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Smart Coffee Table

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Senior Design Project

Matthew Owens

Spring 2016

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Introduction

Deciding what to do for my senior project proved to be tricky. My preferences were to work on something as an individual and to actually build it so I could use what I had worked so hard to create. Without having any other restrictions put forth by the college, I was stuck pondering endless possible projects ranging from helpful ways to dispose of trash to modifying quadcopters. But, one stubbed toe later and I realized that I hate my coffee table.

I had heard of fully touch screen tables with enormous price tags and of course would fantasize about being able to afford one as a college student but making one from scratch would be completely impractical. So, my motivation for a project had finally been defined and I decided I would design and build a coffee table with above average luxuries for a much more modest price. This report will document my entire process starting with my research and design, a description of all sub-assemblies and their performance, the system controls, and ending with the problems and limitations dealt with along the way.

Engineering Process

Having learned the engineering process in a professional environment for four co-op terms I knew exactly where I was headed. First, I made a list of every feature I could possibly think of knowing that all of them would not be included. The first note I made on my piece of scratch paper was to make a table that cannot cripple toes when walking by followed by several more extravagant features like hidden compartments that open at the push of a button, cup holders that can cool drinks, hidden speakers, and a few ideas on how to make each a reality.

After deciding on the overall dimensions by measuring my current table, I used AutoCAD to visualize the basic shape and for the rest I used Inventor (see Appendix 2.1). I already knew I would be using ¾" white oak plywood which was important to determine before drawing because the thickness would take up a significant amount of space and seeing the preliminary two-dimensional drawing allowed me to quickly narrow down which features would be possible to group together. The final assembly would have trays that fold out, chilled cup holders, hidden speakers, phone chargers, cabinet and drawer space, and other minor features, all controlled by a phone, computer, or tablet via Bluetooth connection. My rationale, design, and performance of these individual features will be detailed later.

I then modeled the entire structure in Inventor including all fasteners and some commercial parts for the sub-assemblies. I chose only one type of l-bracket and wood screw to make purchasing and assembly simpler. The modeling process was tedious and time consuming but after creating over 50 parts and placing over 200 brackets and screws, I was confident that everything would fit without interference and that it would be possible to assemble and maintain.

While going through the drawing process, I needed dimensions of any commercially purchased parts. This means I had to decide what I would buy before the model could be completed. My bill of materials helped me not only track what I needed to buy but also what quantity and where I could purchase these parts for the cheapest. I employed a similar structure as the bills of material that I used while on co-op and to organize myself even more I created my own part and drawing number convention (see Appendix 2.2). Each commercially purchased part starts with a 1, purchased parts with any custom modifications start with a 2, made parts start with a 3, and all

fasteners start with a 4. With this convention it was not only easier for me to track what I would need to buy but it also allowed me to rename and organize the parts tree in my model.

Finally, since I had no means of cutting the wood at home, I had to figure out how to manufacture everything. The electrical components would be simple to breadboard, test, and lastly implement at final assembly but I was also fortunate enough to have a high school friend with wood working equipment who was willing to help. The fact that I was able to go to his house and work on it myself saved me money and gave me a better appreciation of the fabrication process for any engineering project.

Sub-Assemblies

The following sections will discuss all of the important sub-assemblies as well as more minor features that were included for specific purposes. Preliminary designs, material and component selection, calculations, and performance will all be covered when applicable to the feature.

Trays

The trays were one of my first ideas because they would solve another problem that I have with my current coffee table. They would let me comfortably set a plate of food in front of me while on the couch, an area that a normal TV tray does not fit. My initial design requirements for the trays were to have a way to lock the tray in place so it would not collapse under the weight of a full plate and for the space that the tray moved away from to be covered so the inside of the table was not exposed. I thought about operating the tray with a sliding mechanism but settled on the simplicity of a four bar linkage. I found, with a preliminary AutoCAD sketch (see Appendix

3.1), that my trays could comfortably travel six inches forward. Six inches is close to the entire depth of the tray which is 8.875 inches and this dimension was restricted by the fact that the two trays would interfere if they were any deeper. Since the trays must be flat in both of their resting positions, the arms must be equal in length and connected to the tray and the table at an equal distance. This results in a very simple four bar linkage in which both pairs of links that are opposite of each other are equal in length. I decided on three inch arms so the tray would completely cover them when retracted. The arms hinge on a smooth maple dowel which rotate inside of low friction nylon flange bushings (see Appendix 3.1).

Since I decided on a rotating motion, I would need a motor capable of generating enough torque to unfold and refold the trays that could be powered with something as modest as a 12V power supply. After extensive research I was able to find a reasonably priced low speed, high torque, 12V DC gearbox motor. The outer diameter of this particular motor is about an inch and a half making it easy to mount in tight places.

The motors' specifications state that they are capable of 120 N*cm which is equivalent to 0.8851 ft*lbs. By using Inventor's mass properties to find an accurate volume for the tray and arms along with the density of white oak (47 lb/ft^3) I found that the motors would be moving approximately 3.75 lb. With the arm length of 3 inches, the torque that the tray would exert against the motor is approximately 0.9375 ft*lb. This obviously presents a problem since the motors are not capable of this but rather than using a larger motor or multiple motors per tray, I found that there is room for a pair of gears since the mounting be can flexible. I was able to find two pinion gears with a bore size that matched what is necessary for my chosen motor, one with

24 teeth and the other with 32. By attaching the larger one to the dowel that turns the tray, the system has a gear ratio that now allows the motors to create 1.180 ft*lbs of torque which results in a design factor over 1.25 (see Appendix 3.2).
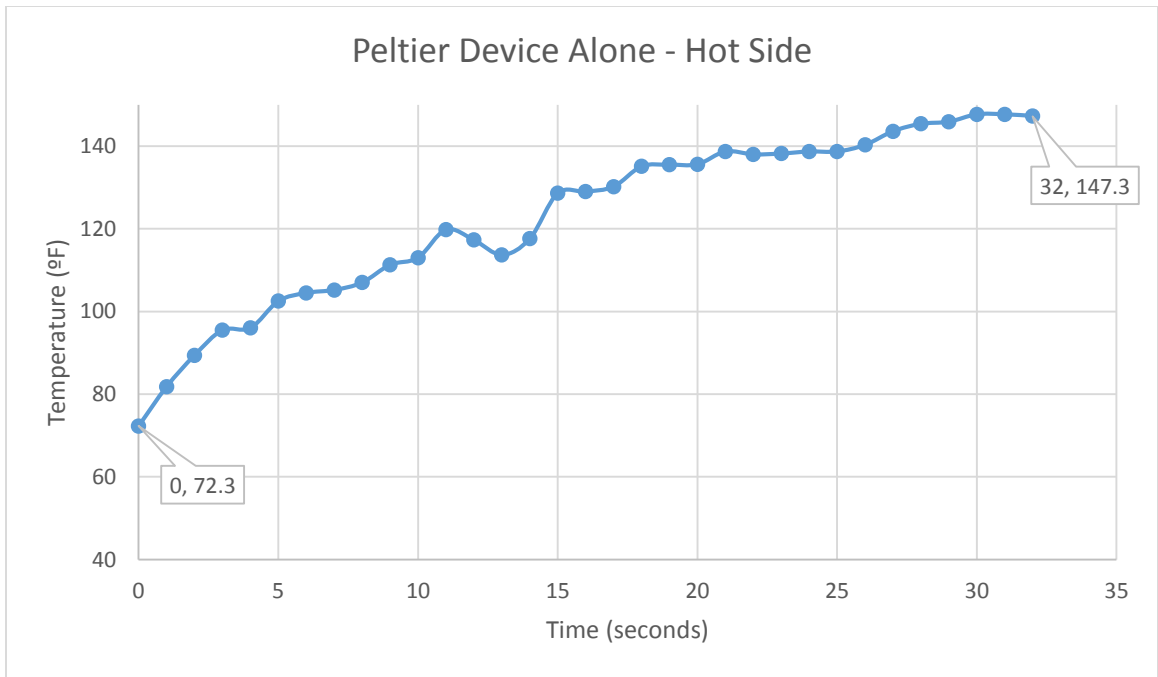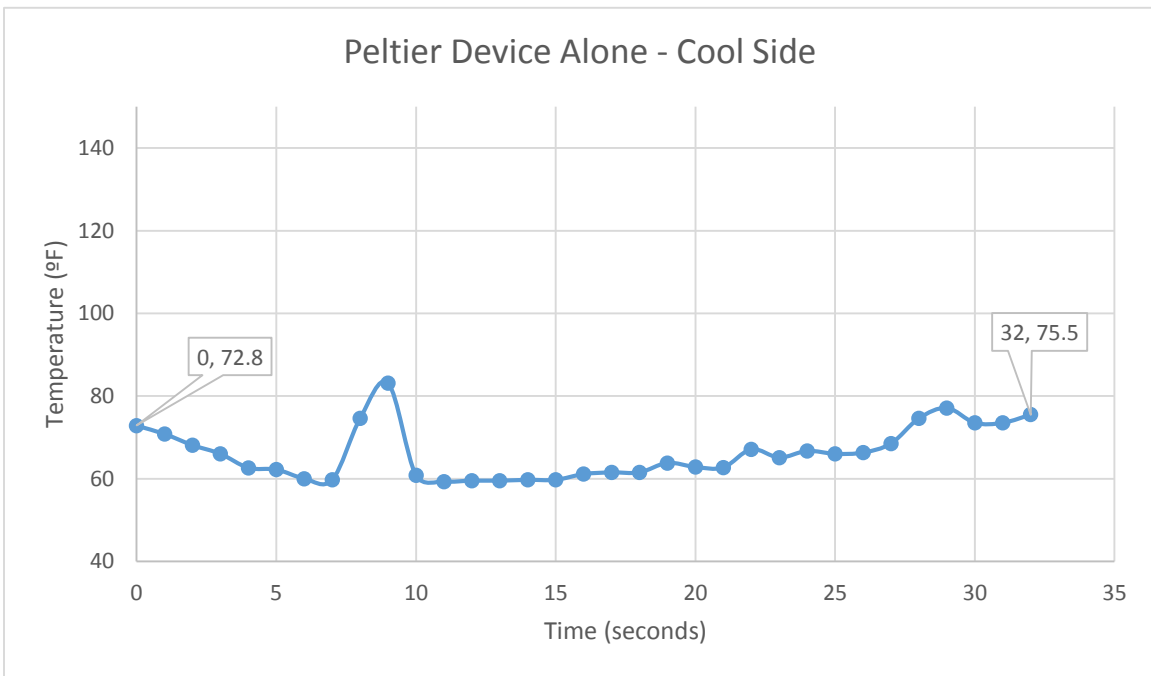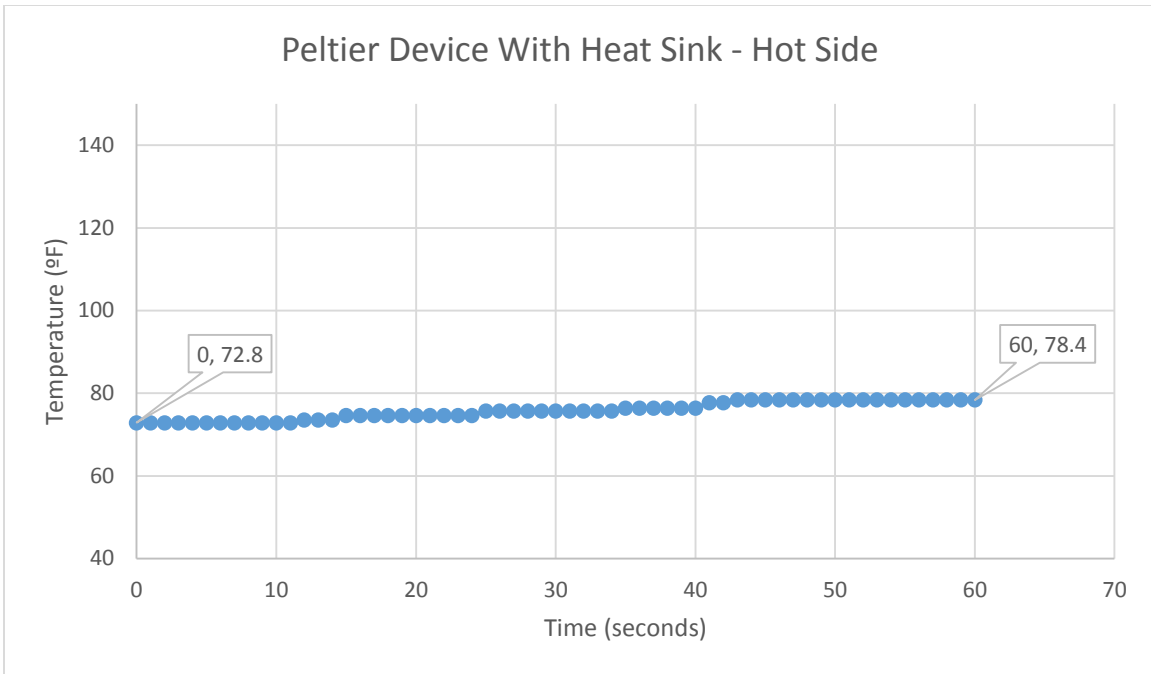
Cup Holders

Chilled cup holders provided a unique engineering challenge but led me to learn more new information than any other section of this project. My original idea was to create a miniature refrigeration system in an effort to apply what I learned in thermodynamics. This would require two sets of coils, an expansion valve, and a small compressor that, in the interest of having a consistent power supply, worked with 12V. This approach would not be impossible but a much cleaner and cheaper solution rested beyond my discovery of thermoelectric coolers that operate by the Peltier effect.

The Peltier effect (or thermoelectric effect) is the presence of heating or cooling a junction of two dissimilar conductors when an electric current passes through (see Appendix 3.3). Thermoelectric coolers, or Peltier devices as I will refer to them, simply create a temperature differential when subjected to an electric current. The approximate maximum differential that a powerful Peltier device can create is 70ºC. This is to say the hot side can get to 35ºC above ambient temperature and the cold side 35 ºC below. 70 ºC is a huge number especially for my application and would only be theoretically achievable with a very high end Peltier device. My chosen component costs only a few dollars and is 1.5 x 1.5 x 0.125 inches in order to fit neatly under an aluminum cup holder and secured with thermal paste. An LED will signal if a cup holder assembly is on so there is no risk of leaving it running unintentionally.

The Peltier device that I purchased only specified that it should operate at 12V and did not have a specification on the temperature differential that it is capable of so I started my own testing. I knew before starting that I would also need a heat sink for the hot side, otherwise the cool side would also start to rise in temperature. To evaluate the performance of my heat sink system I took measurements of both the hot and cool side while the Peltier device was alone and in a full test assembly. The heat sink apparatus is merely thermal adhesive attaching aluminum fins to the hot side and then a small fan to create convection (see Appendix 3.4). The results can be seen in Figure 1.

Peltier Device Alone - Hot Side

Peltier Device With Heat Sink - Hot Side

0, 72.8

60, 78.4

Peltier Device Alone - Cool Side
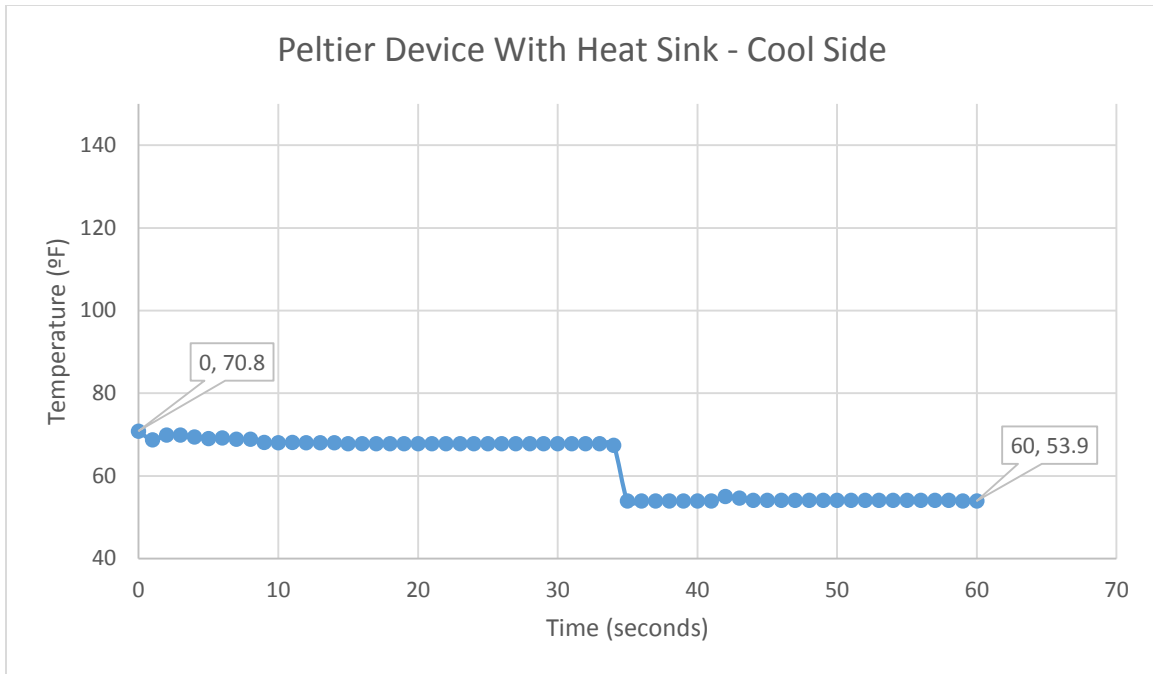
0, 72.8

32, 75.5

Figure 1. Temperature vs. time plots of all cup holder tests.

All of the graphs are plotted on the same temperature scale to make comparisons easier. The tests with heat sink were run for about one minute and the tests without for thirty seconds using a non-contact infrared temperature gun. It is possible for a Peltier device that does not have a heatsink to damage itself if it gets too hot, so the tests were kept to the minimum time necessary to recognize the trend. All of the tests started around 73 ºF, which was the temperature of the room, and multiple tests were done for each with the average appearing in the graphs above.

Comparing the two hot side tests, we get very intuitive results. Without the heat sink, the temperature quickly climbs and eventually levels off. These tests were stopped before the apparent limit was reached but it is safe to say that the final value in the graph of 147.3 ºF is close to the max temperature it will reach. The temperature for the heat sink test was taken as

close to the center of the base of the fins as possible and the results were a very slow and steady increase that levels off at a practical 78.4 °F.

The cool side test with no heatsink is the best representation for why the heatsink is necessary in this application. We see a quick drop off in temperature that eventually turns around and finishes even hotter than it started. Because the hot side is able to achieve such high temperatures, the max differential of the device is met and the cool side begins rising along with the hot side. After implementing the heatsink, we see a gradual decline in temperature until finally, the cup holder tapers off around 53.9 °F, roughly 20 °F lower than ambient temperature.

The nature of this test made it difficult to achieve high accuracy and consistency. Without a way of mounting the temperature gun, there was a lot of human error associated with not always taking the temperature of the exact same spot. The metallic finish of the cup holder also seemed to affect the readings. The above data would probably not include so many sharp spikes and outliers if the testing was more perfect in these two ways and in the case of the cool side test with the heatsink, the graph would look more like a mirror image of the hot side test with the heatsink.

Speakers

The speakers would be included in the minor features if it was not for the fact that that will be hidden and, similar to the trays, will be revealed when in use. Two corners of the table will have small speakers mounted in them and can rotate outward (see Appendix 3.5), so implementing 12V DC motors again makes the most sense.

Similar to the tray arms, the speakers use a maple dowel and nylon flange bushings. The dowel is vertical and the whole assembly rests on the low friction bushing to rotate. The top is attached with a set screw hub to a smaller, cheaper motor since the torque requirements are achievable by most hobby motors. The speakers themselves have a small circular volume dial which is also where the auxiliary plug is connect to the device that is playing music. This will be mounted to the front control panel for easy access (see Appendix 3.6). The original housing will be removed in order to mount the speakers to the rotating towers and the small subwoofer will sit inside the table where there is a small rectangular space next to the cabinet. The wiring for the control dial will be the only part that needs extended by stripping the wire and soldering extra length to it.

Other Features

The table includes several minor features that required enough engineering to at least mention briefly.

The bottom of the table is raised off of the ground by four inches by a square base. This creates a small overhang so the largest dimensions of the table are larger than the area that someone could stub their toe. It is also high enough to vacuum up to the base without having to lift the table (see Appendix 3.7).

The top of the table is removable and without this feature it would be impossible to assemble. It has a channel cut into it so it always rests snugly in the same spot. This feature also makes it easier to do maintenance on the mechanical parts (see Appendix 3.8).

Two USB ports are available for phone charging on either side of the speaker dial. They are buried in the panel and secured there by the inner structure of the table and glue. The table top overhangs the control panel so any spills will not immediately reach exposed electronics (see Appendix 3.6).

Any spare room on the inside of the table is taken up with storage. Two large drawers that extend almost the entire length of the table are on one side opposite of the trays and on the other is a cabinet. The drawers rest on gliders that can extend to the full length of the drawer and are rated for 100 lbs. The depth of the cabinet extends until the back acts as the mounting location for the drawer gliders and the other side is mounted on the tray support panel. The bottom cabinet shelf is able to fit DVD cases and the top can hold smaller miscellaneous clutter (see Appendix 3.9).

Controls

The brains of the table consist of an Arduino Uno (see Appendix 4.1) with a BLE (Bluetooth Low Energy) Shield and a long breadboard. This allows for control over all mechanical devices with any Bluetooth connectable device such as computers, smart phones, or tablets.

The breadboard circuit that I have built (see Appendix 4.2) consists primarily of four the LM293D which is a four channel motor driver IC. Each can control two DC motors with forward and reverse controls and use only one power supply. The fans and Peltier devices can also be controlled with these by using only the "forward" direction which is convenient when wiring the power.

Two 12V power supplies will be used to run all of the devices and the 5V signal from the Arduino powers all of the ICs. Two power supplies are necessary because the cup holders require two components to operate simultaneously, the fan and Peltier device, and to achieve the performance discussed earlier, they both need 12V.

Writing a program to operate each device is very simple. Arduino automatically keeps track of time as a program runs, so in the case of the tray and speaker motors, I can simply define the amount of time necessary for it to reach its final position. I initially ran into trouble with my programs running forever. So, to solve this in a more creative way that I tried originally, my programs run the motor in the desired direction, ceases commands for the set amount of time while the motor continues turn, and then sends the Arduino into and infinite empty loop. Microcontrollers, like the Arduino UNO, do not suffer any ill effects of being caught in a loop and this was one way to terminate motion automatically until another command is given (see Appendix 4.3).

The Arduino requires a 9V power supply, the mechanical components use two 12V supplies, the USB chargers use a USB splitter wall plug in, and the speakers have a standard wall plug as well, all of which get power from a standard surge strip that runs from inside the table to the nearest outlet.

Problems and Limitations

My number one limitation over the course of this project has been my lack of convenient access to wood working equipment. I mentioned before that an old friend has helped me with this

problem but since he lives an hour away and we were only able to meet up a few weekends throughout the semester, the project remains unassembled. I still plan on finishing the table and using all of the features in the near future since I have purchased every component but I am a little disappointed that I could not include a picture of the finished table in this report. Instead, I have included my full model with proper coloring to display everything that I described in unison (see Appendix 5.1).

The only other significant roadblock that I experienced was the lack of availability for some of my components. I checked back frequently to some websites to make sure I did not miss a restocking, but still to this day I am waiting for my BLE Shield which is paid for but had the delivery date pushed back by several months because of their lack of stock and abundance of orders. This has not been a problem with testing the validity of anything since the only difference with running the programs is they require a wired connection. Once, the BLE Shield arrives I will be able to run these programs with more intuitive controls using the Arduino iPhone app.

Conclusion

My approach to this project was based more heavily on trial and error rather than calculations. I would try a test, research something new, add an idea, and in the light of new evidence I would tweak my approach. I am glad I used this method because it allowed me to practice problem solving skills and flexibility. I get plenty of calculation practice while in the classroom but designing my own tests and solving problems that were created by my own decisions is something every engineer needs to learn but cannot from merely reading textbooks. I will not forget the valuable lessons learned during this process and I also realize that the first iteration of

anything is never the best. Maybe one day I will have the means to improve on my smart coffee

table by making it simpler, cheaper, and more efficient in its construction.

Appendices

Appendix 2.1
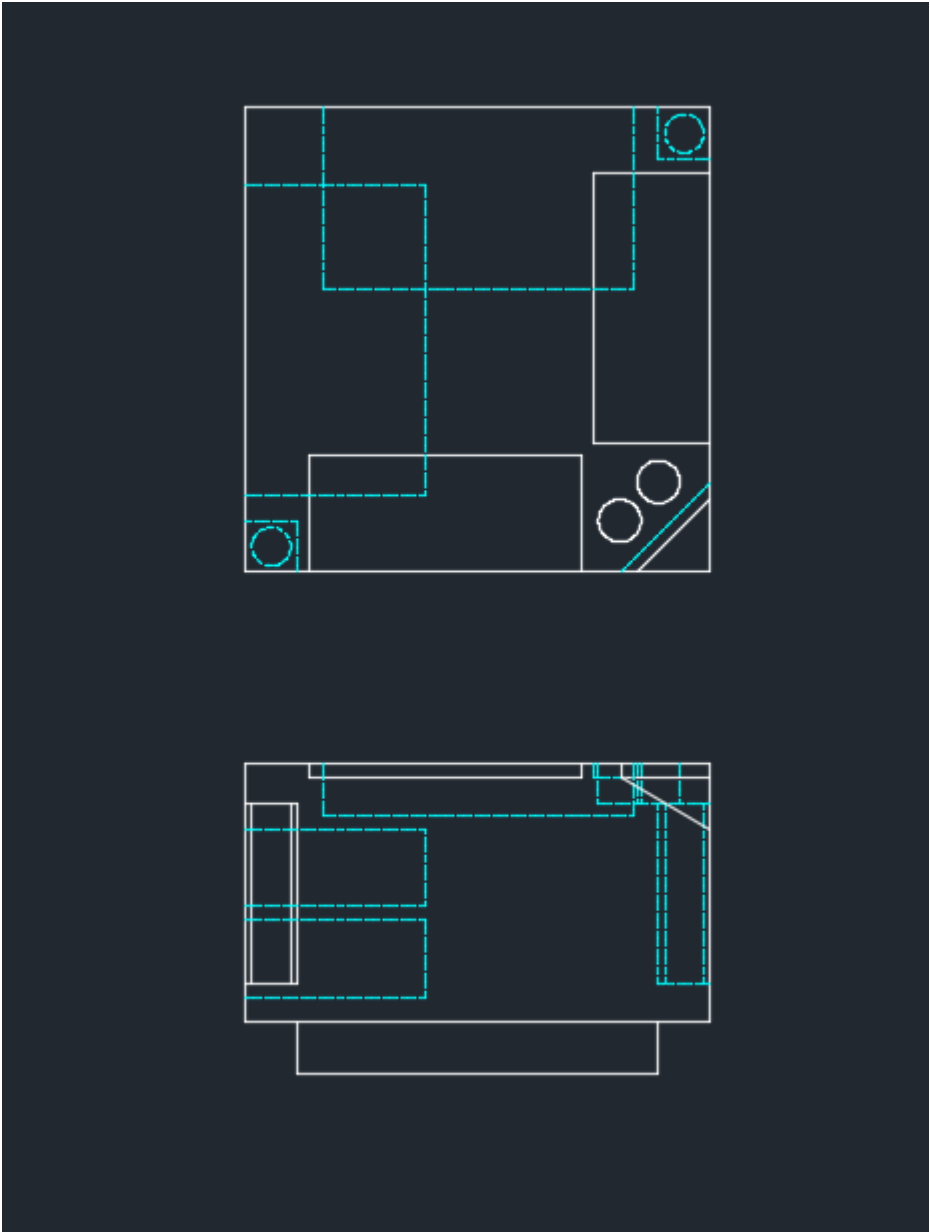
Appendix 2.2

Smart Coffee Table Bill of Materials - 100				
DRAWING NUMBER	ITEM	PCS. REQ'D	MATERIAL OR VENDOR	DESCRIPTION
	101	1	Amazon	ARDUINO UNO REV 3
				DESCRIPTION: https://store.arduino.cc/product/GBX00066
	102	1	Amazon	BLE SHIELD FOR ARDUINO
	103	4	Amazon	NEXTROX 37mm 12V 15rpm ELECTRIC MINI GEARED BOX
	104	2	Newegg	12V 6A 72W TEC1-12706 THERMOELECTRIC COOLOER
				COOLING PELTIER PLATE MODULE 40x40mm
	105	1	Amazon	CYBER AUCUSTICS CA-3602FFP
	106	2	Amazon	BRUSHLESS MINI DC COOLING FAN
	107	2	Discount Poker Shop	ALUMINUM CUP HOLDER
	108	2	Amazon	SMOOTH FOAM INSULATION
	109	2	ebay	50 x 40 x 18MM ALUMINUM HEAT SINK
	110	2	Amazon	ARCTIC ALUMINA THERMAL ADHESIVE 5g
	111	2	sparkfun	PINION GEAR (24t; 6mm BORE)
	112	2	sparkfun	PINION GEAR (32T; 0.25" BORE)
	113	2	sparkfun	SET SCREW HUB - 1/4" BORE
	114	2	Amazon	USB - MALE TO FEMALE EXTENSION
	115	1	Amazon	2 PORT USB WALL CHARGER
	116	22	McMater Carr	Light Duty Dry-Running Sleeve Bearing
				1/2" Flange OD, Nylon, for 1/4" Shaft Diameter, 3/8" Length
	117		McMater Carr	1/4" DIAMTER MAPLE DOWEL ROD

Smart Coffee Table Bill of Materials - 200				
DRAWING NUMBER	ITEM	PCS. REQ'D	MATERIAL OR VENDOR	DESCRIPTION
1201	201	8		20mm x 20mm STEEL CORNER BRACKET

DRAWING NUMBER	ITEM	PCS. REQ'D	MATERIAL OR VENDOR	DESCRIPTION
				Smart Coffee Table Bill of Materials - 300
1301	301	4	WHITE OAK	LEG
1302	302	1	WHITE OAK	BOTTOM PANEL
1303	303	1	WHITE OAK	TRAY PANEL (RIGHT)
1304	304	1	WHITE OAK	TRAY PANEL (LEFT)
1305	305	1	WHITE OAK	DRAWER PANEL
1306	306	1	WHITE OAK	CABINET PANEL
1307	307	1	WHITE OAK	REMOVEABLE TOP PANEL
1308	308	1	WHITE OAK	FIXED TOP PANEL
1309	309	4	WHITE OAK	SPEAKER PANEL
1310	310	2	WHITE OAK	SPEAKER BASE
1311	311	1	WHITE OAK	CHARGING PANEL
1312	312	1	WHITE OAK	CABINET BOTTOM
1313	313	1	WHITE OAK	CABINET TOP
1314	314	1	WHITE OAK	CABINET SIDE (RIGHT)
1315	315	1	WHITE OAK	CABINET SIDE (LEFT)
1316	316	1	WHITE OAK	CABINET BACK
1317	317	2	WHITE OAK	CABINET SHELF
1318	318	2	WHITE OAK	CABINET DOOR
1319	319	1	WHITE OAK	DRAWER SUPPORT (TRAY SIDE)
1320	320	1	WHITE OAK	DRAWER SUPPORT (CABINET SIDE)
1321	321	1	WHITE OAK	DRAWER SUPPORT (CABINET LEG)
1322	322	2	WHITE OAK	DRAWER FRONT
1323	323	2	WHITE OAK	DRAWER SIDE (RIGHT)
1324	324	2	WHITE OAK	DRAWER SIDE (LEFT)
1325	325	2	WHITE OAK	DRAWER BOTTOM
1326	326	2	WHITE OAK	DRAWER BACK
1327	327	2	WHITE OAK	SPEAKER HOUSING (FRONT)
1328	328	4	WHITE OAK	SPEAKER HOUSING (SIDE)
1329	329	2	WHITE OAK	SPEAKER HOUSING (TOP CAP)
1330	330	2	WHITE OAK	SPEAKER HOUSING (BOTTOM CAP)
1331	331	1	WHITE OAK	TRAY SUPPORT (LEG)
1332	332	1	WHITE OAK	TRAY SUPPORT (PAD)
1333	333	2	WHITE OAK	TRAY SIDE (RIGHT)
1334	334	2	WHITE OAK	TRAY SIDE (LEFT)
1335	335	2	WHITE OAK	TRAY BACK
1336	336	2	WHITE OAK	TRAY
1337	337	4	WHITE OAK	TRAY ARM
1338	338	2	WHITE OAK	TRAY ARM (BASE)

| Smart Coffee Table Bill of Materials - 400				
DRAWING NUMBER	ITEM	PCS. REQ'D	MATERIAL OR VENDOR	DESCRIPTION
	401	152		FLAT HEAD SLOTTED WOOD SCREW #5 x 1/2"
	402	4		FLAT HEAD SLOTTED WOOD SCREW #5 x 1/4"
	403	77		20mm x 20mm STEEL CORNER BRACKET

Appendix 3.1
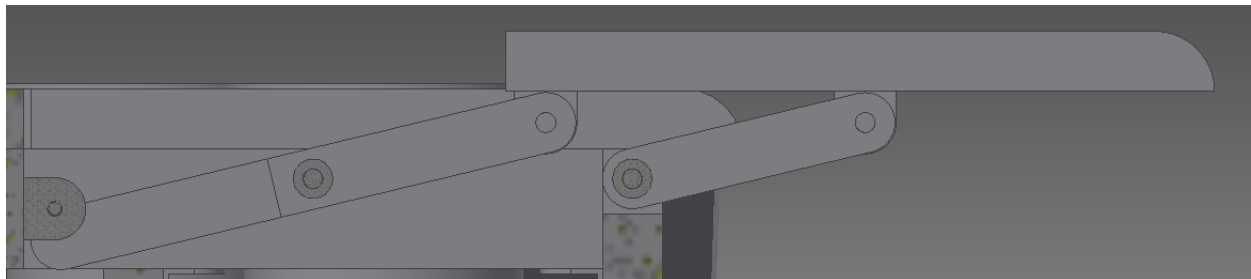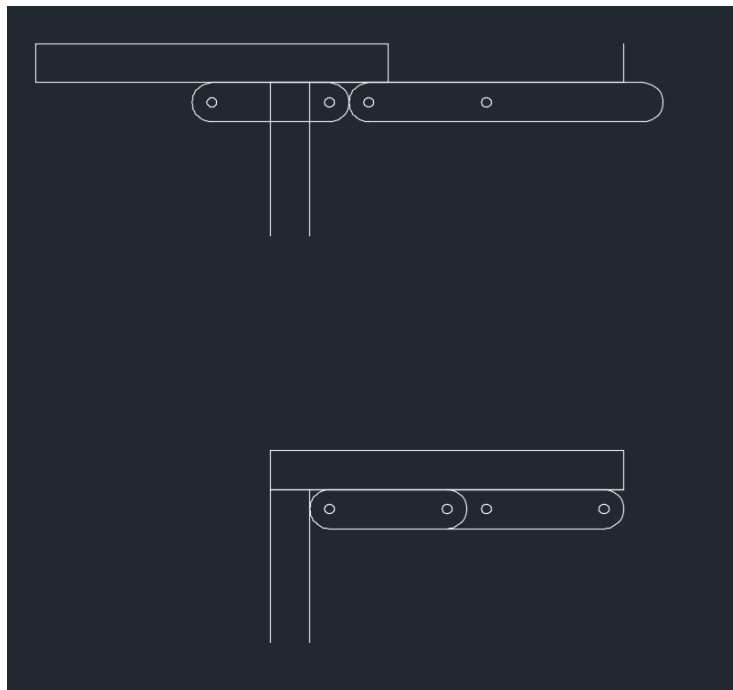
Appendix 3.2

$$\frac{T_1}{T_2} = \frac{t_1}{t_2}$$

Where t_1 is the number of teeth on the smaller gear, t_2 is the number of teeth on the larger gear, T_1 is the original torque of the motor, and T_2 is the torque that the motor is capable of transmitting after applying the gear system.

$$\frac{0.8851 \; ft * lbs}{T_2} = \frac{24 \; teeth}{32 \; teeth}$$

$$\boldsymbol{T_2 = 1.180 \; ft * lbs}$$

Appendix 3.3
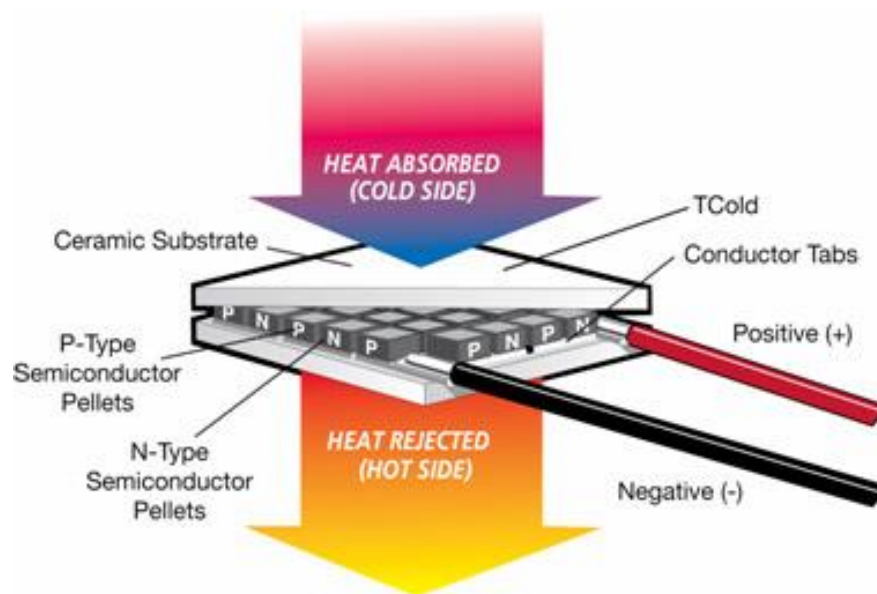
Appendix 3.4

Temperature gun.   Aluminum cup holder.   Temporary insulation.

Peltier device and mini cooling fan (not pictured).   12V Power supplies.

Appendix 3.5
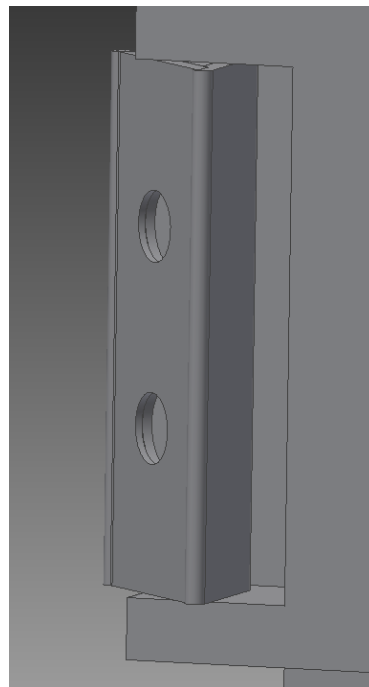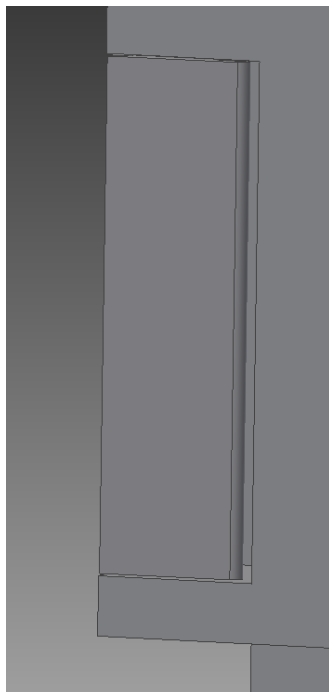
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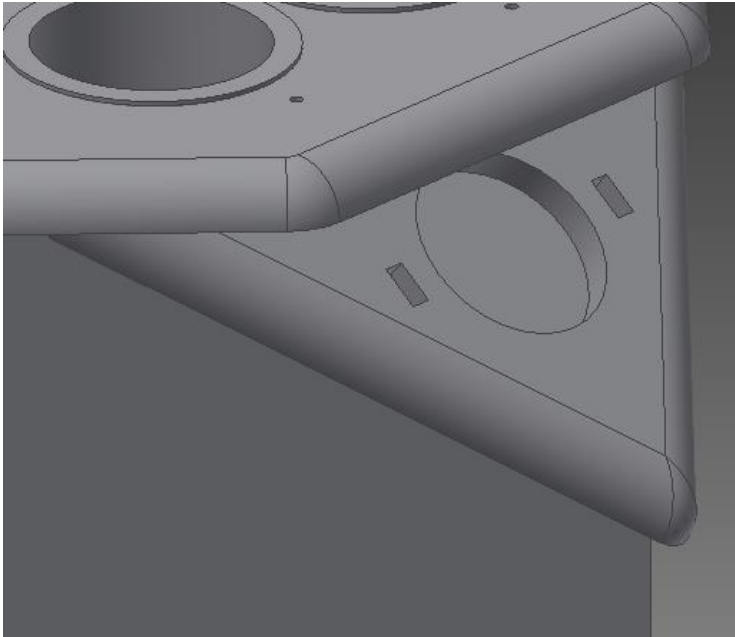
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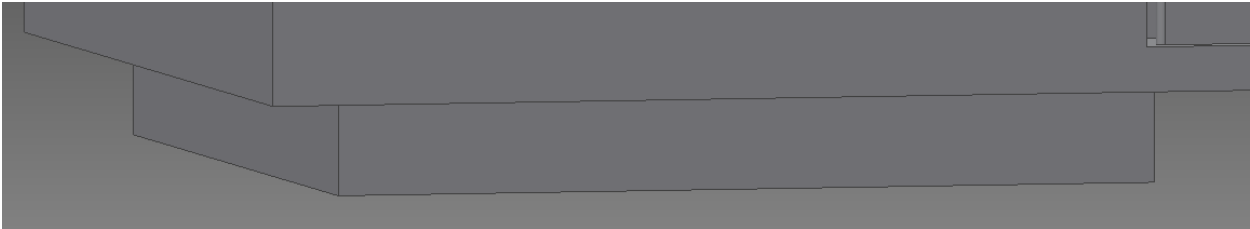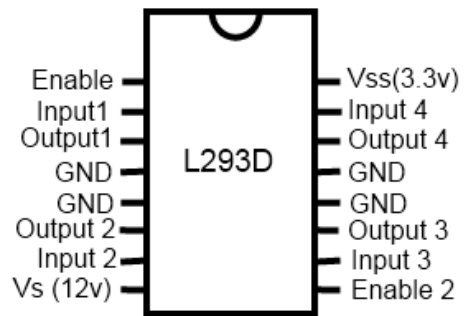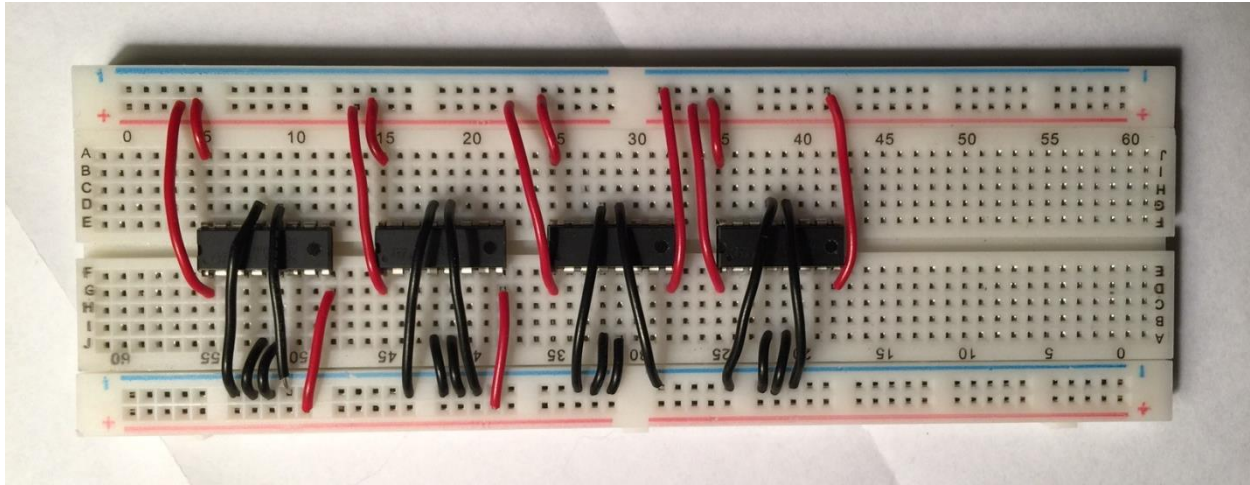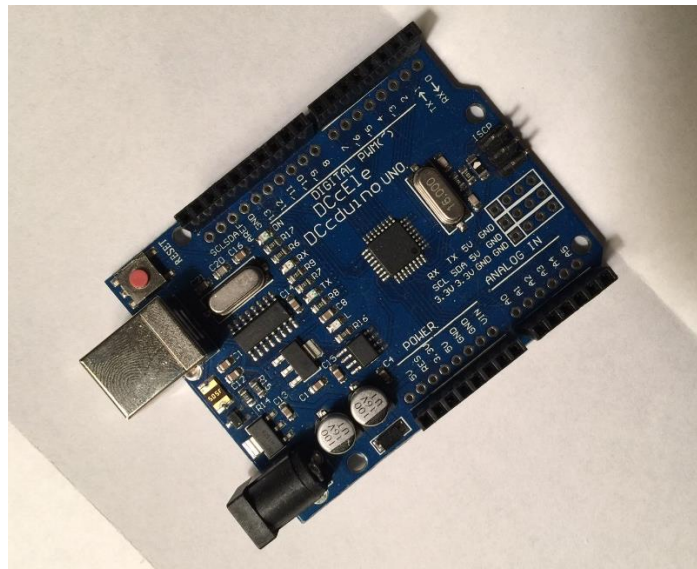

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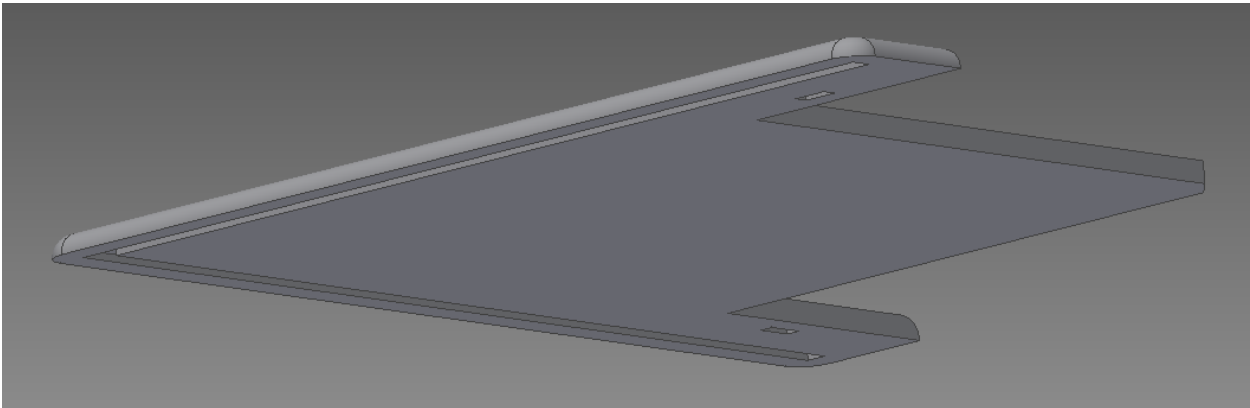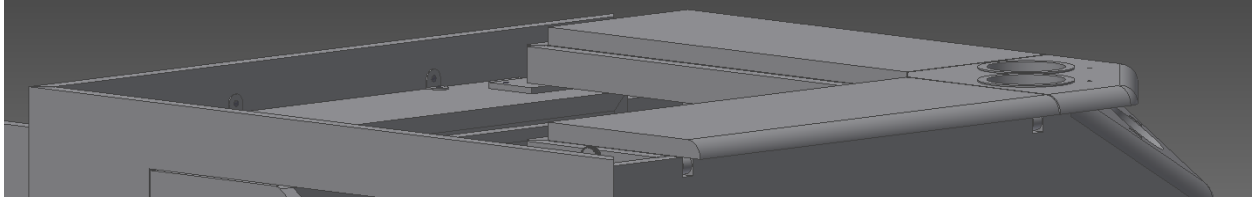
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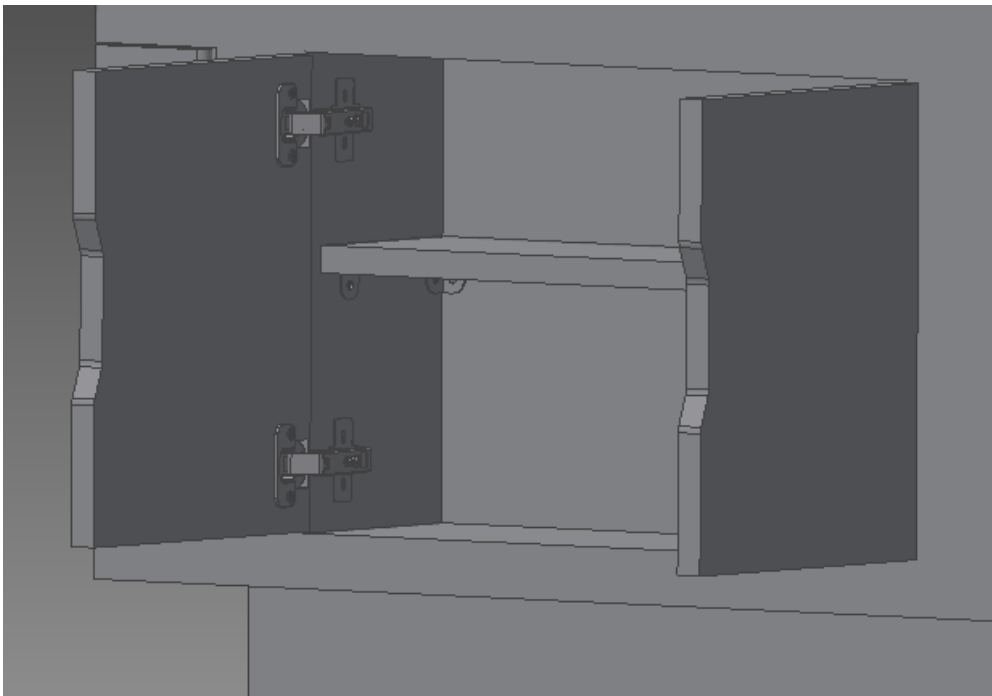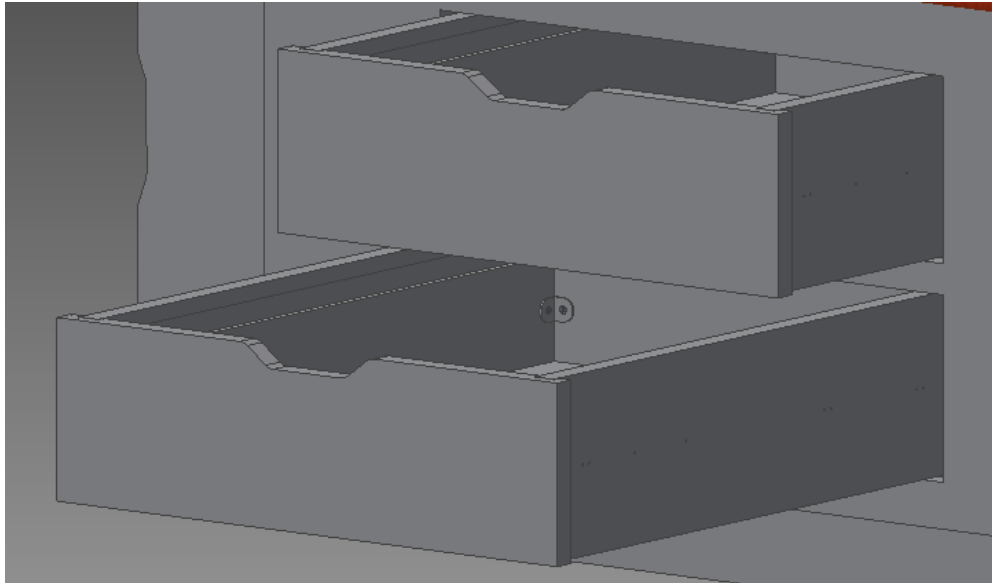
Appendix 4.1

Appendix 4.2

Appendix 4.3

```
Cup_Holder_1

void setup() {

  pinMode(4,OUTPUT);   //Fan Pins
  pinMode(5,OUTPUT);

  pinMode(6,OUTPUT);   //Peltier Pins
  pinMode(7,OUTPUT);

  pinMode(8,OUTPUT);   //LED Pin


}

void loop()

  digitalWrite(4,LOW);    //Drive Fan
  digitalWrite(5,HIGH);

  digitalWrite(6,LOW);    //Drive Peltier
  digitalWrite(7,HIGH);

  digitalWrite(8,HIGH);   //Drive LED
```

```
Open_Tray_1

void setup() {

  pinMode(2,OUTPUT);  //Motor Pins
  pinMode(3,OUTPUT);

}

void loop()
{
  digitalWrite(2,HIGH);   //Drive Motor Forward
  digitalWrite(3,LOW);

  delay(2500);             //Delay for 2.5 seconds motor is driving

  digitalWrite(2,LOW);    //Stop Motor
  digitalWrite(3,LOW);

  for(;;){}
}
```

```
Close_Tray_1 §
void setup() {

  pinMode(2,OUTPUT);   //Motor Pins
  pinMode(3,OUTPUT);


}

void loop()
{
  digitalWrite(2,LOW);      //Drive Motor in Reverse
  digitalWrite(3,HIGH);

  delay(2500);              //Delay for 2.5 seconds motor is driving

  digitalWrite(2,LOW);      //Stop Motor
  digitalWrite(3,LOW);

  for(;;){}
}
```

Appendix 5.1