance in providing accurate measurements and effective heat management, respectively. The Motor/Drive Train follows closely with a relative weight of 17.86%, indicating its significant role in the overall functionality of the roaster. Additionally, the Chassis and Window carry a relative weight of 15.94%, emphasizing their importance in user interaction and visibility during the roasting process. Together, these components are essential for achieving optimal roasting performance and satisfying customer needs.

Conclusion

The analysis highlights that the Sensors, Heating Element, Motor/Drive Train, and Chassis and Window are the most critical components of the coffee roaster, collectively ensuring accurate measurements, effective heat management, overall functionality, and enhanced visibility. By prioritizing these elements, the design effectively addresses customer needs for optimal roasting performance and user satisfaction.

Failure Modes and Effects Analysis

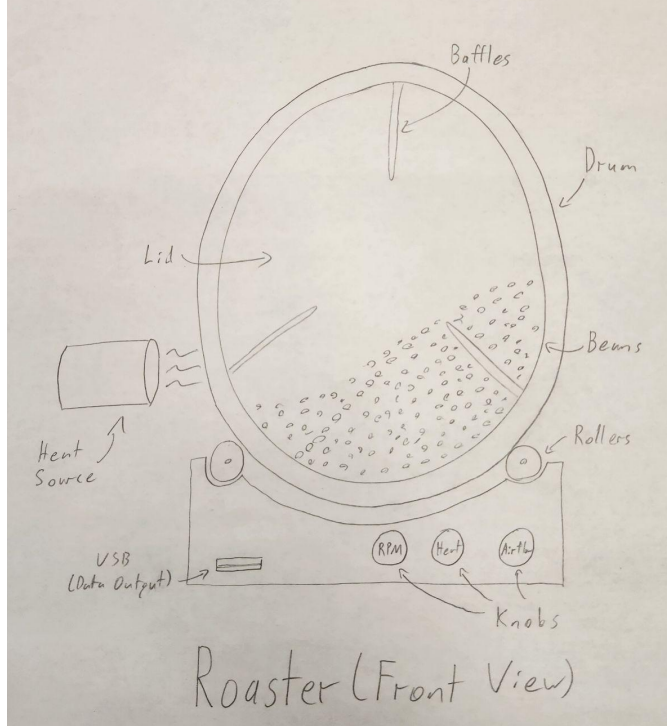
Component	Failure Mode	Effect	Severity	Occurance	Detection	RPN
Chassis	Burn on glass and metal	User Injury	9	5	1	45
Heating Element	Overheats	Overroast	6	3	9	162
	Doesn't heat	No heating	4	2	9	72
Sensors	Malfunction	Under/overcook beans	8	1	9	72
Drum Drive Train	Motor stops working	Drum doesn't rotate, overroast	6	2	9	108
Drum	Disconnects from motor					
Display	Doesn't show any information	Unable to read from sensors or track roast	7	1	9	63
Controls	Disconnects from roaster	Unable to control roaster	8	1	7	56

- Using our prototype as a datum, we were able to identify several modes of failure that could result from our work.
- We found that the highest Risk Priority Number (RPN) was associated with the Heating Element (162), which can lead to overheating and potential roaster failure. This significant risk emphasizes the need for enhanced monitoring and control mechanisms for the heating element to prevent overheating incidents.
- The Chassis poses a risk as well, with an RPN of 45. Testing revealed that the chassis can become extremely hot, leading to potential burns and user injuries.
- Moreover, the Drum Drivetrain registered an RPN of 108, highlighting the risk of the drum stopping its rotation and consequently causing overroasting of the beans..
- These analyses emphasize the critical nature of these components and the potential risks they pose, highlighting the need for stringent quality and safety measures in the coffee roasting process.

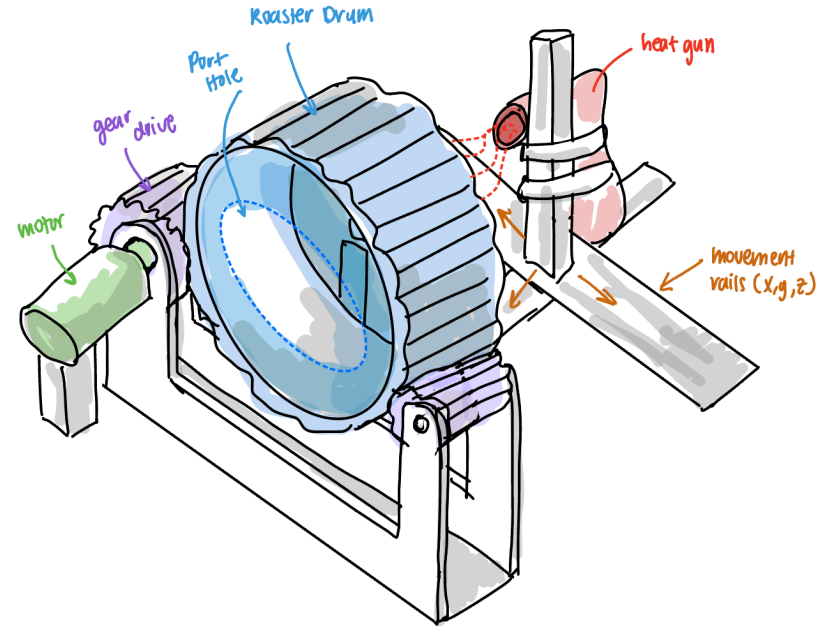
Prototyping & Testing

Prototype 1 - Low Fidelity Sketches

Initial concept sketch from one of the teams



Initial concept sketch from the other team



Prototype 1 - Low Fidelity

First prototype from one team

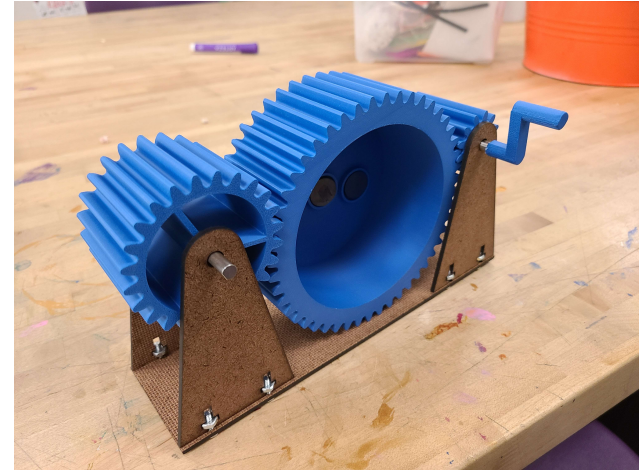


Intent: to show the proof of concept of using magnets to hold the lid on to the drum

Learnings: Magnets could be a viable way forward if we add kinetic stops so the door wouldn't spin off

Next Steps From this: What magnets are needed to withstand heat. What ranges of temperature, drum speed, and airflow rate do we need to design for

First prototype from the other team



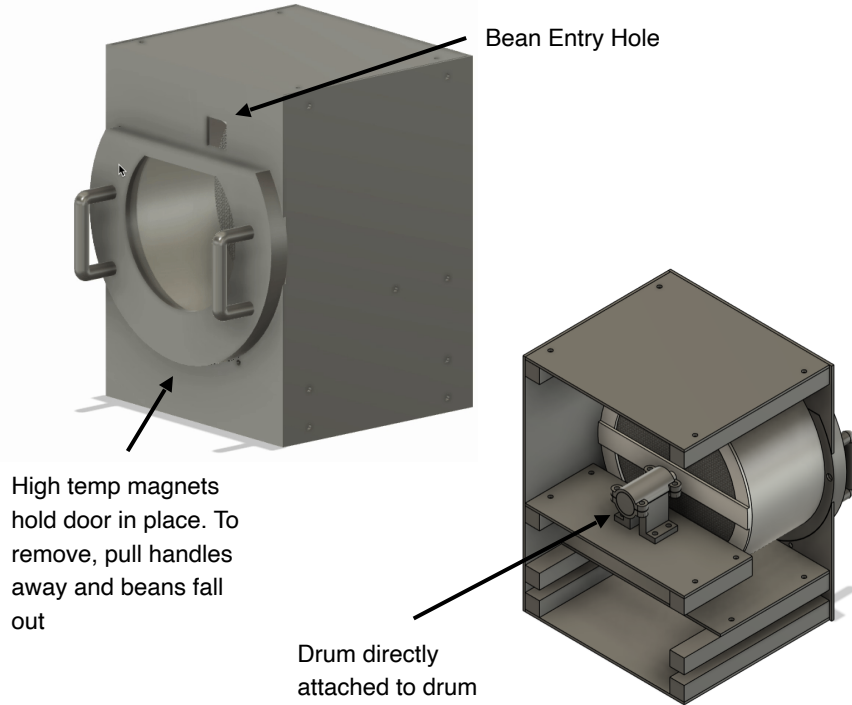
Intent: demonstrate how the the drum would fit inside a chassis and spin

Learnings: Needed a bean entry port and that gears could be a potential way to drive the drum

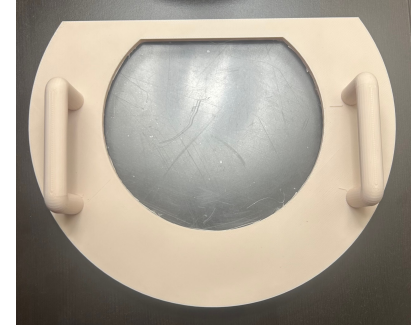
Next Steps From this: How should the beans be loaded efficiently, how to hook up a motor and drivetrain, where should the heat source go

Prototype 2 - Medium Fidelity Chassis

CAD for Chassis



Chassis Prototype

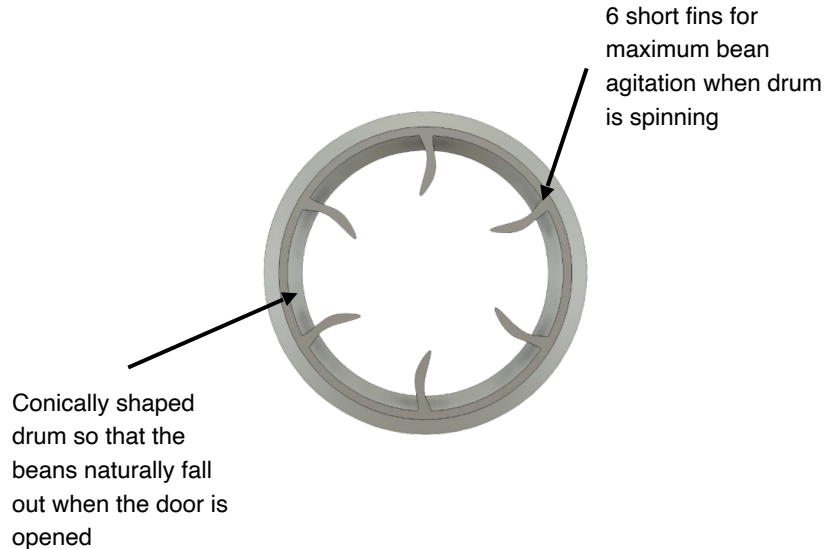


Learnings:

- Would be hard to find magnets that were strong enough to hold up the door
- Need an outer layer for insulation
- Have to move the motor mount outside the box so the motor isn't damaged

Prototype 2 - Medium Fidelity Drum

CAD for Drum Fins



Medium Fidelity Prototype



Learnings:

- Manufacturing a conical drum would be difficult
- Using more fins that were shorter was the best way to loft the beans
- Need to develop a way to attach the drum to the drivetrain

Prototype 3 - High Fidelity

Chassis



Drum with Fins



Door



- 8020 frame with aluminum sheet panels and insulation
- Purpose is to constrain components and direct airflow through the drum

- Optimized design for manufacturability
- Drum and fins constructed from lightweight aluminum, while mesh is steel

- 6" Borosilicate viewing glass
- Securely attached with hinges and a clasp
- Hinges allow for door to be taken off easily for cleaning

Prototype 3 - High Fidelity

Drivetrain

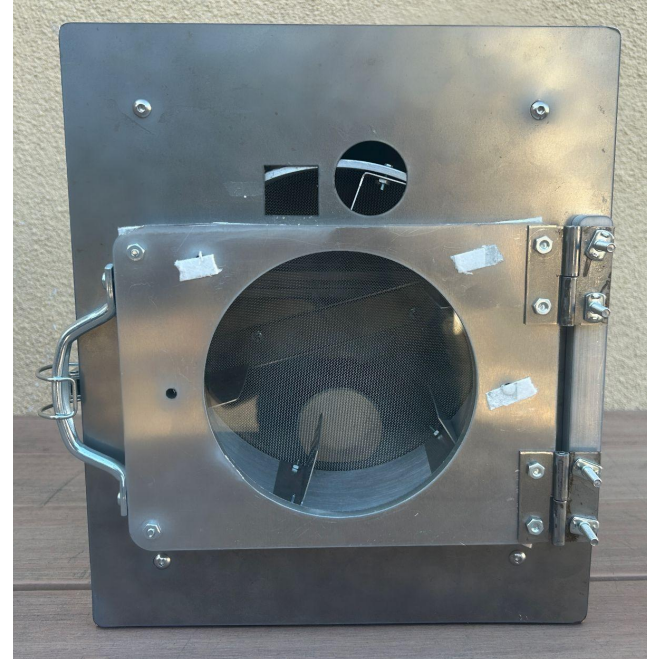
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- CNC/Waterjet cut parts securely attach the drivetrain to the drum
- Robust support bearings ensure smooth rotation

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High Fidelity Assembled Prototype



Prototype 3 - High Fidelity Testing

Bean Agitation Test

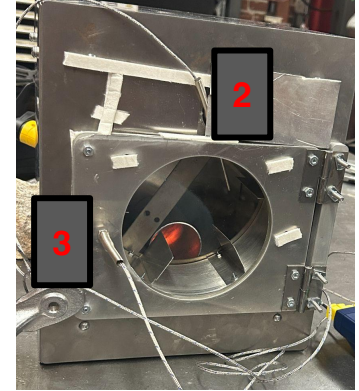


- Spun the drum to determine if bean agitation was adequate

Learnings:

- Bean agitation was satisfactory
- Need to refine tolerances so beans don't fall out of the drum when the door is closed
- Need to attach a motor

Temperature Test



Temperature Readings

1	380.0 °C
2	189.1 °C
3	196.6 °C

- Used thermocouples to test if the roaster could heat up to 235°C
- After 30 minutes, could get within 30°C of the goal temperature

Learnings:

- Need to put in more insulation so that the target temperature can be reached

Final Product & Verification

Final Product — Overview

RoastRig incorporates the **drum-type construction** of larger commercial roasters, modular heat, temperature, and airflow control, and unmatched **visibility of the bean mass** during roasting. In previous iterations, we expected to manufacture our own heat source and drum, but due to manufacturability concerns, we opted for off-the-shelf solutions for our final product.

Prototype 1 also informed the addition of the **bean entry port**. Prototype 2 demonstrated both the need for **insulation** to better retain heat and reduce the hazard of touching a hot surface, and the need for the robust **door latching system** we use in our final product. Prototype 3 informed the addition of the **top handle**, and the **pivoting leg system** to assist in both loading beans, and evacuating beans to the cooling tray, as well as the **perforated metal drum backing** which replaces the steel mesh which wouldn't hold up to the heat.



Final Product — Fabrication

Chassis

At the core of our roaster is our chassis. Built as an 8020 frame with aluminum sheet panels, its purpose is twofold:

1. Constrain all other components while directing internal airflow
2. Retain as much heat as possible. This is done by placing ceramic wool insulation between the inner and outer chassis walls



Final Product — Fabrication

Drum

Constructed from aluminum, our drum features 6 fins. Fin count was determined by initial prototyping where we found a positive correlation between the number of fins and the lofting beans undergo at any given drum speed.



Final Product — Fabrication

Visibility Port

Assembled from aluminum sheet metal and borosilicate glass, our visibility port has multiple functions:

1. Glass enables observation of color change and bean lofting throughout the roasting cycle
2. Retains heat and provides a location for our bean temperature probe
3. Allows users to empty the roaster once the roasting cycle is complete



Final Product — Fabrication

Exhaust

To control the airflow through the roaster, a fan was connected in-line with the roaster's exhaust tube. The exhaust tube to fan adaptor was made using aluminum foil and kapton tape. Currently, roasts have been achieved with and without the fan. This is possible as the heat gun connected at the roaster inlet actively pushes air through the system.

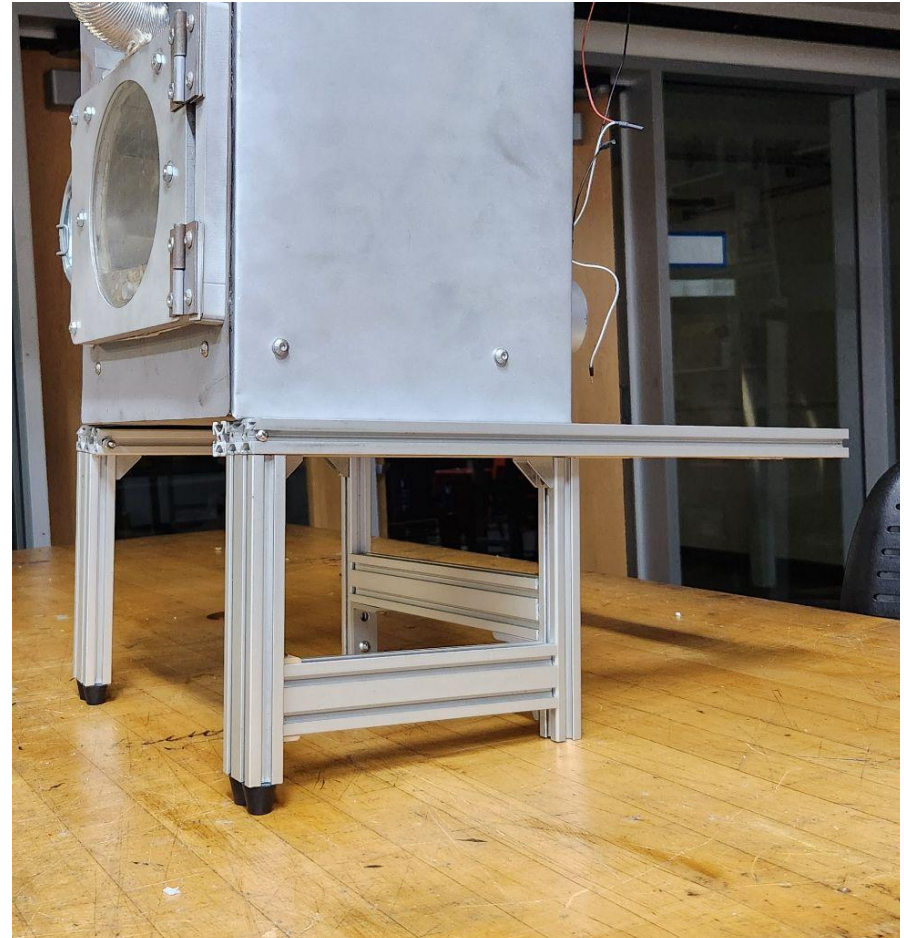


Final Product — Fabrication

Platform

Once roasting is complete, the roaster must be tilted and emptied into a cooling tray. Our solution was to create a platform underneath our roaster. A pivot located just beneath the front of the roaster allowed us to easily empty roasted beans into a waiting cooling tray below.

Additionally, this platform allowed us to slightly tilt the roaster back. This was crucial in ensuring beans didn't fall into the chassis as there exists a very small gap between the front of the drum and the lid.



RoastRig One



RoastRig One

Final Product — How to Use

- **Prepare**
 - Preheat RoastRig, Install Thermocouples, Load Green Beans
- **Roast**
 - Spin Drum and Begin Roast, Watch the beans, Yellowing Phase, First Crack, Development Phase
- **Remove**
 - Prepare Cooling Tray, Remove Thermocouples, Stop Drum and Heat Gun, Unlatch and Open Door, Tilt and Pour

[RoastRig One Product Video](#)



RoastRig One



Step 1: Preheat RoastRig



Step 4: Spin Drum & Begin Roast



Step 5: Watch the beans and relax.



Roast until desired development time.



Step 11: Unlatch and Open Door



Step 12: Tilt and Pour



Cool beans.

Final Product — Verification

To verify our final product, we ran RoastRig through the entire roasting process, from preheating through evacuating beans to the cooling tray. Throughout the process, we monitored temperature at three locations along with the ambient temperature.

Qualitative targets:

- Achieve yellowing
- Achieve first crack
- Load and evacuate beans efficiently
- Bean lofting is adequate to avoid facing or tipping

Empirical targets:

- 235 C preheat temperature in under 30 minutes
- Monitor temperature throughout the roast



Final Product — Verification

Our test setup replicates the usual conditions of operating RoastRig, described here:

1. Place heat source in intake tube.
2. Insert thermocouples in intake tube, bean-mass port, and exhaust tube. Connect thermocouples to reader, and place a fourth away from RoastRig to measure ambient temperature.
3. Turn on heat source to begin preheat period.
4. Attach cordless drill or motor.
5. Preheat period: wait until bean-mass sensor registers 235 °C.
6. Once preheated, rotate the bean inlet port keeper and open the bean inlet door.
7. Activate fan.
8. Load the dose of green beans, close and secure inlet door.
9. Activate drill or motor.
10. Roast period: monitor roast progress via viewport, thermocouples, and any other desired method.
11. Once roast is complete, place cooling tray below RoastRig's front door and deactivate heat source and motor.
12. Open RoastRig's front door by opening the clamp on the left side.
13. Using the insulated handle on top, tip RoastRig forward to evacuate beans into the cooling tray.
14. Leave door open and fan running as long as necessary to assist with cooling, or reactivate heat source for another roast.



Final Product — Testing Results

Our most important result was that RoastRig was able to **successfully roast** a batch of coffee, during which we were able to observe yellowing and then first crack. During the preheat phase, we successfully achieved **235°C** internal temperature, in less than 30 minutes. After the roast, we observed **no tipping or facing**, so bean lofting was adequate.

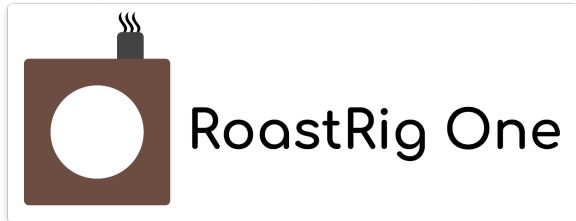


Final Product — Reflection

Overall, our experience working on RoastRig was a valuable learning opportunity that challenged us as engineers. With little prior knowledge of coffee roasting, we engaged deeply in this domain and aimed to design a product that would benefit various stakeholders in the coffee industry.

Initially, we had the freedom to explore designs and experiment at the intersection of our engineering education and interest. This led us to develop multiple prototypes that excited our team. However, as we progressed, we had to pivot based on the engineering metrics we used in class. Combined with material constraints, this resulted in significant changes to our design over a short period.

Through this process, we gained insights into the complexities of product development, allowing us to better align our design with user needs and industry standards. Working on RoastRig enhanced our technical skills and increased our understanding of the coffee roasting process.



Appendix



Isometric View

The image shows an isometric view of the RoastRig, featuring its compact design with a metallic casing, a circular viewport for monitoring the roasting process, an aluminum drum, while roasted coffee is positioned in the cooling tray beneath the roaster.



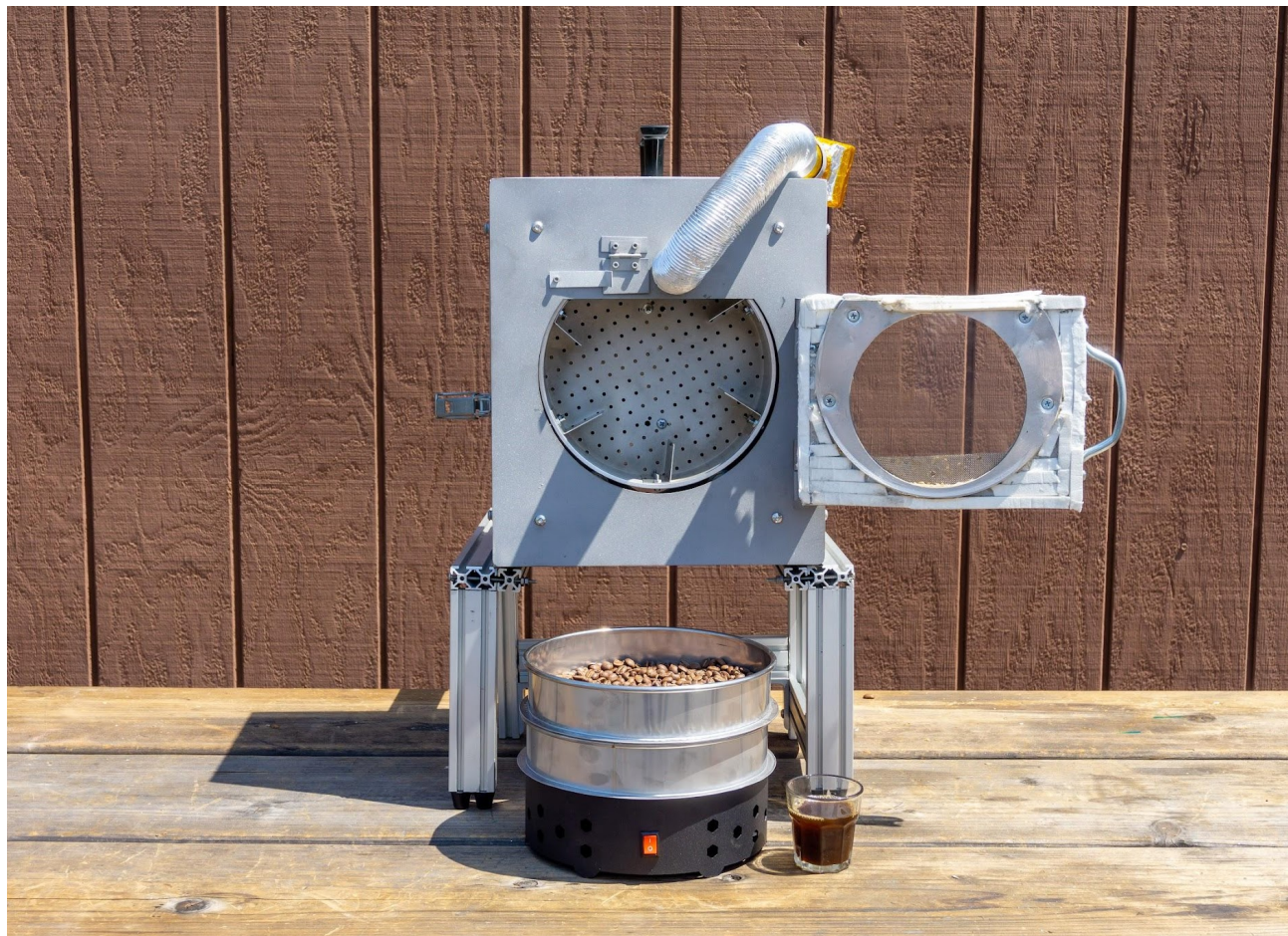
Additional View

The image depicts the RoastRig tilting on its pivoting stand to evacuate the roasted beans into the cooling tray below, demonstrating the design's functionality in transferring the beans after roasting.



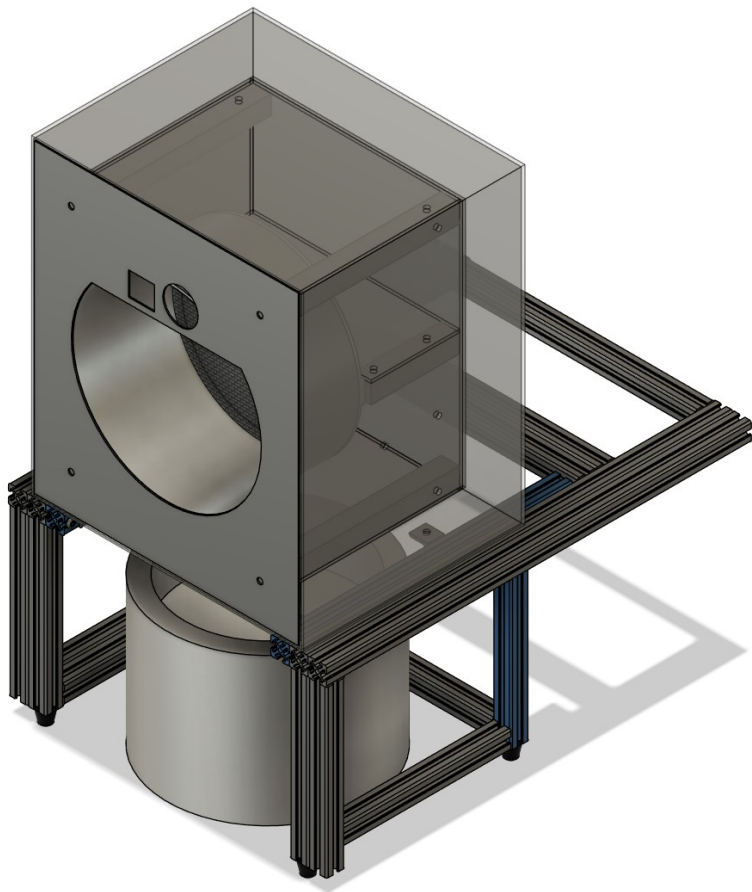
RoastRig in Use

The image captures the RoastRig in action, with roasted coffee beans being lofted within the roaster as they are actively roasted. A thermocouple is visible, measuring the temperature of the bean mass.



RoastRig in Context

The image shows RoastRig with the door open, revealing the interior drum where coffee beans are being roasted. The insulation tape on the door highlights its design for optimal heat retention and safety, while the door's easy operation is evident. In addition, roasted coffee beans are visible in the tray below, and a cup of brewed coffee sits beside the roaster, showcasing the product in use and its end result.



CAD Model

The latest CAD model of RoastRig in Autodesk Fusion.