Jack Button
Julia Combs
Jack Dibachi
Isabel Franco
Helene Levy
Aine McNulty

ME 153: CAD Lads Final Report

1.0 Design Process

1.1 Introduction

Throughout our college career, we have noticed countless people attempt to cool scalding hot coffee inefficiently and burn themselves in doing so. Often times, people remove the lid from their coffee or tea in an attempt to cool it down faster. Unfortunately, the hot drink can spill if knocked over, especially with the lid removed.

This problem affects anyone who enjoys hot drinks on the go, but does not have the time of day to wait for the drink to cool. For example, a user could be a student striving to stay awake in lecture depending on their coffee to cool.

Our solution is the Lid Lad: an easy to use lid for your mug. It is controlled via a downloadable app on Bluetooth devices. On this app, one can set the preferred temperature of the drink. When the lid senses that your drink is above that temperature, it will open, allowing natural convection to cool your drink. When the lid senses that your drink is at or below the desired temperature, it will close, insulating your drink to maintain that desired temperature. In addition, if the mug is knocked over while the lid is open, the lid will close before it spills the drink everywhere.

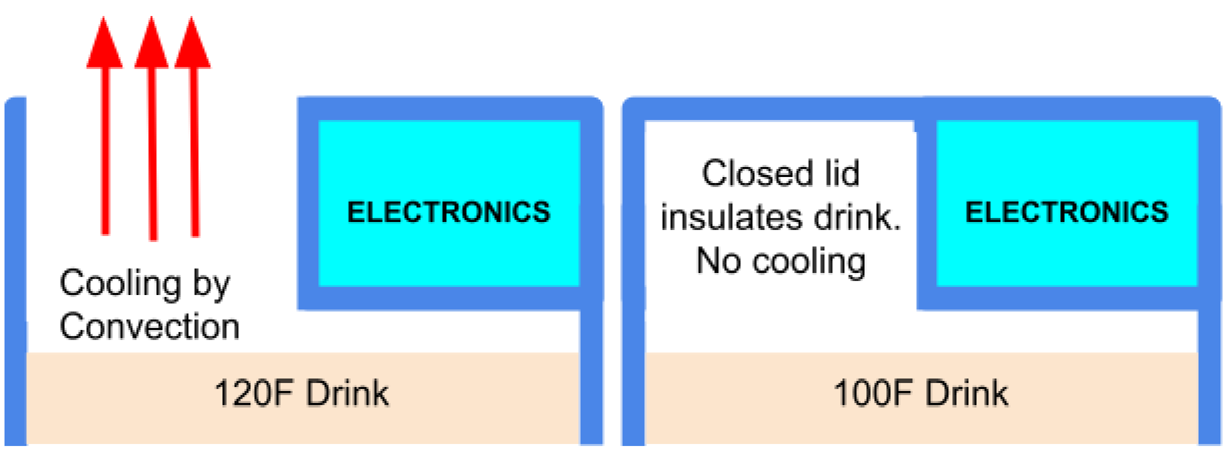


Figure 1: The user's desired temperature is 100°F, but their drink is at 120°F

1.2 Prototype 1

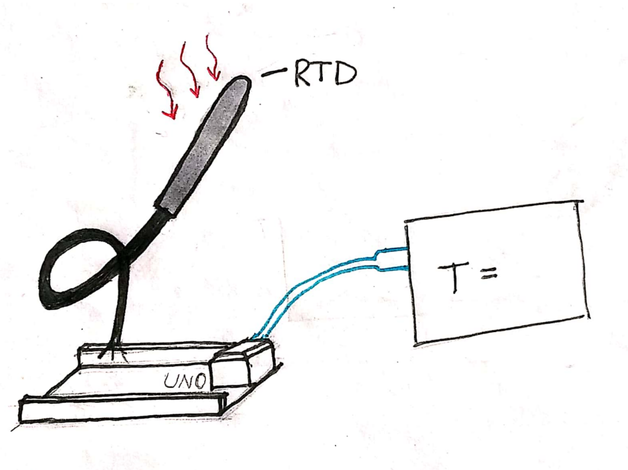


Figure 2: Prototype 1 Idea

```
Temperature is: 80.04 Requesting temperatures...DONE
Temperature is: 79.93 Requesting temperatures...DONE
Temperature is: 80.04 Requesting temperatures...DONE
Temperature is: 80.15 Requesting temperatures...DONE
Temperature is: 80.04 Requesting temperatures...DONE
Temperature is: 80.15 Requesting temperatures...DONE
Temperature is: 79.93 Requesting temperatures...DONE
Temperature is: 80.04 Requesting temperatures...DONE
Temperature is: 79.93 Requesting temperatures...DONE
Temperature is: 80.04 Requesting temperatures...DONE
Temperature is: 80.04 Requesting temperatures...DONE
Temperature is: 79.70 Requesting temperatures...DONE
Temperature is: 79.81 Requesting temperatures...DONE
Temperature is: 80.04 Requesting temperatures...DONE
Temperature is: 80.04 Requesting temperatures...DONE
Temperature is: 79.59 Requesting temperatures...DONE
Temperature is: 79.93 Requesting temperatures...DONE
Temperature is: 79.93 Requesting temperatures...DONE
```

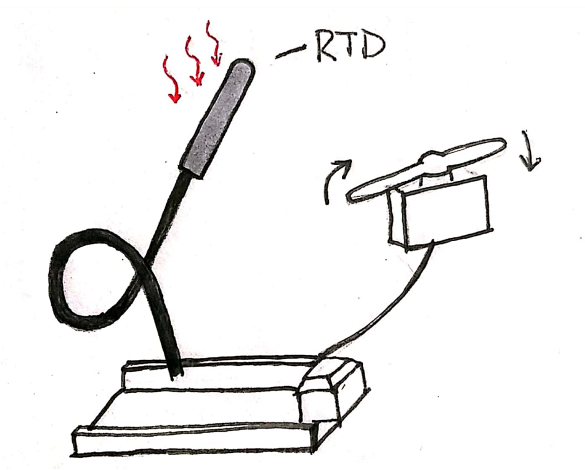
Figure 3: Prototype 1 Temperature Response

The first prototype was designed for the purpose of testing a critical function of our lid: the temperature measurement. For this we ideated an RTD connected to an Arduino Uno.

The critical function was tested by warming up the RTD with body heat and witnessing the temperature response on the serial monitor. The temperature output was also verified by comparing the measurement of the ambient temperature to the thermostat reading in the CAD Lab.

This first prototype was not the ideal size for a small lid. The size of the electronics had to be scaled down. That being said, the RTD read temperature effectively after being calibrated. In addition, the Arduino Serial Monitor provided a simple way to log the live temperature data needed to validate the temperature sensing critical function.

1.3 Prototype 2



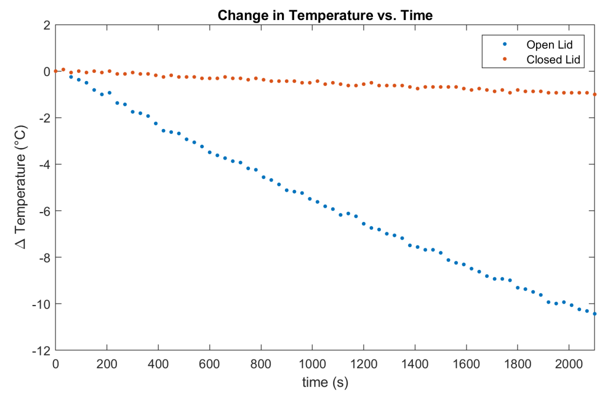


Figure 4: Prototype 2 Idea

Figure 5: Prototype 2 Proof of Concept

Prototype 2 incorporated a servo motor into the system, which was the next critical function to test. Completion of this prototype would confirm the functionality of the opening mechanism for the lid's vent.

The testing for this prototype entailed turning a servo 180 degrees in response to a temperature change sensed by the RTD. With an Arduino code, the servo was actuated from 0 degrees to 180 degrees with high repeatability. The prototype ultimately succeeded in testing a rotating vent enclosure that was actuated by crossing a temperature threshold.

Secondly, a test was run on the effectiveness of convectively cooling a hot drink by comparing the temperature over time of an insulated container and an open lid. The temperature was measured by an RTD over the span of 30 minutes. We proved that an open lid allowed for a significant decrease in temperature, while a fully covered lid with an insulating material would maintain the drink temperature (See Figure 5).

This prototype could have been improved by developing a physical concept for the vent closure in which the servo would be attached to. This would have been useful in the analysis of servo characteristics (i.e. if the servo would be able to provide adequate strength and accuracy for our design).

1.4 Prototype 3

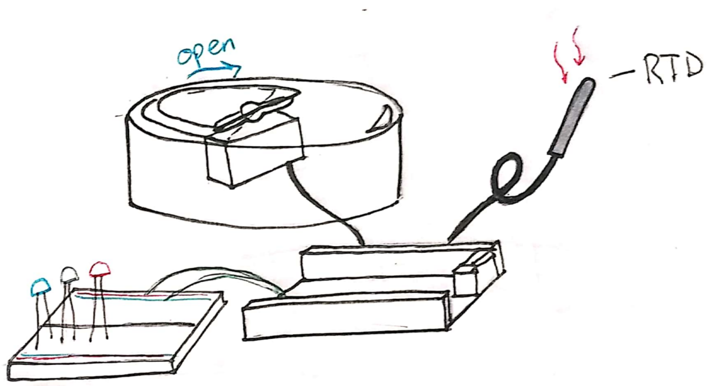


Figure 6: Prototype 3 Idea

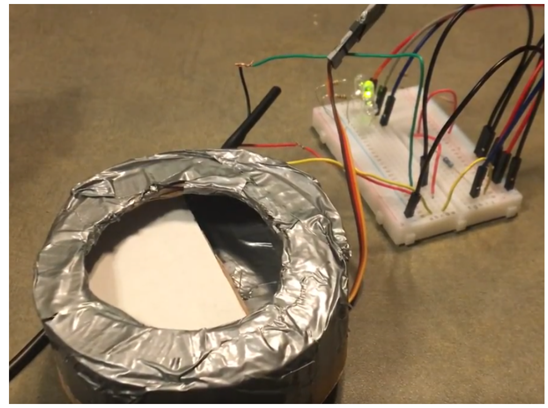


Figure 7: Prototype 3 Lid Response Testing

This prototype added two components to Prototype 2. Three LEDs were added to indicate when the temperature within the mug was far above the desired temperature, near the desired temperature and at the right temperature (indicated by red, yellow, and green LEDs, respectively). A housing for all the components and a cover to close the lid was added to the servo motor in order to test whether the desired geometry would work.

The testing consisted of assembling the geometry and observing the process to visually/qualitatively validate the design. Moreover, another test with a cooling drink was conducted to observe the full response of the system (Servo actuation, temperature monitoring, and the LED indicator).

The testing went smoothly; our system worked, thus validating the geometry. More importantly, the LEDs were able to successfully display different intervals of temperature. The display was easy to see, somewhat intuitive, and well integrated into the system. We found that the servo would frequently twitch, likely due to a high current draw from the RTD. We decided to switch our temperature sensor to a thermistor, because the RTD uses 42.7-36.8 mA whereas a thermistor uses 1.19-1.72 mA. We also decided to switch from Arduino to a Feather microcontroller, partially due to its smaller size, but also due to its Bluetooth compatibilities. This added feature enables the user to change the temperature threshold from an Adafruit app on their phone. The last aspect to add to this prototype was the accelerometer.

1.5 Prototype 4

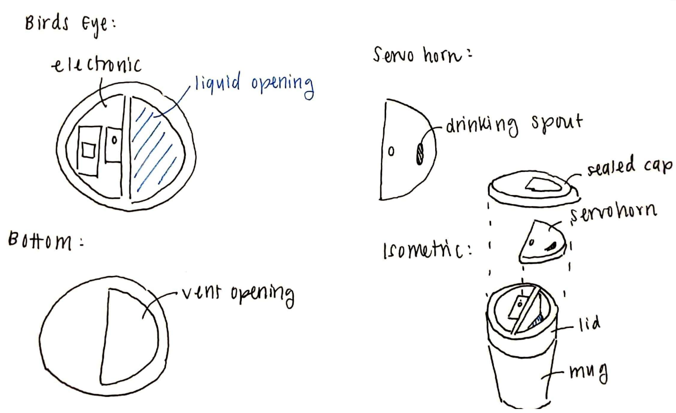


Figure 8: Prototype 4 Idea

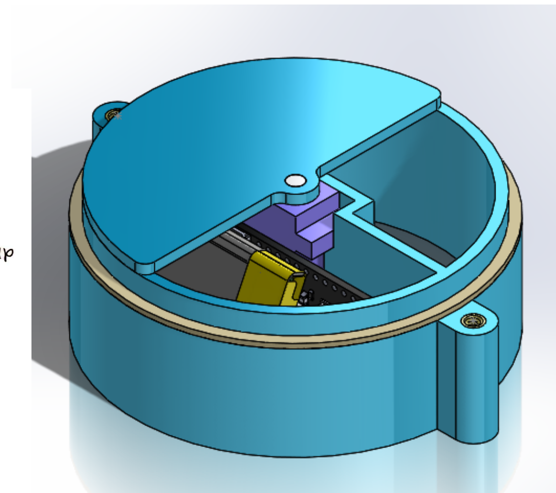


Figure 9: Prototype 4 CAD Model

This prototype was an attempt at producing a well-manufactured and polished version of our lid housing. We also attempted to waterproof the design by creating a wall-separated housing, keeping the electronics safe from water damage. This design would be 3D printed out of PLA (to minimize warping and make the lid food safe).

An Adafruit Feather 32u4 microcontroller replaced the Arduino we were previously using. The Feather was chosen to minimize the profile of the lid without losing the functionality of the Arduino. This prototype would be the first attempt at a final control system, as the IMU was also integrated to determine if the mug is tipping.

Tipping tests were conducted to determine the responsiveness of the lid to various tip speeds and angles. We also tested the temperature setting feature on the app. Since the LEDs could be replaced by notifications using the app, it was important to test this feature.

The app paired with the Feather quite well. The temperature was easily set and the Feather controlled the accelerometer, servo, and thermistor as planned. This meant that the LEDs could be removed, freeing several pins and increasing the operating time per battery charge.

After tipping the lid several times and in several different ways, it was found that setting a tilting angle was consistently more effective at identifying the correct moment to close than relying on identifying “tipping impulses”. This tilt angle is also set using the app.

The biggest issue with this model was that it very clearly wasn’t waterproof. There was a large gap in between the cover and the electronics because of the fact that the electronics were sealed using the cover. A few concepts were considered to fix this, but we ultimately decided to completely alter the exterior geometry.

1.6 Prototype 5

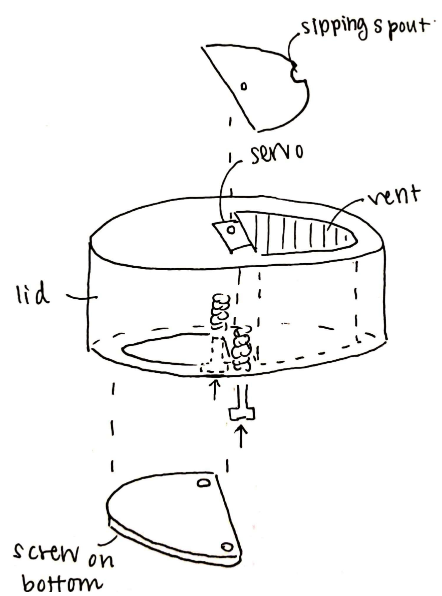


Figure 10: Prototype 5 Idea

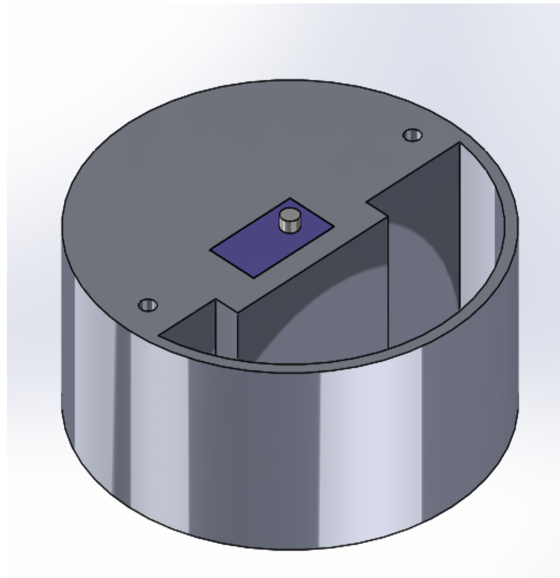


Figure 11: Prototype 5 CAD Model

To address the issues of waterproofing, a screw-on bottom section was implemented so that the compartment with electronics was fully separate from the fluid. The servo would be the only electronic component exposed to the drink, but this is almost entirely protected by the cover and could easily be blocked using putty or epoxy.

The main test performed on this prototype was observing that it was a robust construction. We also performed additional tipping tests to ensure that there were not any unforeseen leaks.

This prototype proved to be robust, well-constructed, and a valid solution to all of the waterproofing issues that affected the previous prototype. The threaded plastic inserts were the only feasible leakage points that were not considered, but they turned out to be sealed well by washers.

1.7 Prototype 6 - Final

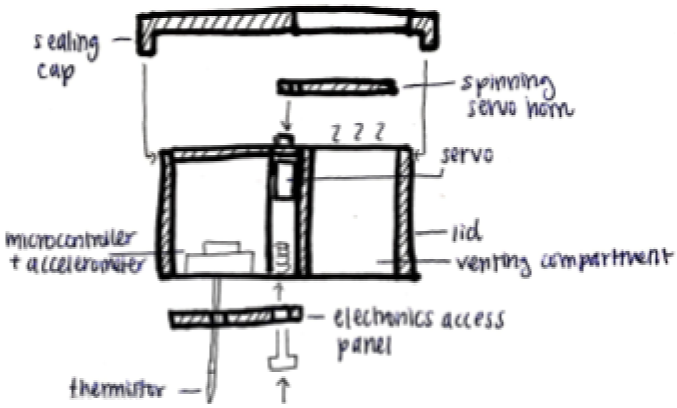


Figure 12: Prototype 6 Idea

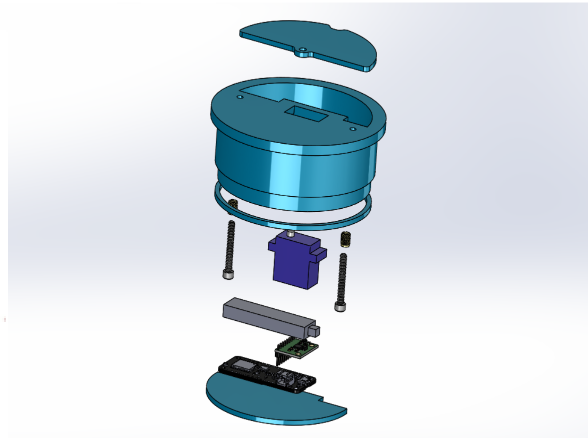


Figure 13: Prototype 6 CAD Exploded View

The final prototype was similar to the previous prototype. A sealing cap was designed to fit on the top of the lid to improve the seat between the spinning servo horn and the servo (See Figure 12). This added cap improved the sealing of the lid by providing a lip that would come in contact with the lid. This improves our design by minimizing spillage.

The sealing cap was tested by pressing the cap in a way that was not permanent before permanently sealing it with epoxy. This was done in order to ensure that the cap did not add too much friction to the cover for the servo to overcome.

Ultimately the cap added little friction to the system and was an effective method of sealing with the cover. In the final testing with the servo horn, we found the servo did not have an instantaneous response time thereby not making the design entirely spill resistant, but the design does minimize spills. Analyzing the physical finish, the method used to seal to the main body of the lid was by applying epoxy which wasn't as “polished” as planned. The finish could have been improved by sealing the cap with a rubber gasket instead.

2.0 Reflect

1. What surprised you about the design process, about your team's product?

There's a lot more prototyping involved than we had expected. Rarely is the solution to a design as simple as putting pen to paper because designs frequently fail.

2. Where did you fail, where did you succeed?

We should have aimed to produce a physical model of our lid sooner, so we would have more time to address interfacing issues. We succeeded in that our critical functions were proven with ease.

3. On reflection, do you feel that your prototype shows that your design has promise? – is it worth developing further?

Our design is worth developing further, as all of our critical functions worked as intended, and a large group of people expressed interest in the product and it was awarded Most Marketable at the ME 153 Design Fair.

4. What changes would you make in the next iteration?

Our next iteration would involve injection molding, waterproofing completely and increasing the response time of the cover closing to reduce spilling.

5. You will work on another design team in Capstone next year. Would you organize your team's work any differently looking back on this quarter's work?

This design project showed how useful it is to have certain people specialize in specific aspects of small projects so that they can get thoroughly familiar with an aspect of the design.