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Entertainment 721

Mark Hendricks
mh192@zips.uakron.edu

Noah John
njj10@uakron.edu

Jadon Vanyo
jtv20@uakron.edu

Chelsea Payne
cmp168@uakron.edu

Entertainment 721

Senior Design Project

Mark Hendricks:	Scheduling, Reporting, and Overall Design
Noah John:	Modeling, Assembly, and Reporting
Jadon Vanyo:	Electrical Subsystem and Reporting
Chelsea Payne:	Reporting, Proofreading, and Overall Design

Abstract

The goal of this project was to design a luxury, aesthetically pleasing entertainment system with a TV lift mechanism that could be remote controlled. The design would also include a cooling cabinet for gaming systems, a remote locking system, and additional storage. Using a morphological chart and weighted decision matrix for each subsystem key features were determined to be included in the design. Several performance benchmarks were determined to accomplish the team's design. Almost every benchmark was successful in the build of the first prototype. Several heat calculations and FEA analyses were performed on the system to ensure the success of the system. The design was overall determined to be a success, and some ideas for future improvements were proposed by the team.

Table of Contents

1. Introduction

1.1. Background

The majority of Americans use some form of entertainment center to place their TV on in their living room. Not only does this save the user from having to wall mount their TV which can be an issue in rented spaces, but it can also give an aesthetic appeal as well as giving the consumer extra storage space in their home. There are many variations to this product but one of the most eye-catching is an entertainment center with the ability to raise and lower the TV in order to hide it when it's not in use. Doing so can provide a number of advantages to a living room such as increased security as a thief would not see the TV, a clean and minimalistic living room design, the ability to look out a window when the TV is down, etc.. Our design team believes there is a strong customer base for a product like this, but the high price and some of the disadvantages described in section 1.2 have been strong barriers of entry for many consumers.

1.2. Product Definition and Benchmarks

This product will be an entertainment system with a TV lift mechanism. The TV will be stored inside of the entertainment system when not in use, and the entertainment system itself will contain a front and a back portion. The back portion will contain up to a 55” TV and TV lift mechanism capable of moving the TV up above as well as back into the entertainment system. Above the back portion of the entertainment system will be a covering board that will protect the TV when it is stored in the entertainment system and move into the front portion of the entertainment system when the TV lift mechanism is extended. The front portion of the entertainment system will contain several drawers and cabinet space to hold gaming consoles, DVD players, cable boxes, and other various home entertainment devices. The front cabinet area will also contain a dedicated gaming cabinet specifically designed to effectively store and cool down next generation gaming devices like Sony’s PlayStation 5, Microsoft’s Xbox Series X, and the Nintendo Switch. These front cabinets will also contain an anti theft remote locking system that will allow the user to lock the cabinet using a remote control from a distance. This will deter thieves and also serve as a child protection feature. The front and back portions will also contain

a cable management system that will effectively store cables as the TV lift mechanism is moved up and down and it will keep the design neat and organized.

The performance benchmarks that the team is looking to accomplish are:

- A 60 second time from the button press to the full lifting of the TV
- An operating sound level of 40 decibels or less since this is less than most computers and will not disrupt the sound in a living room
- Fan system designed to move up to 200 Watts of heat output
- All of the electronic devices can be controlled remotely
- Cabinets can be remotely locked and unlocked
- Cables do not disrupt the TV actuation through proper use
- A removable back for ease of inputting cables using simple household tools
- Less than 30 inches wide to allow for movement through standard doorways
- Weighs less than 250 lbs
- Fit TVs of 55” or lower
- Cabinets all have soft-close capabilities
- No obviously visible screws or bolts showing on the exterior

1.3. Market Review

Reviewing the current market for similar products the design group found a few items that could be improved upon. The largest issue that the design team had with these products is the way that the top surface above the TV enclosure would come up. In the general market space, either the top surface will flip up and behind the TV as shown in Figure 1.1, or the top surface will rise with the TV and sit overtop as shown in Figure 1.2. Both of these options are suboptimal in the team’s opinion. When the top surface is behind the TV, it looks very out of place and does not fit the clean design theme that a product like this is going for when the TV is down. This creates an incoherent design theme in the product and is difficult to fit correctly into a well designed living room. The other option would be to have the top surface rise with the TV. This is better than having the surface behind the TV but still has a random floating piece of wood on top of the TV and the team believes this is a major sacrifice of owning this type of

entertainment system. The team believes this is the biggest issue in the market that needs to be solved.

Figure 1.1: Top surface flip up design

Figure 1.2: Top surface remains above TV

There are a number of other problems that the team noticed in the market for a TV lifting entertainment system. We noticed that all of these products are very expensive. Even the cheaper ones with little features other than the TV lift are approximately $1500. Other factors holding this product back include the weight of the system being too heavy as well as the lack of a locking mechanism to protect expensive electronics from thieves. The team also noticed that there was a lack of a cooling system for customers that would like to place computers or game systems in the entertainment system.

After reading some reviews, it was clear that there were complaints about the cable management systems in these devices. Either it was difficult to plug things into the items located inside the cabinet or the cables would get tangled due to the movement of the TV lift. The team noticed that there were not many complaints about the speed or the noise level of the lift, which came as a surprise to the team as the initial expectation was that this would be a very important design factor. Reviews also stated that customers enjoyed looking out of their windows when the TV was down and that common placement for products like this are in the living room and in the bedroom.

One problem that is presented with many different entertainment systems, especially ones that involve the TV lift systems and lots of closed storage to hide clutter, is that there is not enough ventilation for multiple different electrical systems. Today many consumers own multiple electrical systems that produce heat when used for large periods of time such as gaming

consoles, Wi-Fi routers, cable boxes, etcetera, and are all things that many would like to store and hide within their entertainment. The team planned to solve this problem by including a special cooling cabinet within the entertainment system. This cabinet is one that would have a ventilation system that would allow the cabinet to be cooled, which would allow the system's user to store and hide multiple gaming systems in the same cabinet without worrying of overheating.

This problem is one that affects many people, especially gamers, who may own multiple gaming consoles that they need to safely store. It is recommended to not place gaming consoles such as Xbox, PlayStation, and Nintendo systems near each other or other electrical systems, or to store them in closed cabinets, because it could result in the life span of the consoles to begin decreasing. Overheating gaming consoles could potentially be very hazardous to not only the console itself but to also the entertainment system it's located in. Many consoles have cooling ventilation systems built into them to keep the console from overheating when stored in the proper way the designer intended it to be. This is typically placed upright, so the fans are not covered, away from any walls and out in the open to allow air to flow around it. The way many ventilation systems help cool the console is by using a fan that pulls cold air into the heat sink of the system from its surrounding environment. This cold air is then pushed through the power supply, where it will push the heat created out through the system's vents as hot air. Because of this, if the console is not stored properly causing the fans or vents to be covered, the airflow in or out of the system can be disrupted causing the console to overheat. The console being operated within a closed cabinet could also cause it to overheat because the ventilation system will output hot air into its environment however it will not be able to take in any cold air to cool it.

This proposes an issue for those who do not want to have their consoles sitting out in the open all the time and do not wish to have to set up and put away their console with each use. The idea of the cooling cabinet will solve this problem. It will allow users to safely set up their consoles in a cabinet that can provide the cool air needed for the console’s ventilation systems to continue to work properly. The user will also benefit from this cooling cabinet because they will not have to move their consoles after each use, and they can stay safely hidden within the entertainment system.

1.4. Customer Base

This product is focused on customers of high end entertainment systems. The customer will likely be buying this product for one or more of the following reasons:

- They want to place their TV in front of a window
- They want a clean design aesthetic for the living room
- They want added security for their electronics
- They want something with a “cool factor” in their place of residence or business
- They want the added cooling benefits installed into our system

Based on the advantages that this product provides versus the competition, the team will target the following customer bases for this product:

- AirBnBs
- Hotels
- Upper class families
- Gamers
- Couples looking for a clean living room design

The team thought that this product could be perfect for AirBnBs and hotels since it could add a great “cool factor” into the room and create a memorable experience for anyone who stays there. Upper class families and couples may want it for the increased level of security and for creating a clean aesthetic in their living rooms. Gamers will be able to use the cooling structure and cable management system to clean up their gaming setups.

1.5. Design Standards and Constraints

This project would have to comply with a number of engineering standards in a production environment. Engineering drawings would be drawn in accordance with ASME Y14.5 and 14.5M. The Consumer Product Safety Commission (SPSC) requires a regulation of lead for paint and surface coatings on furniture. The Federal Hazardous Substances Act (FHSA) must be followed to prevent hazardous materials with the potential to cause fires. The Environmental Protection Agency (EPA) has laws and regulations governing materials which may pose a risk to human health and the environment. Title VI of the Toxic Substances Control

Act (TSCA) establishes limits for formaldehyde emissions from composite wood products. Other standards for specific types of components would also be necessary. Plywood does have some standards such as ASTM D3500 that would be very important. Wood screws are also a major part of this system, so ASME B18.6.1 would be heavily referenced for analysis. Since this project used additive manufacturing to manufacture some of the components, it is important that the team considers some of the standards required. For material extrusion based additive manufacturing, the team would need to consider ISO/ASTM 52903 to cover the methods for defining the material extrusion additive manufacturing process. If this project was sold commercially, ISO/ASTM 52901 would need to be considered to define the specific requirements for the purchase of our additive manufactured components. These are all important engineering standards that the team considered during this design project.

In addition, multiple constraints for the design of the entertainment system exist. The team sought to balance the following parameters against each other to come up with the best design possible:

- Size
  - TV size compatibility
  - Weight
  - Overall Dimensions
  - Storage
  - Cost
- Actuation
  - Actuation Time
  - TV thickness compatibility
  - Cost

2. Conceptual Design

2.1. Expanded Design Brief

The purpose of this design is to provide an aesthetically pleasing, easy to use, and functional entertainment system that has the ability to store a standard flat screen TV. The TV will go from its stored position and with the push of a button rise up from the entertainment system to an upright position. This entertainment center will not only provide the user with the ability to store their TV for an aesthetic purpose, but it will also provide them with extra security for their TV. The entertainment system will also have the capability to store various entertainment devices such as gaming consoles, DVD players, movies, games, etcetera. This entertainment system will provide cost benefits, functional benefits, or decorative benefits beyond what is currently available on the market.

2.2. Objective Tree

When the team began brainstorming ideas and concepts there were several factors to consider. Using these factors, the team was able to determine 4 different main objectives of our design. These objectives are safety, aesthetics, bonus selling points, and material choice, all of which were used to create an objective tree shown in Figure 2.1. The first objective, safety, was the team's top objective as it was the most important. This not only included the safety regarding the entertainment center's users, but also included the safety of the TV, gaming consoles and any other objects placed inside of the system. In order to achieve this the team came up with different methods to ensure safety. The first safety methods proposed was to place safety stops on all the motors used in the system as well as placing motion sensors on the moving parts. Both the safety stops, and the sensors would be done to prevent the moving TV and the top shelf from moving too far and colliding, causing damage to the system. The next idea that was proposed was placing compression springs on the top plate that will allow the plate to move after it has been closed in case a finger or another object gets stuck. Lastly was the idea to use soft closing hinges on cabinet doors to prevent them from slamming on the user's fingers.

The second objective was to create an entertainment system that would be aesthetically pleasing. Since the team wanted to design an entertainment system that would be able to store a TV it was necessary to include a TV lift system. In order to have the TV lift system the team had to determine a way for the top shelf to move allowing the TV to rise up. The most aesthetic option proposed was to have a sliding shelf that would hide the shelf when it is open. Other aesthetic features the team discussed including are a glass covered shelf and LED lighting to the inside of the cabinets. The next objective is the bonus selling points. The first bonus selling point feature the team discussed, was a special cooling cabinet designed to house gaming consoles as well as more additional storage. Other bonus features include remote control to lift the TV, a cable management system, and a security locking system. Lastly was the materials objective, in order to meet our expectations, the entertainment system will need to be very large. Because of this the team knew we needed to pick a material for the system that is lightweight, strong, and relatively inexpensive.

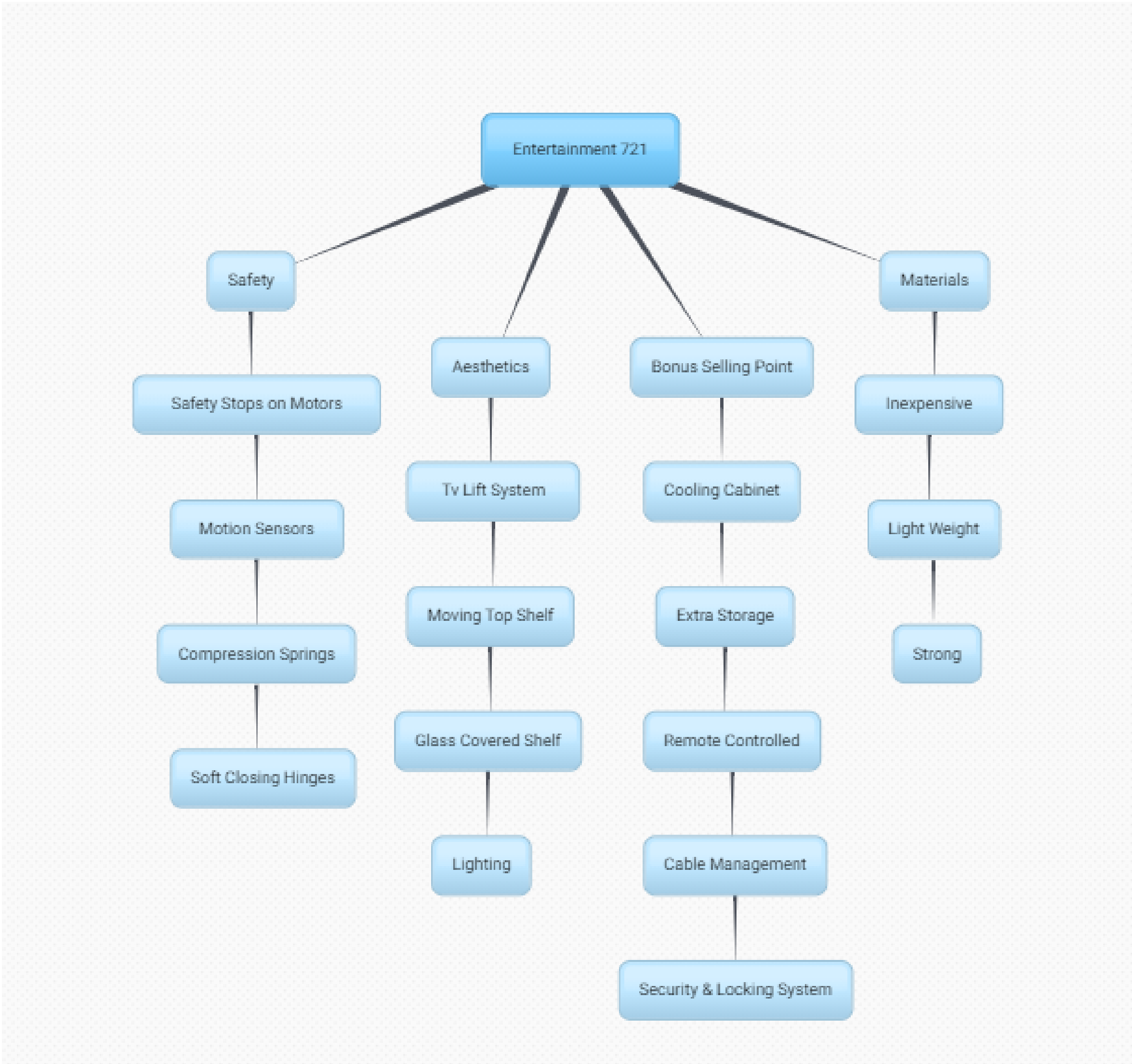


Figure 2.1: Entertainment 721 Objective tree

2.3. Morphological Chart

The team used the morphological method to analyze different design solutions for the entertainment system. This method breaks the overall design down into subcomponents that can be designed differently to accomplish the same overall function. To accomplish this, the first step is to decompose the overall design problem into smaller more manageable subproblems. Next, the team generated several conceptual designs for each of the subproblems. Finally, the team

combined the different subproblem solutions into multiple overall design solutions. Each of these design combinations were evaluated and the best solution was picked. This was the approach that was used for the morphological analysis of this project.

The team applied this approach by first defining the overall function of the entertainment system. From this the design was broken down into subcomponents listed in the first row of the morphological chart shown below in Figure 2.2. These subcomponents include the top shelf, the cooling cabinet, the TV lift, the control center, the aesthetic design, the guidance system for the top shelf, and the cabinet locking system. Once the team had defined the different subcategories it was then time to determine the different concept designs and approaches that the team could use in each subcomponent, which are all listed down below in their respective columns. Using the different proposed concept designs for each subcategory, the team was able to determine the best overall conceptual design.

The team had determined early on that the entertainment system needed to be aesthetically pleasing, of the potential designs proposed it was decided that the modern aesthetic would be best for the targeted audience. Keeping this decision in mind, one of the most challenging features the team wanted to implement was the top shelf. In order for the TV to be safely hidden in the system the team needed to determine the best possible way for the top shelf covering the TV to be removed so the TV can be lifted. Out of the concepts listed, it was decided that the team would use the rail system with a 45 degree cut away to allow the shelf to slide forward out of the way of the TV. While this concept is one of the more intricate solutions proposed, it is also the most aesthetically pleasing. This decision made it easy for the team to determine the necessary guidance system for the top shelf, which would be a 45 degree rail guidance system. Another necessary decision that was needed was the type of TV lift system the team would use. To save time and money the team decided to go with the commercially produced TV lift. Using this decision, it was determined that for the control center subsection the team would use an Arduino. For the cooling cabinet subcategory, the team decided to use forced convection with a fan system because they are simple, effective, and inexpensive. Lastly the team decided to use a servo remote locking system as it is easy to implement with the other decisions already made for the top self.

Morphological Chart for Entertainment 721						
Top Shelf	Cooling Cabinet	TV Lift	Control Center	Aesthetic Design	Guidance System for Top Shelf	Cabinet Locking System
Moves up on top of the TV	Natural convection cooled with ventilation	Commercially produced TV lift	Arduino	Modern	45 Degree Rail Guidance System	Mechanical key locking system
Moves using a rope and pulley system	Force convection with liquid pump and cooling system	Homemade actuator system	Raspberry Pi	Light up	Rope and pulley system	Servo remote locking system
Swings upwards on a hinge connected at the back	Forced Convection with fan system	Rope and pulley system to pull the TV up	Proton Computer	Rustic	90 Degree Rail Guidance System	Fingerprint scanner
Rail system with a 45 degree cut away	Fin heat sink		BeagleBone	Steampunk		Passcode protected
Two doors swing open from the center	Mixed forced convection system using fans and pumps					

Figure 2.2: Morphological chart for the Entertainment 721 project

2.4. Initial Conceptual Ideas

There are many different designs that manufacturers of entertainment systems have thought of in order to maximize both aesthetic appeal and functionality. Through the research performed, the team believes that the functionality of many of the designs can be improved without a large impact to the overall aesthetic appeal of the entertainment system. Through research and brainstorming sessions, the group has thought of many design ideas improving the concept of the entertainment system.

2.4.1. General Design

Based on the customer base that this product is targeted for, the team decided that a simple and modern design would fit best with most people who have interest in the product. Typically those who want a more rustic design to their room would not have technologically advanced furniture such as this product. The simple design structure will also fit in well with the team's solution to removing the top surface from view when the TV is extended (see 2.4.3). The team went with a minimalist look that avoids swooping lines and large amounts of character both for the ease of manufacturing and for fitting into modern spaces.

If this product was to be sold in a retail market, the paint scheme would come in three colors, all black, all white, or a more modern design theme as shown in Figure 2.3. The simple colors would be easy to blend in with most furnishings and would work well for implementation into hotels and Airbnb's. The modern look would be for users who would like to make their entertainment 721 a statement piece.

Figure 2.3: Example aesthetic for the entertainment system that the team considered

The team believes that putting a clear glass or acrylic sheet over one of the storage areas can add functionality by allowing the user to use any IR remotes in combination with their blu ray players or other devices without being forced to set up the device outside of their entertainment 721. The group also believes that adding LED strip lighting to the interior of the cabinet can provide a unique lighting effect that is able to emphasize certain decorations or items

placed inside of an entertainment 721. Another idea was to make the lifting actuation system out of a clear plastic material in order to give the appearance of a “floating TV.”

2.4.2. Safety

Safety for the users as well as their property are a top priority. The team plans to provide a safety stop to the motors or actuators as the TV rises and falls. This will be done to prevent the TV from attempting to rise while the top surface is still in the way, which could cause the TV or the system to break. The safety stop will also help prevent a user’s hand from being stuck in the system. Ideas for this safety stop include finding an actuator or motor with a maximum force applied that will not harm someone’s hand or electronics. Another idea for adding a safety stop is to add sensors into the system that will tell the system when there is an object in the way of the TV when it is in motion. Similar to sensors used on garage doors, these sensors would send a signal to the motor and would prevent the TV from lifting or descending until the user moves the object out of the TV’s path. The team’s third idea is to install springs into the system so that if a finger is stuck, the spring is able to compress and leave room for the user to pull his or her hand back. The concept sketches for this idea are shown below in Figure 2.4.

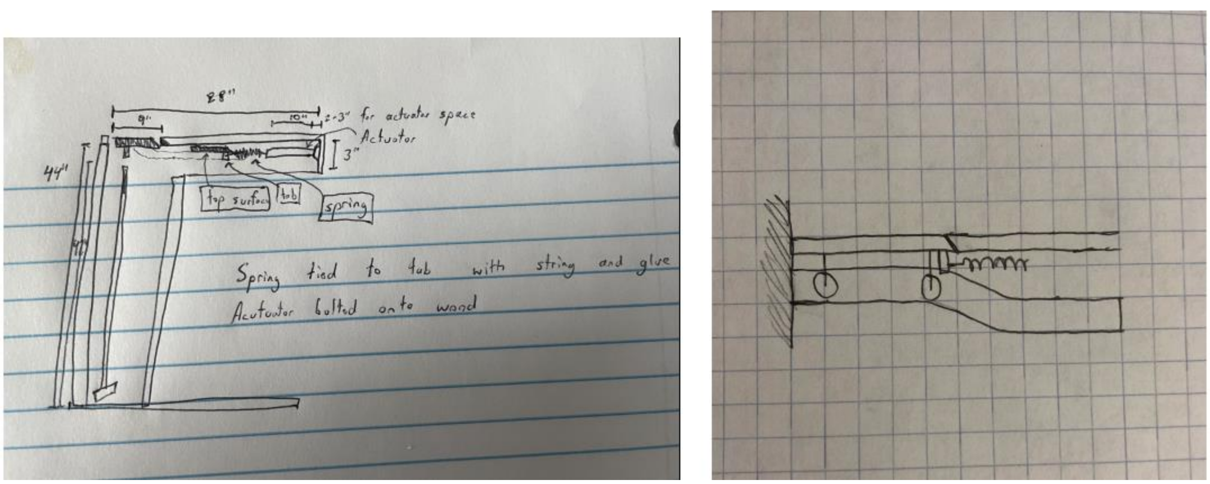


Figure 2.4: Conceptual designs for the rail system

Another safety feature that the team plans to provide is soft closing cabinet doors. Since soft closing door hinges cause the door to take more time to close, they help prevent users from pinching their fingers in the door which provides additional safety to the users. The soft close hinges not only provide safety to the user but can also provide safety to the object inside the

cabinet. Since these hinges allow the doors to close softly, they will not cause the cabinet to shake like a regular hinge would, this prevents objects from potentially getting knocked over and breaking while in the cabinet. In addition to increased safety of both the user and stored objects, these soft close hinges also increase the life of the cabinets. The gentle close helps minimize friction as well as stress placed on the cabinet, and prevents cracks, dents, and marks caused from slammed doors.

2.4.3. Top Shelf

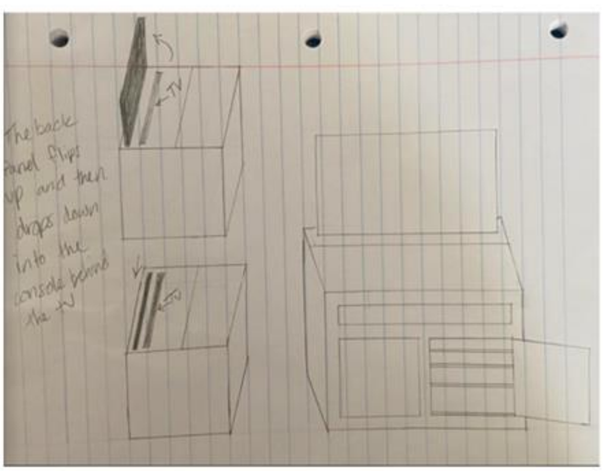
The main problem seen in the market that the team wanted to address was the method of removing the top shelf in order to lift the TV out of the system. Many ideas were brainstormed and can be referenced in Figure 2.5. With all of these initial ideas, the team decided to go with a rail system with a 45 degree cut away in the top shelf. The main advantage of this method was that the top shelf would disappear from view completely which would add a clean and modern design appeal. This system is more complicated and expensive than some ideas such as leaving the top shelf attached to the top of the TV but the team believes that this one of the main improvements made to distinguish the product from others on the market.

The other ideas for dealing with the top shelf were plausible but still had some major flaws. The rope and pulley system would be flimsy and more difficult to design for an automated experience. Having two doors swing open would have added some complexity as well as a clunky aesthetic since the user would have to look at the two pieces sticking out of the top of the system while their TV was up. It would also create a space problem since it would remove much of the usable space on the top of the entertainment system that could be used for decorations. There could also be mechanical difficulties in a case where a user placed an object in the way of the opening doors. Many of the systems that the team reviewed had a hinge on the back of the top shelf that would rotate the shelf back so it would lay behind the TV. The team decided that this looks very unappealing and not many people would like to see a piece of wood sticking out from behind their TV. The next best solution available would be to attach the top surface to the top of the TV and allow it to rise with the TV. This had several advantages since it would be extremely simple, it would allow for decorations to be placed on the surface, and it would allow for a minimized height of the system. The team decided that while these are large advantages, this solution still creates an enormous problem of having an ugly sheet of wood sit on top of the

TV and ruin the aesthetic appeal of this piece of furniture. For this reason, a sliding top shelf was chosen.

Weighted Decision Matrix												
		Options										
Criteria	Weight	Rail System		Pulley		2 Door		Flip Up		Overhead		
		Score	Tota l	Score	Tota l	Score	Tota l	Score	Tota l	Score	Tota l	
Aesthetic Appeal	0.45	9	4.05	2	.9	4	1.8	1	.45	5	2.25	
Differentiation from current market	0.25	9	2.25	9	2.25	9	2.25	1	.25	2	.5	
Design Complexity	0.1	3	.3	1	.1	5	.5	8	.8	10	1	
Cost	0.1	2	.2	3	.3	5	.5	8	.8	10	1	
Space Constraints	0.1	6	.6	4	.4	4	.4	8	.8	10	1	
Total	1		7.4		3.95		5.45		3.1		5.75	

Figure 2.5: Weighted decision matrix for the top shelf actuation



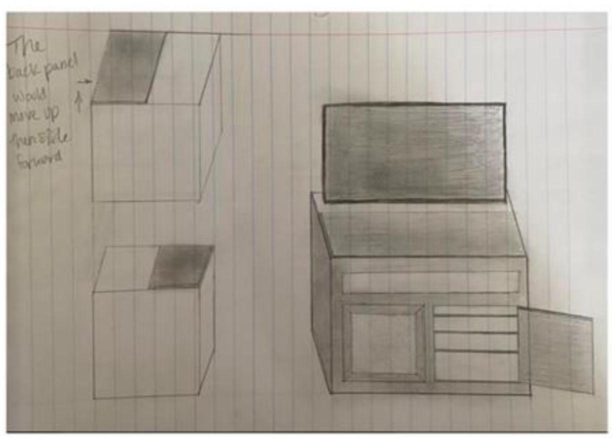


Figure 2.6: Initial conceptual drawings for the TV storage

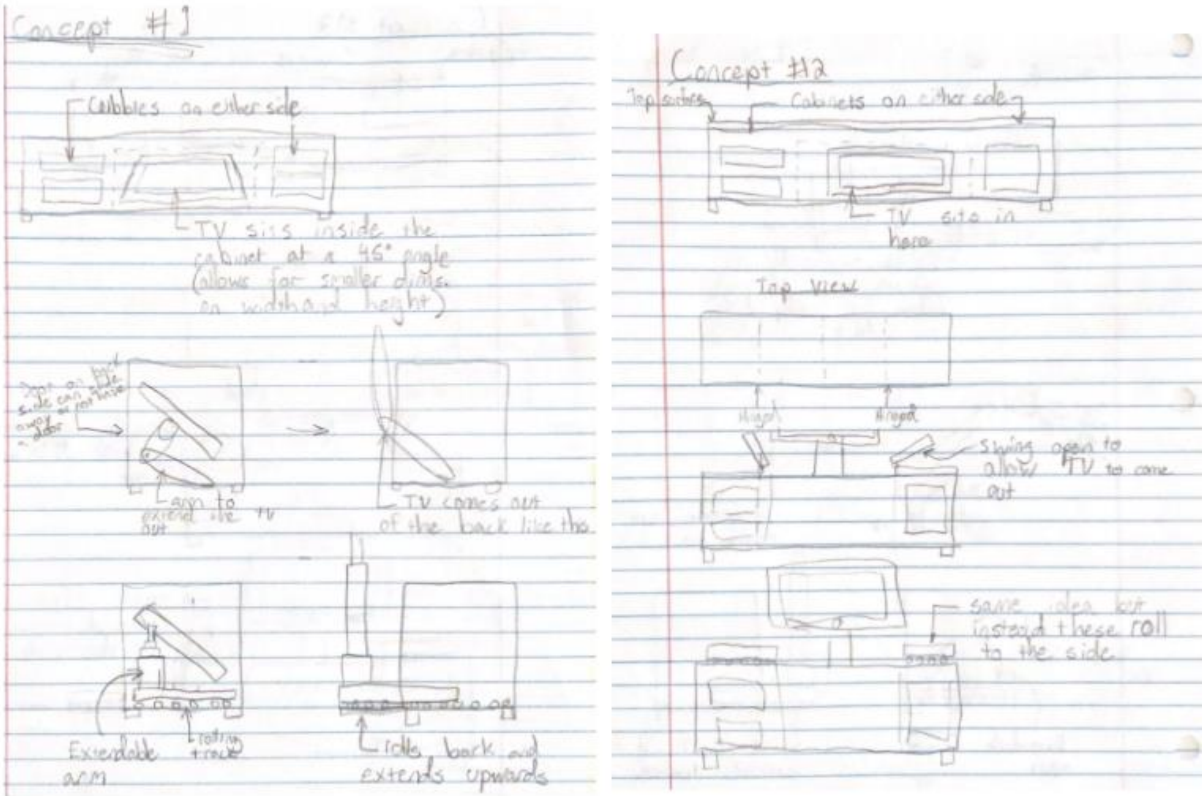


Figure 2.7: More conceptual drawings of ideas for how to store the TV

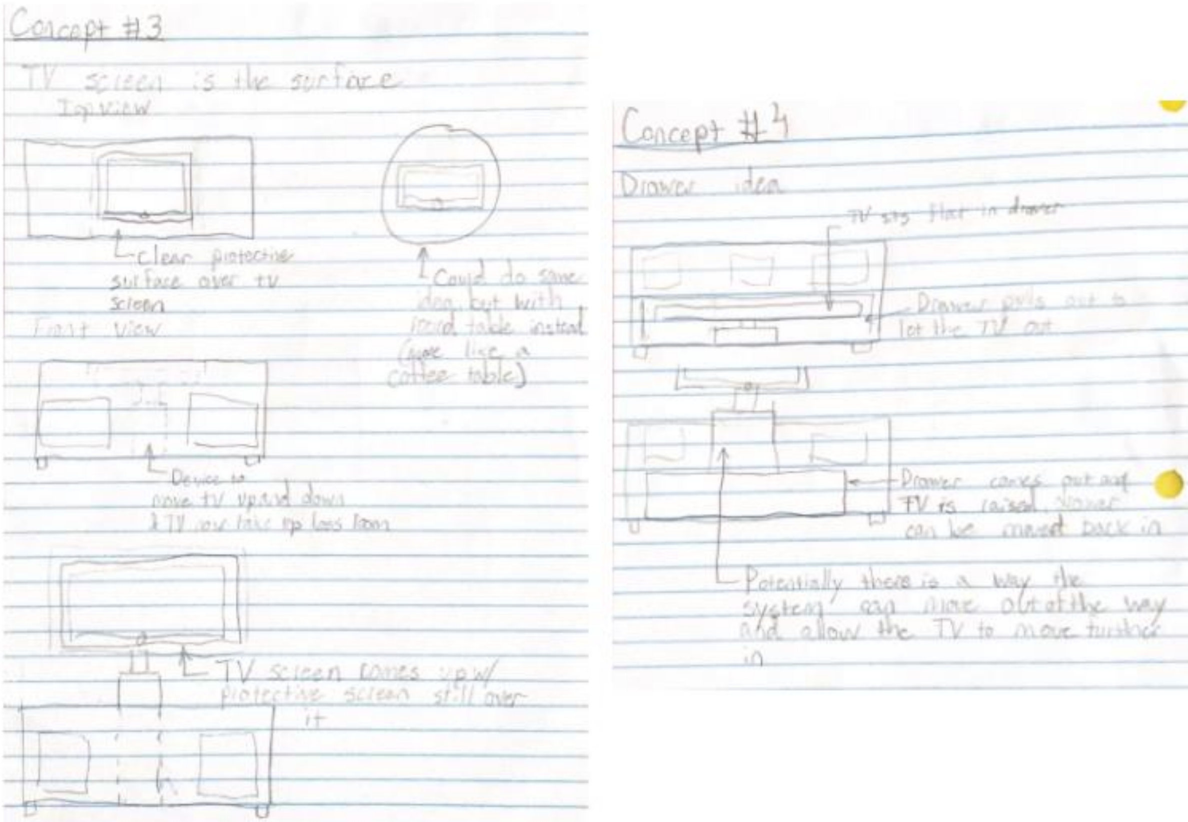


Figure 2.8: More conceptual drawings of ideas for how to store the TV

2.4.4. Material Choice

An important decision the team needed to make was what material would be the best choice for building the entertainment system out of. Several material suggestions were proposed including board, plywood, particle board, and OSB. In order to determine the best choice of material for the entertainment system design a decision matrix was created. Several factors that the team wanted to take into consideration when exploring the material options were listed. The factors included the strength of the material, the cost, the way it looked, how much the material weighed, and how easy it was to work with. These were all important factors to consider, it was important that the material be strong for safety reasons and for it to be able to support the weight of the TV and all of the objects placed within the system. Because it was a goal of our design to cost less than those currently available it was important that the material would be cost friendly. Another goal the team had for the entertainment system was that it would have an aesthetic design, which meant the material should be one that will look nice when the build is completed.

The weight of the material was an important factor due to the size of the system as well as meeting the performance benchmark of the system weighing less than 250lbs. Lastly, the team considered the workability of the different materials, this was important to make sure that the material would be easy to build with. Using the decision matrix shown below in Figure 2.9, each factor was assigned a weighted value which was used to determine the score of each material.

The team decided to use plywood as the material as it received the highest score. The wood board was the strongest of the materials presented but was also the most expensive and the heaviest option. The particle board was the lightest of the suggested materials however it was also the weakest option and difficult to work with. OSB was a decently strong and light option but it would not have provided the desired look the team wanted. Plywood was the best option because even though it is not the cheapest option it would provide the desired look the team wanted, is the easiest to work with and would provide the necessary strength.

		Board		Plywood		Particle Board		OSB	
	Weight	Score	Weighted	Score	Weighted	Score	Weighted	Score	Weighted
Strength	0.20	10.00	2.00	8.00	1.60	2.00	0.40	6.00	1.20
Cost	0.20	2.00	0.40	3.00	0.60	8.00	1.60	6.00	1.20
Looks	0.20	7.00	1.40	8.00	1.60	5.00	1.00	1.00	0.20
Weight	0.20	3.00	0.60	5.00	1.00	9.00	1.80	7.00	1.40
Workability	0.20	2.00	0.40	9.00	1.80	3.00	0.60	6.00	1.20
Total	1.00		4.80		6.60		5.40		5.20

Figure 2.9: Weighted decision matrix for the material used for the project

2.4.5. Cooling System

Cooling gaming systems is becoming an increasingly important consideration for both casual and professional gamers. Overheated game systems can cause issues from minor temporary stoppages in play to complete gaming system failure if temperatures are not properly regulated. This is a problem that several team members have personally dealt with, and with next generation consoles recently being introduced, the team decided it would be important to design a cabinet that caters specifically to gaming consoles and keeping them cool. Combining the concept of a cooling system with an entertainment system was an idea that the team had not seen yet and it was decided that this would be a valuable subsystem to include in the project. The team wanted to design the cabinet with the dimensions for the next generation of consoles and the cooling system in mind.

The cooling system could have been implemented in a number of ways. The team considered a number of possible solutions for how to dissipate heat in the cooling cabinet. During brainstorming, some of the solutions for cooling that the team considered were natural convection using a ventilation system, forced convection with liquid pump, forced convection with a fan system, a heat sink system, and a mixed forced convection system using liquid pumps and fan systems. The team decided that the fan system should be used in the cooling cabinet to increase the airflow and maximize cooling. The team came to this decision after considering the alternatives and comparing them all together using a weighted decision matrix. Before looking at this weighted decision matrix, it is important to look at each of these options in detail to determine their merits and drawbacks.

To start, the team considered using a natural convection system using a ventilation system. These systems are incredibly simple and, especially in the case of a simple cabinet, it could be quickly and easily implemented. This system would work by allowing for the buoyancy forces from the variations of the density that were caused by differences in the temperature of the fluid to cause fluid motion. The less dense fluid is lighter and it will rise to the top while the cooler fluid comes to the bottom. This could be taken advantage of in the cabinet with a vent near the top to let the hot air escape and the cool air can stay on the bottom near the consoles. This system would be quiet, simple, and absolutely silent compared to the other options that the team considered. The major drawback to this system is that it does not create enough convection to effectively cool off the gaming systems in the cabinet. Compared to the other methods that the team discussed, this is one of the worst systems in terms of effectively cooling the cabinet.

The next option that the team considered was forced convection using a liquid pump using some sort of mineral oil or distilled water. This is a common cooling system used in high end personal computers that will dissipate heat faster than air cooling due to the liquid's higher specific heat capacity and thermal conductivity when compared to air. This system would work by allowing the coolant to circulate via a pump through a water block that would be connected to the device that the user wished to cool, then to a heat exchanger, and finally into a reservoir that would start the cycle again. The system allows for a high rate of heat transfer making it much more efficient at cooling parts than an air system. It is also not affected by the ambient air temperature as much either and it is relatively quiet. The major drawback of this system include its extreme complexity, especially with designing a water block to attach the electronics devices

to and the risk of leakage that could damage the electronics devices. They are also timely to maintain and repair and manufacturing them is less reliable than other systems. The increased complexity would make it one of the more expensive systems that was considered, and the liquid running through it would make it extremely heavy.

The team also looked into using forced convection with a fan system to cool the cabinet. A fan system would use one fan, or two fans, either in parallel or series to apply pressure to the air on the inlet side as opposed to the outlet side. This difference in pressure allows the air to flow from regions of high pressure to low pressure and hot air can be moved away from the electronic components and cooler air can be drawn in. Fan systems are relatively simple to design and install and they do an excellent job dissipating heat. They are also lightweight since they only use a fan to move the atmospheric air over the components. Due to how common these systems are in modern day computers, these systems are also incredibly inexpensive when compared to some of the other systems considered. The biggest drawbacks to a fan system are that it is not as effective at dissipating heat as some of the other methods mentioned like liquid cooling due to air's lower specific heat capacity and thermal conductivity. It also becomes less effective when the ambient air temperature is too high. Since it draws in air from the surrounding area, if the surrounding air is warm, it will not be able to cool the cabinet as effectively.

Another system that was considered was a heat sink that would be able to attach directly to the electronic devices in the cabinet. This is a passive system that works by having a metal with a high thermal conductivity that is machined into a shape with a high surface area like fins. Since it is a passive system it will be completely silent, just like the natural convection system. The increased surface area allows for more forced and natural convection. Heat from the electrical component would be transferred to the heat sink via conduction and then it can be dissipated more efficiently via convection. Some thermal paste might be required to ensure that no air gaps form between the heat sink and electrical component that drastically decrease the conductivity. This system would be relatively inexpensive to create and it would be easy to manufacture. These are common in older computers and televisions. The biggest drawbacks to this system are its practicality for end users and its lack of effectiveness when compared to the other methods mentioned. In order to get this system to work efficiently, a thermal paste would need to be applied to the electrical component before it is clamped on. This would be messy and

a hassle to any end users and since it does not dissipate as much heat as the other methods, it would not be very practical for the end user.

The final method that the team considered was for a mixed convection system using a liquid pump and fan air system. This system would be a hybrid between the liquid cooling system as well as the fan cooling system. Similar to the liquid cooling system, it would work by allowing the coolant to circulate via a pump through a water block that would be connected to the device that the user wished to cool, then to a heat exchanger, and finally into a reservoir that would start the cycle again. The changes would come with a fan system cooling the heat exchanger and an additional fan cooling the electronic device. This system would offer the best cooling efficiency of any of the options considered, and it combines some of the best features of each of the systems. The fan system would not be as loud since it was working with the liquid system, so noise would be mitigated. The liquid cooling could also be significantly more effective with the fan system cooling it off. Despite these benefits, this system would be incredibly complex, expensive, and heavy. Combining the two systems is difficult and it would require many components making the system much more difficult to implement.

With each of these systems considered, the team decided to use a decision matrix to determine which system would work best for this project. The team decided that the deciding factors for the decision matrix should be the system’s removal of heat, noise level, complexity, cost, and weight. Each of these factors were chosen for their importance to the cooling system.

Weighted Decision Matrix for Cabinet Cooling System											
		Options									
Criteria	**Weight**	**Natural Convection using a Ventilation System**		**Forced Convection with Liquid Pump**		**Forced Convection with a Fan System**		**Heat Sink System**		**Mixed Forced Convection System with Pump and Fan System**	
		Score	Total	Score	Total	Score	Total	Score	Total	Score	Total
Removal of Heat	0.4	2	.8	4	1.6	9	3.6	3	1.2	10	4
Noise Level	0.25	10	2.5	5	1.25	7	1.75	10	2.5	3	.75
Complexity	0.15	10	1.5	5	.75	8	1.2	7	1.05	1	.15
Cost	0.15	10	1.5	4	.6	7	1.05	6	.9	2	.3
Weight	0.05	10	.5	5	.25	8	.4	4	.2	3	.15
Total	**1**		**6.8**		**4.45**		**8.0**		**3.6**		**5.35**

Figure 2.10: Weighted decision matrix for the different cabinet cooling systems

Since the most difficult objects to cool that would go in the cabinet are game systems and computers, the team focused on creating enough airflow to eliminate any thermal throttling a system may get by keeping it in an enclosed space. By pulling in outside air, these electronics should have sufficient cooling that will be comparable to storing the electronics out in the open. The largest disadvantage of the fan is that it could create unwanted noise compared to a ventilated ambient air system. It also adds complexity due to the fact that power is required for

the fan. Despite these drawbacks, the fan system was clearly the best option for this project. The team then shifted its attention to finding the optimal throttling system.

With the fan system decided, the team needed to determine whether it would be throttled manually or automatically. A manual throttle would allow the user to manually input the fan speed on the remote control, and the user could choose between a low, medium, and high speed setting, similar to many of the models that the team found while doing research for this project. Manual operation would be incredibly easy to implement and it would allow the user to have complete control over the air flow in the cooling cabinet. Some of the drawbacks include not being able to see the temperature inside the cabinet and it constantly requires the user's input which will become tedious over time. The other option was for the fan system to be throttled automatically. With an automatic system, the microcontroller would be set up to vary the speed depending on the temperature inside of the cabinet without user intervention. Automatic operation will allow for easy operation with the fan speed being automatically set based on the temperature of the cabinet. It also would ensure that the cabinet was always getting the correct amount of airflow depending on the temperature. The downside of this system is much more difficult to create as opposed to the manual operation system. The team decided to go with the automatic fan throttling for the benefits it added to end users. Allowing users to maintain proper cabinet temperatures with as little input as possible would be an excellent feature for this product.

2.4.6. TV Lift System

A TV lift has many design parameters. Speed and noise of the lift should be taken into consideration when deciding on a good TV lift to use. The team considered a number of methods of lifting the TV. The TV could be lifted by an actuator in combination with a custom mating piece connecting the TV to the linear actuator. Another idea was to attach the TV to vertical rails and use a motor to lift the TV. The last idea was to use a commercially available TV lift system.

Ultimately the group decided to choose a commercially available system. The rail system would not have worked well since it would add unnecessary complexity to the mounting system that would connect the TV to the rail. This would require extremely strong materials as well as a custom design. This would cause large lead times. The team decided not to choose a custom actuator system since it would run into the same issue where a custom part would be needed to

connect the actuator and TV together. One benefit of choosing a commercially available system is that it is made by the main manufacturer of TV lift entertainment systems. After extensive review in the initial market research phase, the group found that there were no complaints about noise or speed. In this case, the team chose to forego the calculations that would have been required for the speed and noise of the lift since the lift chosen is an industry standard that has a significant history of market use to back it up.

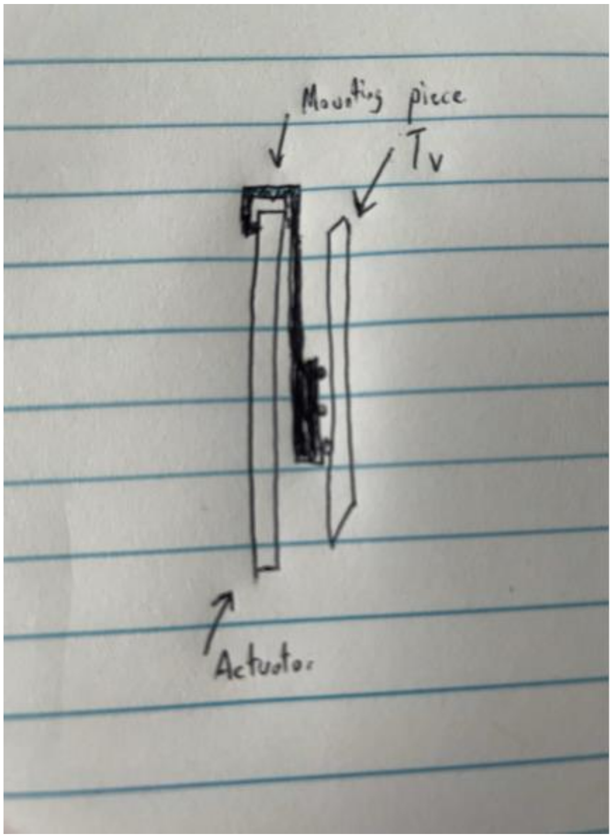


Figure 2.11: Initial TV lift conceptual designs

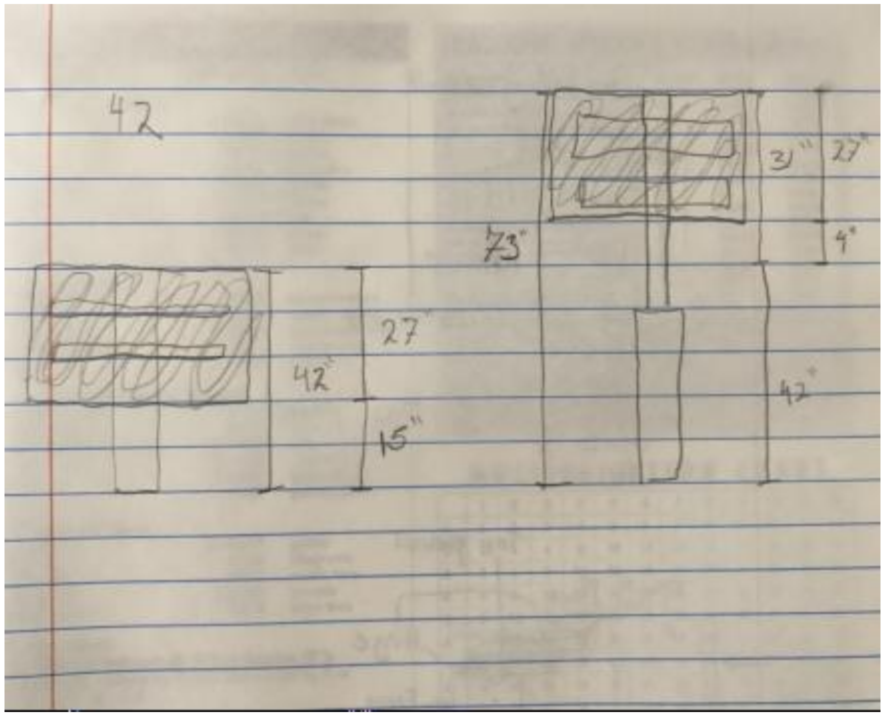


Figure 2.12: Rough sketches for the dimensions of the TV lift that it needed

2.4.7. Control Center

There were several options for the control center for all of the on board electronics for this project. The control center would be the microcontroller or microprocessor in the device that would control all of the electronic devices and processes. This device would be responsible for controlling the TV lift actuator, top shelf actuator, fan system, and potentially the security system. The first major consideration for the control center was to determine if the team needed to use a microcontroller or microprocessor for this project. A microcontroller is stored in a single integrated circuit and it is dedicated to performing a certain task or executing a specific application. A microprocessor is a single integrated circuit that can perform several algorithmic logic unit operations and communicates with other devices. Comparing the two, microcontrollers are similar to calculators and microprocessors are similar to a small computer. This means that microcontrollers are optimized to control electronic devices and microprocessors are optimized for small computing systems. For these reasons, the team decided to use a microcontroller to control all of the electronic devices in the project since that is what the microcontrollers are designed to do.

The team decided to use an Arduino Uno Rev3 microcontroller for several reasons. The Arduino Uno has an ATmega328P microcontroller, operating voltage of 5 Volts, input voltage of 7-12 Volts, 14 digital input/output pins (6 with pulse width modulation), 6 analog input pins, a DC current of 20 mA per pin, 32 KB flash memory, clock speed of 16 MHz, and physical dimensions of 68.6 x 53.4 x 24.5 mm (Arduino, 2020). These values are shown below in Figure 2.13. All of these aspects were important in choosing the Arduino Uno microcontroller. To start, the small size of the Arduino makes it ideal for fitting in the entertainment system where space is limited. The operating and input voltages for the Arduino are also within a manageable range that will allow the team to easily accommodate for its electrical needs. There are 14 digital pins which should be capable of powering and controlling all of the devices. The team needed a microcontroller with lots of pins to accommodate for all of the devices that would be run through it. The microcontroller also needed pulse width modulation (PWM) pins to control the speed for the actuators and fan system. The analog pins are important to ensure that the Arduino can take the input temperatures for the fan system. Each of the pins could support a DC current of 20 mA per pin, which the team determined from online specifications would be sufficient for all of the electrical devices. Finally, the Arduino Uno had an excellent amount of flash memory and clock speed, meaning that it could store all of the necessary programming and efficiently execute it.

Arduino Uno Rev3 Specifications		
		
Criteria	Value	Unit
Size	68.6 x 53.4 x 24.5	mm
Microcontroller	ATmega328P	
Operating Voltage	5	V
Input Voltage	7-12	V
Digital Input/Output Pins	14 (6 with PWM)	pins
Analog Pins	6	pins
DC Current per Pin	20	mA
Flash Memory	32	KB
Clock Speed	16	MHz

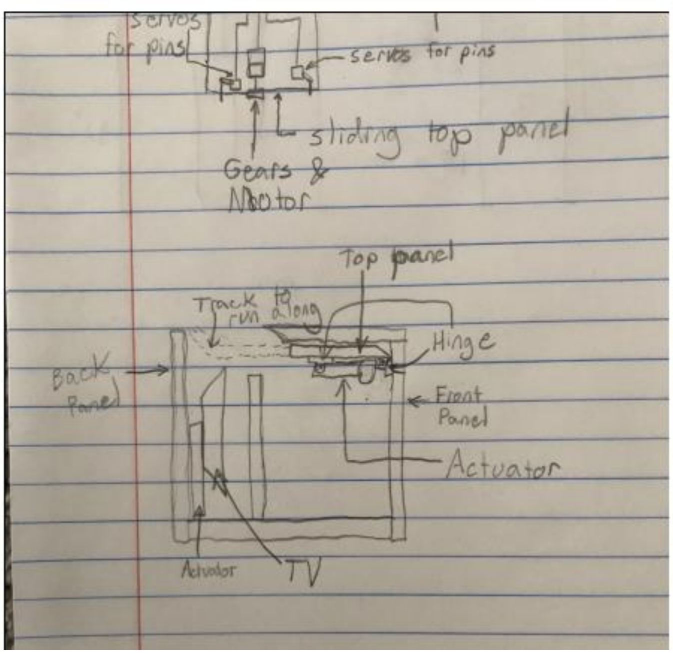
Figure 2.13: Specifications for the Arduino Uno Rev3 microcontroller

The Arduino also has a dedicated community of hobbyists and enthusiasts surrounding it with many online resources. Arduino also has its own open-source Arduino Software (IDE), Arduino IDE 1.8.13. This software makes it incredibly easy to write and upload code to the Arduino. The Arduino uses a C programming language so there were lots of tutorials online covering the basics of programming in this language. All of these factors combined together

made the Arduino an excellent choice for the team since none of the members had any coding experience prior to this project. The coding would be much simpler with a thriving community and lots of online resources.

2.4.8. Rail System

The decision to create a sliding shelf as our method for removing the top shelf requires a more complex system than the other proposed ideas. This system requires a rail system to be placed inside the top of the entertainment center that will allow the shelf to move with the help of a motor attached underneath it. The original proposed concept, which concept sketches for this are shown in Figure 2.14, was the idea of using a track and wheel system, where there would be one track on each the left and right sides of the entertainment center and a wheel on each side that fits inside the track and is attached to the sliding shelf. The group decided that this was not the best option for our design as it would cause the shelf to become unbalanced as it was sliding along the tracks. Because of this we decided to use a rail system that consists of two separate tracks and two wheels that fit inside and roll along the tracks and they will be attached to the shelf on both the left and right sides of the entertainment center. On each side we plan on having one track and wheel for the front end of the shelf and one track and wheel for the back end. A sketch of this concept is shown in Figure 2.15.



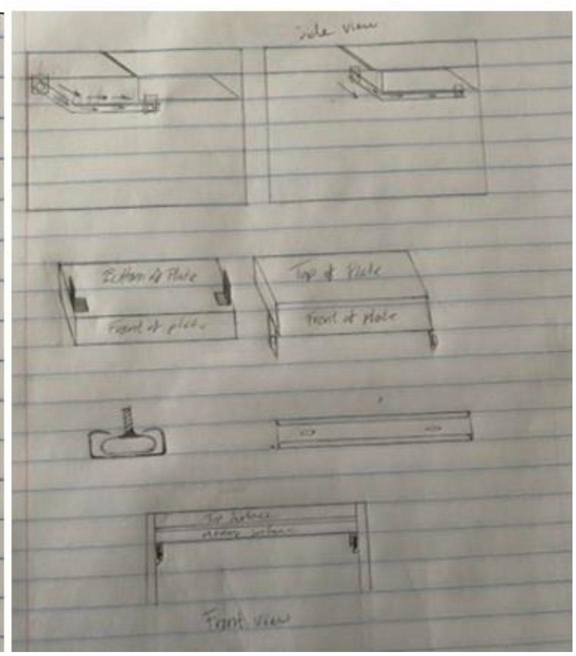


Figure 2.14: Conceptual drawings for the rail actuation system

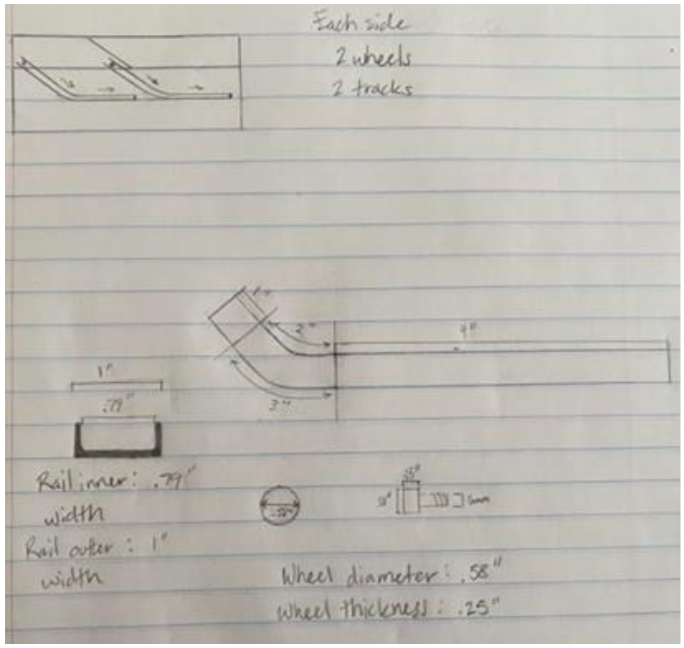


Figure 2.15: Rough sketches for the dimensions for the rails

When researching the different rail system options, it was very difficult to find a system available that we could use because of this the team decided that our best option would be to design, and 3D print the tracks ourselves. This was decided to be the best option because it allowed us to design the rails so that they would properly fit the wheels and because it allowed us to create the unique track that our sliding shelf design requires.

The team needed to decide between using a four motor system or a linear actuator to move the top shelf along the rail system. The four motor system would involve a motor connected to each of the corners of the top shelf. Each of these motors would run along the rail system designed above. The rail system would be modified to have gears and teeth so the motors could move the top shelf. The motors would all be controlled by the Arduino to rotate at the same time. The system would recognize that it was at the end of its actuation based on either time or a position sensor system. This system would be complicated to implement and wiring 4 motors to the same Arduino board would increase the complexity of the wiring. In addition to these issues, if one motor failed, the other motors would continue running, potentially destroying the system. The sensor system would also add a layer of complexity that the team was unprepared to face with their beginning knowledge of Arduino programming. The next method

that the team considered was a linear actuator to move the top shelf. The actuator would be attached to the underside of the top shelf and there would be wheels that ran along the rail system to guide the top shelf. The actuator would be extremely easy to wire into with the Arduino and it would be run on a timer. The actuator could also serve as a lock for the top shelf if the rated force was high enough. Based on these reasons, the group decided to use an actuator to move and lock the top shelf.

2.4.9. Security and Locking System

Security is a central feature to a TV lifting entertainment system. One of the key advantages to a TV lift system is that it hides expensive electronics from thieves and intruders. The goal of a security system is to restrict access to unwanted users. This can come in the form of a parent restricting TV privileges by hiding the remote. In a traditional system, users can still access the TV by using the manual buttons on the side of the television. In our system, the remote would be required in order to gain access at all. Due to the locking mechanism on the doors, it can also restrict access to any electronics placed inside. The top surface will be locked in place by an extended actuator that will not lower without the remote. The team believes that even if the remote is not hidden, if a thief we're to try to gain access, they may not realize that there are expensive electronics stored inside and they may not know how to open the system. Additionally, a screwdriver would be required to remove the TV from the system.

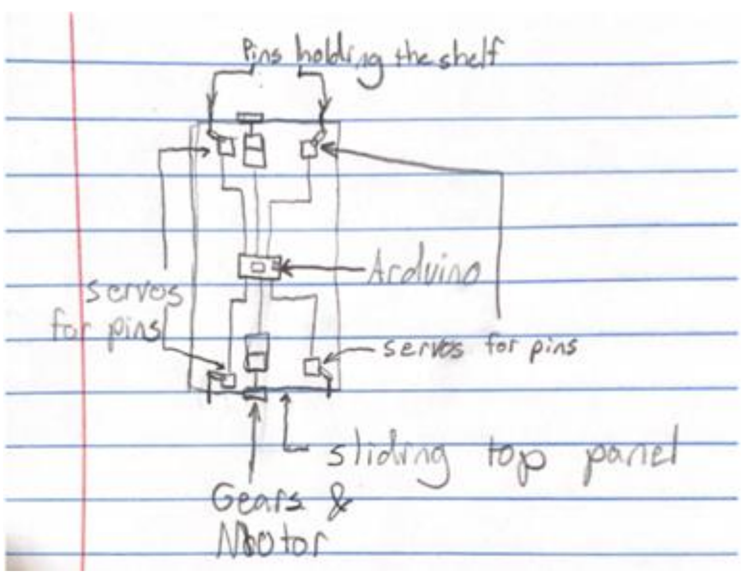


Figure 2.16: Initial concept drawing for the wiring of the top shelf actuation

The locking system will be specially designed to prevent theft of valuable electronics or any other valuables placed in the cabinets. Stolen items can be incredibly expensive to replace and some items cannot be replaced. For example, on some console devices, video game progress is only stored on the harddrive so a stolen device could mean years of saved games and files lost. These files are valuable to individuals so the team wanted to find a way to protect these devices. The team chose to go with the remote locking feature over the traditional locking feature on the cabinet doors for several reasons. To start, the remote locking system would not require any additional software and minimal additional hardware to implement. The entire system could be programmed using the Arduino. The top shelf actuator has a high enough force rating to protect the inner contents in the back portion of the cabinet from any attempted burglary. The front doors would also need to be locked to prevent burglary of any of the items in the front cabinets. The team decided to do this using micro servos that would be placed on the inside of each door. The four micro servos would each have an arm that attached to it that would block the door from opening. There would be a metal tab that would prevent the doors from opening once the servos had been activated. When the servos were deactivated, the servo arm would swing out of the way allowing the doors to be opened. The servos would be controlled remotely using the remote system that the team had planned to use to actuate the TV lift. This system would prevent entry into the main body of the entertainment system without access to the remote. These systems would help ensure the security of the entertainment system.

3. Embodiment Design

3.1. Assembly

A major aspect of this project was assembly of the prototype. The team decided to create the main body of the entertainment system from scratch rather than modify an existing entertainment system for a few reasons. First, it would have been very difficult to find an entertainment system on the market already that met all of the size requirements. Second, it would have required such heavy modification that the system would have looked very unappealing afterward. Third, the cost of buying the initial entertainment system would have been more than the cost of buying the materials needed to build the entire system, especially

when considering that a number of the parts from the purchased system would not be able to be used in the final result.

With the assembly, it had to be determined how best to attach different components. The first consideration was whether the system should be modular such that the consumer could disassemble the product. The group decided that due to the skills of the group and the main scope of the project, that it makes more sense to make the system in a way that it can not be easily disassembled. Due to this, air-nailing parts together was determined to be the best option for most of the build. Air nailing is beneficial because it does not take as much time or precision as other methods such as using screws. Screws, in many cases, require pilot holes in both parts such that no cracking occurs and the parts align the way they are designed. With air-nailing, the nail-gun just needs lined up correctly and the two parts are almost instantly attached once the trigger is pulled. Connections that used air-nailing also had wood glue added between the two pieces to help form an even stronger bond.

Because the boards used for the majority of the build were 15/32 inches thick, nailing strips were needed to provide extra area. If nailing strips were not used, the area would be so small that while screwing or nailing the boards could crack. Nailing strips also provide extra strength at the major joints as well as providing extra area for wood glue.

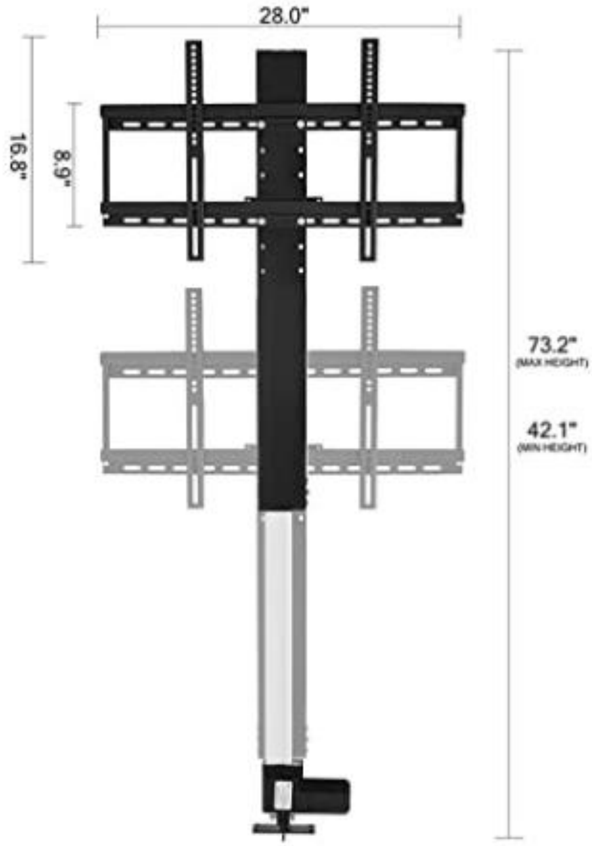
3.2. TV Lift System

One of the most important components of this project was the TV lift system. The team had decided to go with a commercially available system to decrease the amount of complexity involved in the build and save money and time. The TV lift would need to be capable of actuating at least 28 inches to bring the bottom edge of a standard 55 inch TV above the frame of the entertainment system body. When retracted, the lift also needed to be capable of being completely closed in the entertainment cabinet. This meant that the maximum retracted height was 42 inches. It also needed to be capable of lifting a 55 inch TV’s weight and dimensions with fast and quiet actuation. Making sure the system was compatible with the Arduino control center and easy to install was also important, so that the team could save both time and money on the build. Finally, the team wanted a system that was inexpensive since this was going to be the most expensive component in the project. The team also considered having the TV be capable of rotating 30 degrees in either direction around the center actuation vertical axis, but this idea was

scrapped due to the potential complications and complexity that would be involved especially with the lack of electrical experience that the team had. This swivel system could be an excellent idea for future iterations of this project. With these parameters set, the team was able to narrow down on a TV lift to use for this project.

The team chose the Mophorn TV Lift Stand Motorized for Flat Screen LCD/LED/OLED Plasma TVs. This was a linear screw actuator that was designed to lift 32-60 inch flatscreen TVs. It had an input voltage of 110V, maximum load of 176 pounds, stroke length of 31 inches, a retracted height of 41 inches and expanded height of 72 inches, a lifting speed of 15 millimeters per second, operating temperature between 0-140 ℉, and weighed 21.2 pounds. The lift also came with brackets to mount it to the floor and wall, a mounting frame for the TV to attach to it, and it was painted a sleek black that matched the team's decided aesthetic for the overall system (Mophron, 2017). All of these specifications are shown below in Figure 3.1. The Mophron TV lift covers all of the necessary deliverables that the team had set. The retracted length was 41 inches with a stroke length of 31 inches. This allows for up to a 55 inch TV to be safely stored inside the cabinet and to come fully out of the cabinet when extended. The TV lift is also capable of lifting a full 55 inch TV, meeting the maximum requirements set by the team. It was also one of the most cost effective models available and it only cost $146.99 while other models cost more than the entire project. Finally, this model could be easily integrated with the Arduino. The input voltage is designed to be plugged into the wall however, it is converted to 29 V and 2.1 A before reaching the linear actuator, so a motor drive board could be easily placed between the converter and actuator. The lift could be easily installed into the system using several wood screws to secure the brackets of the lift to the entertainment system's frame. This TV lift system was perfect for the team's requirements.

Mophorn TV Lift Stand Motorized for Flat Screen LCD/LED/OLED Plasma TVs Specifications



Criteria	Value	Unit
Input Voltage	110	V
Maximum Load	176	lbs
Stroke Length	31	in
Retracted Height	41	in
Extended Height	72	in
Speed	15	mm/s
Operating Temperature	0-140	°F
Speed	5.7	mm/s
Weight	21.2	lbs

Figure 3.1: Specifications for the Cytron 10Amp 5V-30V DC Motor Driver

3.3. Rail System

For the rail system, the team chose to use 4 rails that would attach to the bottom of the moveable top surface using wheels that could ride along the rails. The system will have 2 rails on each side, one attached behind the other as shown in Figure 3.2. This prevents the surface from rotating and will keep it level along the full length of translation. The team chose to put one rail below the other due to a space constraint in the direction that the surface will be moving.

Figure 3.2: Rail system secured to the project

A figure of the important dimensions of the rail can be seen in Figures 3.3 and 3.4. There are a few important concepts to note. The rail will cause the top surface to drop down by approximately 0.8”. This will provide plenty of clearance to drop below the .5” thick wood that it needs to move under. The rail also will drop at a 45 degree angle which coincides with the angle of the interface between the moveable and unmoveable top surfaces. The curved portion of the rail is tangent to each straight portion which allows for a smooth transition for the wheels. The holes for the screws are spaced out evenly which will increase stability and allows for a secure connection to the body of the entertainment system.

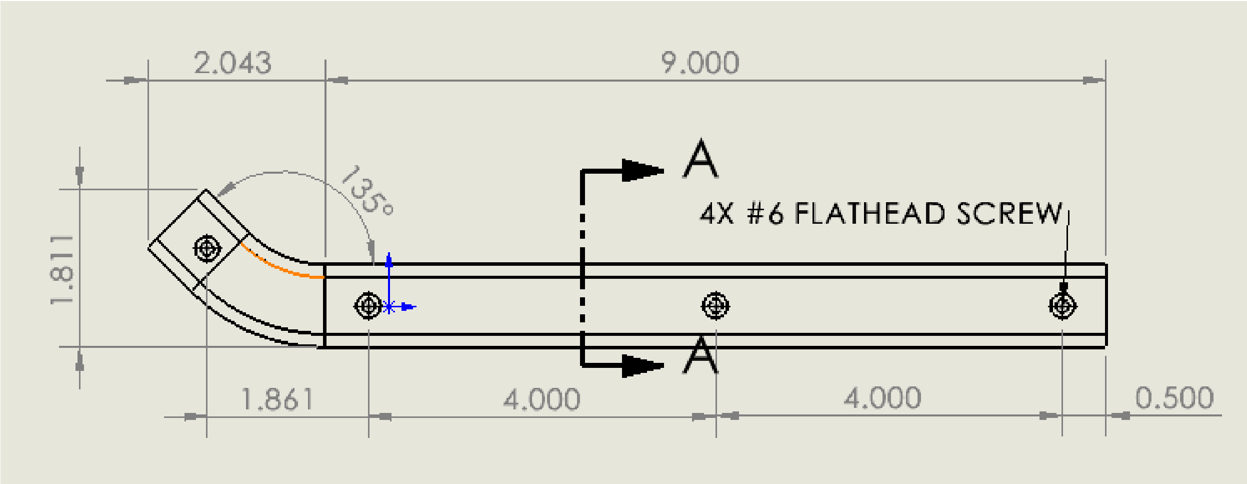


Figure 3.3: Top view dimensions of the rail system

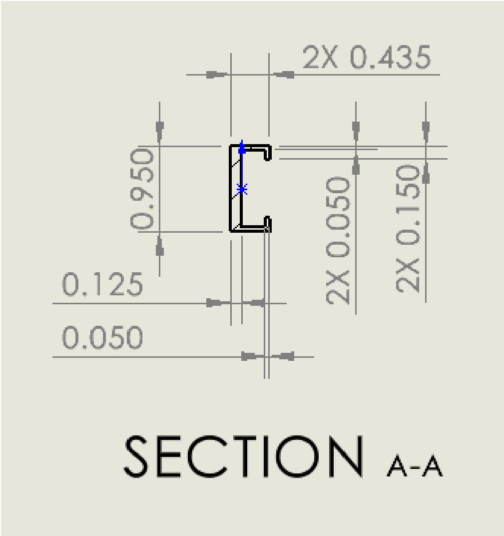


Figure 3.4: Right side view dimensions of the rail system

The rails for this project were custom designed to fit the specifications of the entertainment system and were 3D printed using makerbot replicator + printers. The first print of the rails resulted in an extreme amount of curvature as shown in Figure 3.5. To fix this issue, the team decided to split the rail into sections along the length of the rail in order to minimize curvature in this direction.

Figure 3.5: Warped initial print of the rail system

A DC House 10” Stroke Linear Actuator was purchased and used for the movement of the top shelf. This pushes and pulls the top surface up to 10”. The team originally planned to use a spring that would be attached between the actuator and top surface to provide an easy method of 2 dimensional movement rather than 1 dimensional. It also would have had the purpose of preventing injury to an individual's hand since the individual would be able to compress the spring and take his or her hand out if the actuator pushed the top surface into his or her hand. This idea was scrapped because the actuator would easily push the top shelf into place all by itself and adding a spring would be redundant to the system since the actuator was already pushing the top shelf into place. Instead, the top shelf actuator was connected directly to the top shelf.

3.4. Electrical System

There were numerous challenges that the team faced for the electrical system of this project. Since none of the team members had any experience in electrical engineering, the team needed to learn many of the basics to get the electrical system to work properly. The first challenge that the team faced was how they were going to power all of the devices.

Since the team has very little experience with electrical engineering, the team decided to go for the simplest solution and just plug everything into a power strip housed within the entertainment system. The power strip cord would then be passed outside of the entertainment system, so that the end user will only need to plug in one cable to power the device. The power strip will need to be capable of handling both the Arduinos, both the actuators, the fans, and the TV. The power strip would also be capable of powering various electronics and gaming devices like cable boxes, DVD players, Xboxes, and Playstations. This greatly simplifies the design of the electrical system that would have been needed to power the system and has the added bonus of letting the end user plug their own electronics into the self contained system. Next, the team needed to find motor drive boards that would allow the Arduino to control the actuators.

The voltages and currents required to operate the actuators are too large for the Arduino to handle on its own, so the team decided to use a motor drive board. The motor drive board would work similar to a transistor. Only a small current would be needed to control the flow and direction of the current to the linear actuator motor. The motor drive board that the team decided to use was the Cytron 10Amp 5V-30V DC Motor Driver. This motor drive board was capable of an operating voltage between 5-30 volts, a peak current output of 30 A for 10 seconds, continuous current of 13 A, PWM frequency of 20 KHz, bidirectional control for one motor, does not require a heat sink, and is 75 x 43 x 25 mm (Cytron, 2018). These values are summarized in Figure 3.6 below. The leads to the power source and motor channel went into one end and the leads for the direction, PWM, and ground could be plugged directly into the Arduino. It was also cost effective, only costing $11.50 per board. The only drawback to this board is that it can only power one motor at a time, but this can be easily fixed with two boards. The operating voltage, continuous current, and easy compatibility of the input voltage with the Arduino made this board the ideal choice for controlling the actuators.

Cytron 10Amp 5V-30V DC Motor Driver Specifications

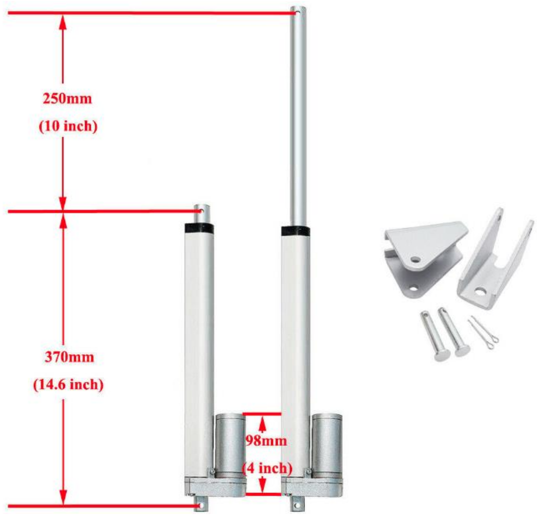
Criteria	Value	Unit
Size	75 x 43 x 25	mm
Input Voltage	3.3-5	V
Operating Voltage	5-30	V
Peak Current	30	A
Continuous Current	13	A
PWM Frequency	20	KHz

Figure 3.6: Specifications for the Cytron 10Amp 5V-30V DC Motor Driver

The next step was for the team to pick an actuator for the top shelf. The actuator needed to fit within the 18.5 inches of space provided when it was fully retracted, have at least a 9 inch stroke length to move the top shelf out of the way, have a high rated load for security, a rated voltage below 30 V and a rated current below 5 A to keep the operating level within the limits of the motor drive boards, a noise rating below 60 decibels which is considered moderate to quiet noise level, it needs to be resistant to dust, and it needs to be cost effective. Based on this list of requirements, the team picked the DC House 10” Stroke Linear Actuator for the top shelf. The DC House actuator was a linear screw actuator with a stroke length of 250mm (10in), 370mm (14.6in) length when retracted, rated load of 1500 N, rated voltage of 12 V, rated current of 3 A,

operating temperature from -20 to 65 °C, noise level of less than 50 decibels, speed of 5.7 millimeters per second (0.224409 inches per second), and a protection class of IP65 (DC House, 2018). This actuator fit comfortably within the limit that the team set for the length requirements, being only 14.6 inches when retracted. The stroke length is 10 inches meaning that it is capable of effectively moving the top self into the cabinet when retracted. The operating voltage and current are well within the limits set by the motor drive boards, so this model can be effectively controlled with the motor drive board and Arduino. Next, the team wanted to maintain a noise level of below 60 decibels to keep the project from being irritating to use. A noise level of 60 decibels is equivalent to a normal conversation or background music at a restaurant. This actuator has a noise level of less than 50 decibels so it has about the same noise level of a quiet office, dishwasher, or soft rain when in operation. This is ideal for the product since it will not annoy the end users when in operation. The DC House actuator also has a protection class of IP65 meaning that it is completely protected from any dust entering the system. This is important since the actuator is encased in the entertainment, if it gets dusty, it will be very difficult to clean, so it is important that it is able to handle dust. Finally, this actuator cost $39.43 making it incredibly cost effective for the team. All of these factors lead to the team choosing this actuator for the final design.

DC House 10” Stroke Linear Actuator Specifications



Criteria	Value	Unit
Stroke Length	250	mm
Length	370	mm
Rated Load	1500	N
Rated Voltage	12	V
Rated Current	3	A
Operating Temperature	-20-65	℃
Noise Level	<=50	dB
Speed	5.7	mm/s
Protection Class	IP65	

Figure 3.7: Specifications for the DC House Linear Actuator

The final step in the electrical system was to find a remote system to control the entire system. This remote control system needs to be compatible with the Arduino and capable of sending multiple commands to the Arduino. For these reasons, the team decided to use an infrared remote control. The infrared remote control transmitter will send out pulses of infrared light that represent specific binary codes. These light pulses are received by the infrared sensor which sends the binary code to the microcontroller which will decode it to hexadecimal and

carry out the operations assigned to each hexadecimal code. This system allows signals to be sent at a distance, but they can only be received if the infrared transmitter is pointed directly at the infrared sensor and if the transmitter is close enough to the sensor that the infrared signals are strong enough to be picked up by the sensor. The IR remote system that the team chose for this project was the KOOBOOK HX1838 NEC Infrared IR Wireless Remote Control. This remote control system has an operating voltage of 3.3-5 V, static current of 3-5 uA and dynamic current of 3-5 mA, transmission distance of up to 8 m, effective angle is 60 degrees, the transmitter is 8.5 x 4 x 0.65cm, and it has 21 individual buttons (KOOBOOK, 2019). All of these specifications are summarized in Figure 3.8 below. This IR remote system has been specifically designed to work with the Arduino which eased the installation process for the team. It was designed to have an operating voltage of 3.3-5 V so it could be plugged directly into the Arduino 3.3 V or 5 V voltage outputs. The ground and input could be plugged into the Arduino's ground and any of the input pins respectively. The IR receiver had a good effective angle and distance so that the transmitter could be used comfortably by the end user even if they were sitting on the opposite side of the room. Finally, the transmitter was small and compact so that it can easily fit in a pocket or be stored elsewhere. With the electrical components assembled, the team moved on to creating the basic circuitry for the components.

KOOBOOK HX1838 NEC Infrared IR Wireless Remote Control Specifications

Criteria	Value	Unit
Operating Voltage	3.3-5	V
Static Current	3-5	uA
Dynamic Current	3-5	mA
Transmission Distance	8	m
Effective Angle	60	Degrees
Transmitter Dimensions	8.5 x 4 x 0.65	mm
Transmitter Buttons	21	Buttons

Figure 3.8: Specifications for the KOOBOOK HX1838 NEC Infrared IR Wireless Remote Control

The basic wiring circuitry for the project is shown below in Figure 3.9. This system was based on the descriptions from each component. The remote was programmed to move the system up when the “one” button was pressed, and move the system down when the “two” button was pressed on the IR transmitter. These buttons could not be pressed together and if one was pressed, it needed to run through the entire cycle before the other button could be pressed. The system was programmed to change its state to “up” and “down” after having completed the respective cycle and only the button for the opposite cycle would work. This ensured that if the

wrong button was pressed on the remote, the user would not be stuck waiting through the entire cycle before being allowed to press another button.

In this diagram the basic components are an Arduino Uno, two Cytron 10Amp 5V-30V DC Motor Drivers, four micro servos, an IR receiver, 12 V power supply, 29 V power supply, lift actuator, and top shelf actuator. To start, two servos that go to the right hand doors and two servos that go to the left hand doors have their PWM controls wired to the 10 and 9 pins on the Arduino Uno respectively. All the servos grounds are connected to a common ground on the Arduino and the voltage ins are all connected to the 5 V pin on the Arduino. Next, the motor driver boards are connected to a common ground that run to the ground on the Arduino. On the motor driver for the top actuator the direction pin goes to the 2 pin on the Arduino and the PWM pin goes to the 3 pin on the Arduino. The “A” and “B” terminals are connected to the positive and negative actuator terminals and the “+” and “-” terminals are connected to the 12 V supply power. On the motor driver for the lift actuator the direction pin goes to the 4 pin on the Arduino and the PWM pin goes to the 5 pin on the Arduino. The “A” and “B” terminals are connected to the positive and negative actuator terminals and the “+” and “-” terminals are connected to the 29 V supply power. Finally, the infrared receiver is connected to the common 5 V and ground pins that run to the Arduino. Input pin runs to the 13 pin on the Arduino.

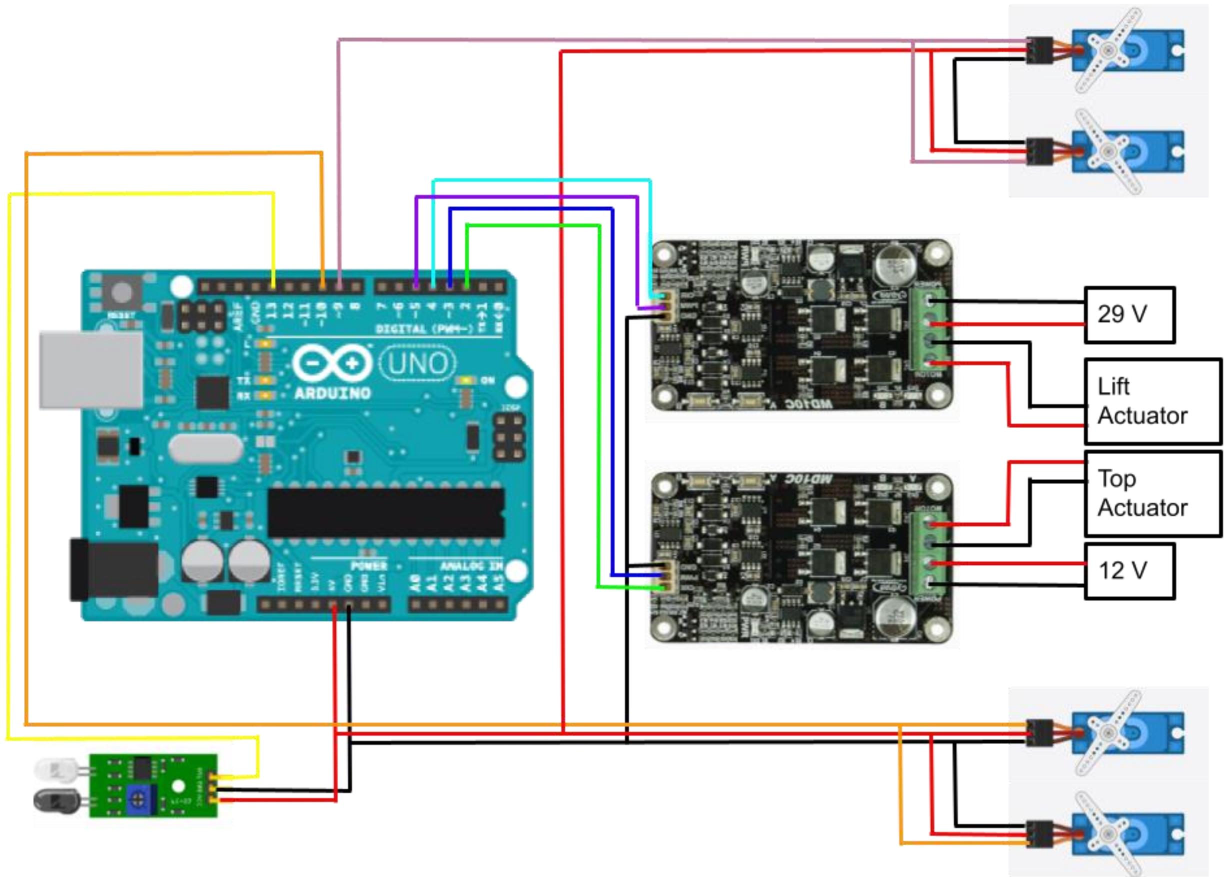


Figure 3.9: Wiring schematic for the main electrical system for the entertainment system

3.5. Fan System

The fan system in the gaming cabinet is specifically designed to house the next generation of consoles that are becoming available on the market. The team chose to use the PlayStation 5, Xbox Series X, and Nintendo Switch as the benchmark consoles for what the cooling system will have to deal with. To run the appropriate calculations for the fan speeds, the team needed to know the temperature range that each console was designed for, maximum reported temperature that each console would run at, and the wattage load of each of the consoles. From the research collected, the team found that the PlayStation 5 was designed to run between 50 to 80 degrees Fahrenheit, the Xbox Series X between 41 and 95 degrees Fahrenheit, and the Nintendo Switch also between 41 and 95 degrees Fahrenheit (SportsGaming.win, 2020). The average run temperature across all three consoles is 67 degrees Fahrenheit. The maximum temperature recorded for each gaming console was 149 degrees Fahrenheit for the PlayStation 5

and 144 degrees Fahrenheit for the Xbox Series X and Nintendo Switch (Mott, 2017). Finally, the wattage load for each of the consoles varies depending on what the console is doing. Playing video games takes more power than just watching Netflix or YouTube, and the intensity of the graphics and systems in the game also will increase the power required for the console. The maximum measurements found for the worst case wattage load for each of the consoles were 210 Watts for the PlayStation 5, 202 Watts for the Xbox Series X, and a very small 39 Watts for the Nintendo Switch (Deakin, 2020). All of these results are recorded in Figure 3.9 below.

	Gaming Consoles			
	Nintendo Switch	Xbox Series X	PlayStation 5	Average
Designed Temperature Range (degrees F)	41-95	41-95	50-80	67
Maximum Temperature (degrees F)	144	149	149	147.33
Watt Load (Watts)	210	202	39	150.33

Figure 3.10: Key metrics for the gaming consoles for determining the fan system

The fans could be installed in series or parallel depending on what the system needed from them. Fans in series would have one fan placed in front of the other fan so that the outlet of the first fan is directly connected to the inlet of the second fan. Parallel fans would be placed side by side. Assuming the two fans are the same model, fans in series would double the available static pressure while only increasing the flow by a factor of the square root of the doubled pressure (1.41). Fans in parallel would double the free air flow rate, but not have any effect on the pressure. The equation for forced cooling convection is,

$$Q = f * C_p * \Delta t$$

In this equation, Q is the heat transferred in British Thermal Units per hour, f is the airflow in pounds per hour, C_p is the specific heat of air in British Thermal Units per pound degree fahrenheit, and Δt is the change in the air temperature in degrees fahrenheit (Bergman & Lavine, 2017). This equation can be rearranged to solve for the fan speed like so,

$$f = \frac{Q}{C_p * \Delta t}$$

This equation is often used by individuals who build personal computers to determine the fan speed needed to cool their electronics. This equation assumes that heat loss through the wood in the cabinet is negligible, there is no significant difference between laminar and turbulent flow from the fans, and that the specific heat and density of the air in the cabinet are constant. Companies will usually give fan speed measurements in cubic feet per minute so this equation can be adjusted to fit this requirement. Using constants for the specific heat and density of air at sea level, it is possible to adjust this equation to plug in the watt load for each of the consoles to determine the cubic feet per minute of the fan required. The density of air (ρ) at sea level and 70 degrees fahrenheit is $0.0749\,\frac{lbm}{ft^3}$and the specific heat of air at sea level (C_p) is $0.2403\,\frac{Btu}{lbm*\circ F}$. Plugging these values into the equation gets the result,

$$f = \frac{W}{\rho * C_p * \Delta t} = \frac{W[W][3.413\,\frac{\frac{Btu}{h}}{W}][\frac{1}{3600}\frac{h}{s}]}{\rho[\frac{lbm}{ft^3}] * C_p[\frac{Btu}{lbm *\circ F}] * \Delta t[\circ F]}$$

$$= \frac{W[W][3.413\,\frac{\frac{Btu}{h}}{W}][\frac{1}{60}\frac{h}{min}]}{0.0753[\frac{lbm}{ft^3}] * 0.2403[\frac{Btu}{lbm *\circ F}] * \Delta t[\circ F]} = \frac{3.1605[\frac{ft^3 *\circ F}{min * W}] * W[W]}{\Delta t[\circ F]}$$

In this equation, f is the flow rate of the fan in feet cubed per minute,W is the watt load of the device being cooled, ρ is the density of air in slugs per feet cubed, C_p is the specific heat of air in British Thermal Units per degrees Fahrenheit pounds, and Δt is the change in temperature in degrees fahrenheit. This equation also makes all of the necessary conversions so that just the watt load of the device and change in temperature are needed to calculate the flow rate. The initial calculation for the fan speed used ideal numbers, the team took the largest watt load, the average temperature that the consoles were designed to work in, and the minimum maximum temperature from the designed temperature range of all the consoles. The biggest watt load came from the PlayStation 5 with 210 Watts, the average temperature that the consoles were designed to work in was 67 degrees Fahrenheit, and the minimum maximum temperature from the designed temperature range recorded was for the PlayStation 5 at 80 degrees Fahrenheit. These numbers assume that the room temperature is 67 degrees Fahrenheit and the maximum temperature that

the cabinet can reach is 80 degrees Fahrenheit. Plugging these numbers into the equation above gets the following results,

$$f = \frac{3.1605[\frac{ft^3 * \circ F}{min * W}] * W[W]}{\Delta t[\circ F]} = \frac{3.1605[\frac{ft^3 * \circ F}{min * W}] * 210[W]}{(80 - 67)[\circ F]} = 51.0542 \frac{ft^3}{min}$$

This is assuming that the room's temperature is the average temperature that the consoles were designed to work in, 67 degrees Fahrenheit. This will often not be the case, so it is important to design this system for realistic room temperatures. Room temperature is typically between 68-72 degrees, so the team decided to round the upper bound of this range up to 75 degrees to run a worst case scenario. The fan speed required for this is,

$$f = \frac{3.1605[\frac{ft^3 * \circ F}{min * W}] * W[W]}{\Delta t[\circ F]} = \frac{3.1605[\frac{ft^3 * \circ F}{min * W}] * 210[W]}{(80 - 74)[\circ F]} = 132.741 \frac{ft^3}{min}$$

This is the upper bound of the cubic feet per minute that the fan system will need to deliver to keep the cabinet below the 80 degrees Fahrenheit threshold that the gaming consoles were designed for.

With these numbers, the team was able to start looking for fans to use in the cooling system. The team had a selection of five fans to choose from and used a weighted decision matrix to narrow down the fan based on its noise level, air flow, how easy it would be to integrate it into the system, its cost, and size. The most important feature that the team wanted to consider was the noise level of the fan chosen. The team wanted to keep the fan system quiet, so that it would not distract the user from their entertainment experience. A loud fan would be incredibly distracting and would annoy end users more than help them. The team focused on keeping the noise level of the fan system below 40 decibels. A 40 decibel noise level is the equivalent of average house noise, a soft rain, or the sound of a refrigerator ("Noise measurement," 2016). At this level, the noise level from the entertainment system would be similar to all the other noises in the house, and it should not disrupt the viewing experience on the TV (Bergmann & Ward, 2019). The next category that the team focused on was the air flow that the fan could create. Since this system would not be effective if the air flow was not sufficient, this was an important criteria. The next category was the ease of integration of the fan into the electrical system. It was important to choose a fan that would work with the Arduino, so that it would not be too difficult to learn how to program the Arduino to control it. Since none of the team members had extensive experience with programming, it was important that the fan

could be easily programmed. The next category that the team considered was the cost of the fan. Since this was a self-funded project the team agreed that considering the costs would be important to try and keep costs low without sacrificing the main features. In a large scale manufacturing setting, the cost of the fan will affect the profit margins of the company and the price for the end users. Finally, the team considered the physical size of the fan. Since the cabinet has a limited amount of space, it is important that the fan is not too big or bulky in the cabinet. These criteria and their weights are shown in the Figure 3.10 below.

The team decided to look at five different options for the fan. The options that the team considered were the Noctua NF-A14, Airplate S5, CONBOLA Bladeless Desk Fan, USB Cooling Fan for Xbox One, and Noctua NF-P12 redux-1700. Each of these options have their own merits and drawbacks, and the team will briefly cover the basics of each of these options.

To start, the Noctua NF-A14 fan is a square shaped 4-pin computer fan with quiet aerodynamic fan blades that is typically used to cool personal computers. This fan is 140 by 140 by 25 millimeters, has 4-pin pulse width modulation, 1500 revolutions per minute, 82.54 cubic feet per minute airflow, 26.4 dB noise level, 12 volt operating voltage, and 0.13 Ampere max input current (Noctua, 2020). Two of these fans in parallel could easily cool the system. This is an excellent fan that is very basic while supplying the system with great airflow, it is easy to integrate, and cost $21.95 per fan. The major drawbacks of this fan are it is a bit loud and a little big for the cooling system that the team had planned.

The next fan considered was the AC Infinity's Airplate S5. This fan had the advantage of being two fans in parallel to provide extra cooling for the system. It is 8.5 x 4.4 x 1.3 inches, with a maximum airflow of 52 cubic feet per minute, 18 dB noise level, the operating voltage 3 to 7 Volts, and current draw of 0.38 Amperes (AC Infinity, 2019). The fans are powered using a wall outlet or USB port, and the speeds can be controlled using a manual switch that can adjust the speed between off, low, medium, and high. The frame for the fans was made of a CNC machined aluminum with a brushed black finish that could be mounted to any flat surface. This system would not supply enough air for the system even with two units. On top of this, the system would not be very easy to integrate the manual switch with the temperature sensor from the Arduino. The Airplate is very quiet and a decent size, but it would cost too much for three units.

The next option considered was the CONBOLA Bladeless Desk Fan. This fan is unique in its bladeless design compared to the other fans considered. It has a single button control that can toggle between off, soft medium and strong fan speeds with a USB cable for power. This fan is one of the quietest models the team saw, with only 15 dB noise level. It also has one of the lowest airflows with only 30 cubic feet per minute. It is 11.8 x 3.5 x 4.5 inches, has an operating voltage of 5 volts, current input of 1 Ampere, and cost $40 per fan (CONBOLA, 2019). This fan has the best noise level of any of the fans that the team considered, but it also had poor airflow compared to the other options and the fan had an odd shape making it difficult to integrate into the physical design. The touch control would also be difficult to integrate with the Ardunino, and it would require additional research to learn how to use it in the system. The low airflow would mean that more fans would be required to move the air, and this would not be practical for how expensive these fans would be.

The next fan considered was the USB Cooling Fan for the Xbox One X Console. This fan served as an additional add on for the Xbox One X that could be plugged directly into the Xbox to help cool the device. It has a compact design, contains three small fans in parallel, and it has an on, off, and auto mode. The device does its own temperature sensor and will turn on automatically if it senses a temperature over 104 degrees Fahrenheit. It is 5 x 2 x 1.18 inches, has an input voltage of 5 volts, input current of 0.07 Amperes, 30-50 dB noise level, air flow of 35 cubic feet per minute, and it costs $20 (FYOUNG, 2018). The simple USB connection would be easy to integrate into the system with the Arduino and the built in temperature sensor make the circuitry incredibly easy to assemble. Other than the ease of integration, the fan had the worst noise level of all the fans, bad air flow, and it was too small to be effective. The cost could not justify the number of fans that would be needed to cool the cabinet.

The final fan that was considered was the Noctua NF-P12 redux-1700. This fan was very similar to the Noctua NF-A14 fan that the team considered earlier, but with a few key differences. It is a square shaped 4-pin computer fan with quiet aerodynamic fan blades that is typically used to cool personal computers. It has dimensions of 120 x 120 x 25 millimeters, 4-pin pulse width modulation, 1700 revolutions per minute, 70.747 cubic feet per minute air flow, and a noise level of 25.1 dB. The fan needed an operating voltage of 12 Volts, input current of 0.09 Amperes, and it cost $13.90 (Noctua, 2020). Two of these fans in parallel would be necessary to cool the system. This fan improves on the Noctua NF-A14 with better noise level,

cost, and it is smaller so it will fit into the physical build better. This fan also came with a 4th pin for pulse width modulation which is important since the Arduino can directly control the pulse width modulation.

Weighted Decision Matrix for Fan Choice											
		Options									
Criteria	**Weight**	**Noctua NF-A14**		**Airplate S5**		**CONBOLA Bladeless Desk Fan**		**USB Cooling Fan for Xbox One X Console**		**Noctua NF-P12 redux-1700**	
		Score	Total	Score	Total	Score	Total	Score	Total	Score	Total
Noise Level	0.4	6	2.4	8	3.2	9	3.6	5	2.0	8	3.2
Air Flow	0.25	8	2.0	5	2.5	3	0.75	4	1.0	7	1.75
Ease of Integration	0.15	9	1.35	6	0.9	4	0.6	8	1.2	9	1.35
Cost	0.15	9	1.35	5	0.75	2	0.3	4	0.6	9	1.35
Size	0.05	7	0.35	7	0.35	3	0.15	3	0.15	9	0.45
Total	**1**		**7.45**		**7.7**		**5.4**		**4.95**		**8.1**

Figure 3.11: Weighted decision matrix for the different fan choices for the cooling cabinet system

From the research that the team collected above, the team was able to come to the decision to use the Noctua NF-P12 redux-1700 fans for the cabinet cooling system. It had the second best noise level only coming behind the bladeless fan and it had a noise level of 25.1 dB. This noise level is equivalent to rustling leaves, whispering, or the library ("Noise measurement," 2016). At this level, the fan system will not be noticeable, and the user will only hear the TV/sound system. It had the second best option for air flow as well being able to deliver 70.747 cubic feet per minute per fan. Two fans combined in parallel could deliver 141.494 cubic feet per minute which would be enough to meet the 132.731 cubic feet per minute that the team determined the system would need. These fans also had pulse width modulations which made integrating them with the Arduino incredibly easy. These fans also cost the least of any fan that was considered for this system at a reasonable price of $13.90 per fan. Finally, these fans were the ideal size for the cabinet with dimensions of 120 x 120 x 25 millimeters, they would fit comfortably in the back panel of the cabinet. A brief summary of the specifications of the Noctua NF-P12 redux-1700 is included below in Figure 3.12.

Noctua NF-P12 redux-1700 Specifications

Criteria	Value	Unit
Size	4.72 x 4.72 x 0.98	inches
Connector	4-Pin PWM	
Rotation Speed	1700	RPM
Air Flow	70.747	CFM
Acoustic Noise	25.1	dB
Static Pressure	0.58	psi
Max Input Current	0.09	A
Operating Voltage	12	V

Figure 3.12: Specifications for the Noctua NF-P12 redux-1700 fan

The chosen fans will be placed on the backboard of the designated cooling cabinet. The fans will go on the panel that separates the TV compartment from the front cabinet section. The fans will need to be placed parallel to each other to achieve the required air flow for the cooling system. The fans are twice the thickness of the separating panel, so the team decided that the fans would be secured flush to the front portion of the separating panel. The team needed to decide between putting the fans on the outer wall of the cabinet or the separation panel. The outer wall on the cabinet would supply the cooling system with less restricted air that was less likely to have heat from the TV, but the would stick out and look clunky and not match the aesthetics of the cabinet. The fans were secured to the separation panel using screws and a dust shield between the mounting bracket and the fan to prevent dust from entering the system and interfering with any electronic devices in the cabinet.

To allow the system to run entirely on its own without any interference from the TV lift system, the team decided to use a second Arduino Nano to control the system. This second Arduino Nano was very similar to the main Arduino Uno being used, but it had fewer pins and a slightly smaller flash memory. This would be fine since it was only running the fan system. The Arduino Nano would be powered using a USB cable to the power strip. The fans were powered using their own power supply that was too high for the Arduino.

The next step was to program the system to turn on and off the fans when the cabinet reached a specific temperature. The temperature of the cabinet was measured using the MF52 NTC Thermistor. This thermistor requires a 10k ohm resistor to work properly in the system. In

programming, the team set a temperature mapping program to map the temperature of the cabinet to the speed of the fan. The lower boundary of the temperature range for the fan to run was set at 80 degrees Fahrenheit. This is because this was the highest temperature that the PlayStation 5 runs optimally in, so the team wanted to set that as the floor temperature. The temperature ceiling was set to 90 degrees Fahrenheit. At 90 degrees Fahrenheit or above, the team programmed the fans to operate at maximum speed. This ensured that the system would stay cool even if the temperature readings were very high. Between 80 and 90 degrees Fahrenheit, the Arduino will automatically adjust the fan speed to a certain percentage between these two temperature points. This system does not take into effect the outside air temperature, which is a big factor when calculating the air flow. To get a better temperature mapping, future iterations of this project could have a thermistor that measures the outside air temperature and a device to measure the wattage load in the cabinet to calculate a best fan speed. That kind of detail was outside of the scope of this project and the team would have struggled to implement this intricate system in time.

The wiring schematic for the fan system is shown below in Figure 3.13. The basic components of this diagram are an Arduino Nano, 12 V power source, 10k Ohm, MF52 NTC thermistor, and two Noctua NF-P12 redux-1700 fans. This system shows the fans positive and negative terminals are connected together and then connected to an external 12 V power source. The ground terminal is also connected to a common ground that is attached to one side of the terminal. This same side of the terminal is also connected to a 10k Ohm resistor that leads to the A0 input pin on the Arduino Nano. The other side of the thermistor goes to the 5 V pin on the Arduino Nano. Finally, the PWM control of the fans were connected together and connected to the D3 pin on the Arduino Nano.

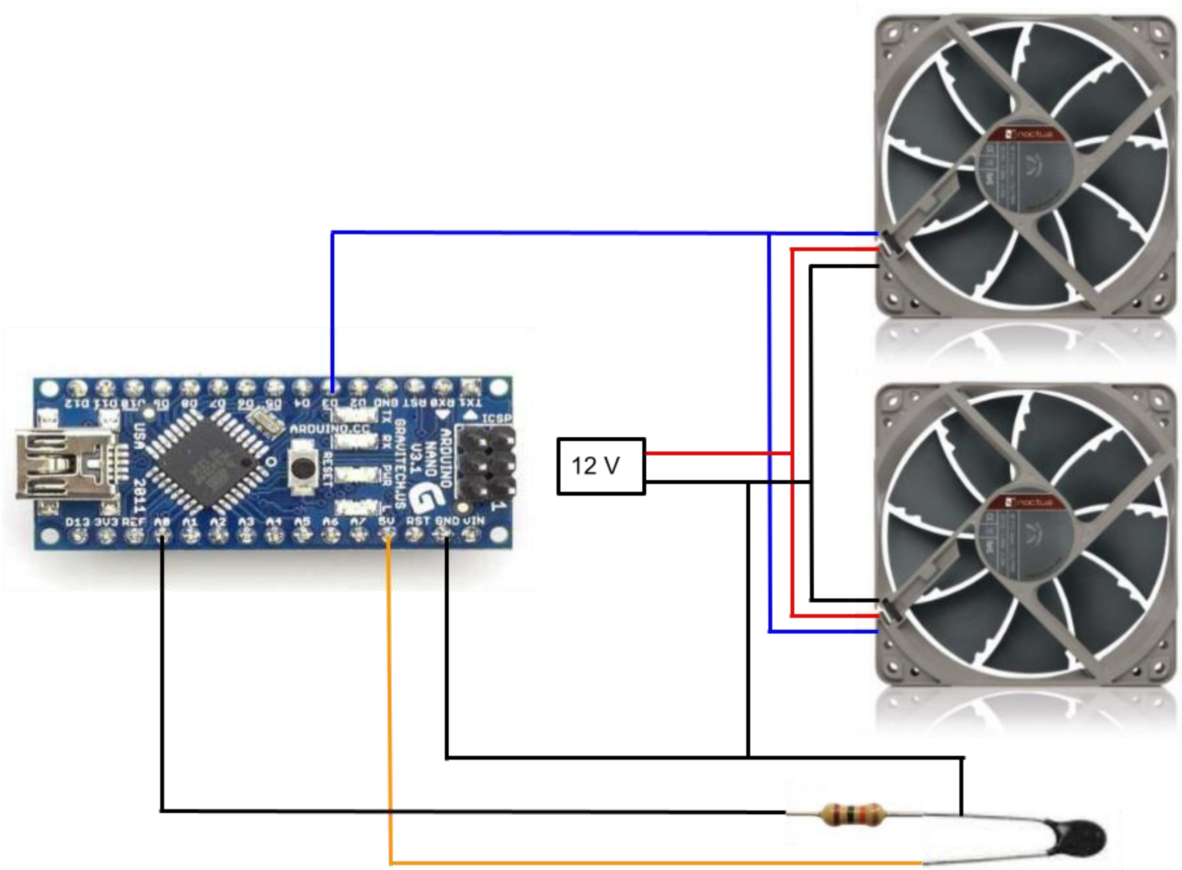


Figure 3.13: Wiring schematic for the fan electrical system for the entertainment system

3.6. Security

The security system for the cabinet doors was a simple, yet effective remote locking system using servos controlled using the IR remote control and Arduino. Four servos were attached to each of the doors near the upper outside part of the cabinet door, and a wire was run along the top of the door to connect the servos to the Arduino. The servos had an arm that would rotate 180 degrees when a button on the IR transmitter was pressed. This arm would rotate to a position in front of a metal tab that was attached to the bottom of the top surface of the inner cabinet area. The metal tab would prevent the door from swinging open when in the locked position, but allow the door to open when in the unlocked position.

The servos used for the locking system were SG90 Micro Servos. These servos were attached directly into the cabinet door using a polymer based adhesive. The arms for the servos were made of plastic and they were attached to the servo motors using screws. The servos on the

right hand doors were programmed to rotate clockwise and the servos on the left hand doors were programmed to rotate counterclockwise to lock the cabinet. For demonstration purposes, the servos were programmed to lock and unlock with the press of just the “three” button on the IR remote control transmitter, but they can easily be reprogrammed to lock and/or unlock with a 3 digit code entered in on the keypad of the transmitter to ensure for safety. The servos are shown attached to the cabinet door in Figure 3.14. This system should be proficient to discourage thieves from entering the device without the code. Thieves look for easy break ins and just having a lock on the system should be enough to deter them. Using the remote as the key is a modern improvement over the typical lock and key system and it is a much quicker way to lock and unlock the system. In addition, the remote locking system also eliminates any ugly key holes that would have been necessary in a traditional lock and key system.

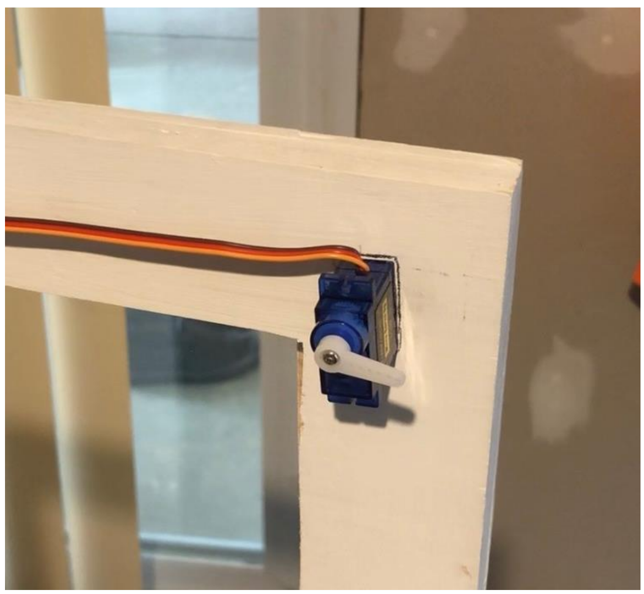


Figure 3.14: Servo on the far right door in the locked position

The final security measure that the team took was to ensure that the back area where the TV was kept was secure against any attempted break ins. This could be done with just the actuator that had been installed to move the top shelf. The top shelf covers the only way to remove the TV without destroying the entertainment system, so it is important that it is kept secure. The actuator is rated to be capable of taking 1500 Newtons of force directly on it. Since it is at approximately a 15 degree angle with the top shelf, it would require roughly 5795.6 Newtons of force or 1303.1 pounds of force directly downwards on the top shelf to move it out

of the way. This force rating should be more than enough to keep the average thief out of the TV area of the cabinet. These are the systems that work as security for this project.

3.7. Cable Management

The cable management of the system is extremely important in keeping the look of the system clean and uncluttered. Certain cables such as ones for cable or satellite service can also disrupt bluetooth signals affecting the performance of certain devices. (Audio Technica) The cable management strategy that the team implemented is mostly revolved around holes in the back panel of the storage area that allows for devices to be routed into this area which minimizes the amount of visible cable in the system. Cable clips will also be added near these holes to keep cables straight and under a controlled path.

The biggest challenge with this solution is that individuals will need to purchase long cables to reach the TV, since the TV ports will be a high distance from the wiring location. It also requires that the back panel be taken off to input cables into the TV, which users can do easily with a screwdriver. This will allow for easy access to any of the TV ports. After some testing, the team decided it did not need additional cable management resources to ensure that the cables would not be snagged by the top surface when the system actuates. Since cables are not visible and are behind and therefore away from electronics, the team believes that this is the best solution for cable management.

4. Detail Design Stage

4.1. Stress Analysis

To test the strength of the system, the team decided to perform a few types of analysis with different forces using ANSYS. The team selected the materials plywood and pine wood and applied these materials to the appropriate parts in the assembly. A bonded contact was chosen between all of the assembly parts since the parts will not be able to separate or slide due to the screws holding them together. This was analyzed using 3D solid analysis with a mesh size of 1 inch. The team chose this size because it allowed for enough elements in each smaller wood structure to be accurately analyzed. A fixed support was applied to each of the feet of the assembly.

The following cases were tested and the results can be found in the Figures below:

- 100 lbs of weight on the static top surface (Figures 4.1 and 4.2)
- 50 lbs of weight on the shelves (Figures 4.3 and 4.4)

After reviewing the results, the team is satisfied that the design criteria is met and there is little risk of failure in the material when compared to plywood's tensile strength of 4000-5000 psi. (Matweb, 1990)

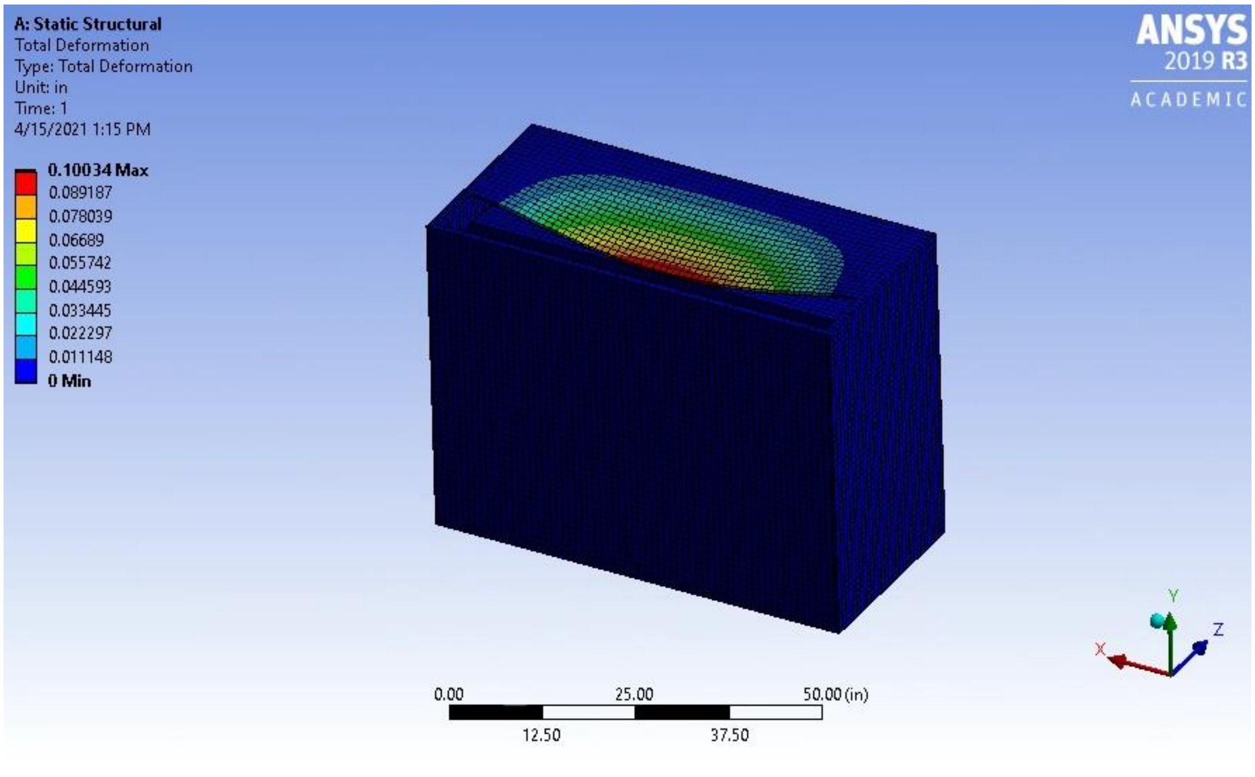


Figure 4.1 - Weight on Top Surface, Total Deformation

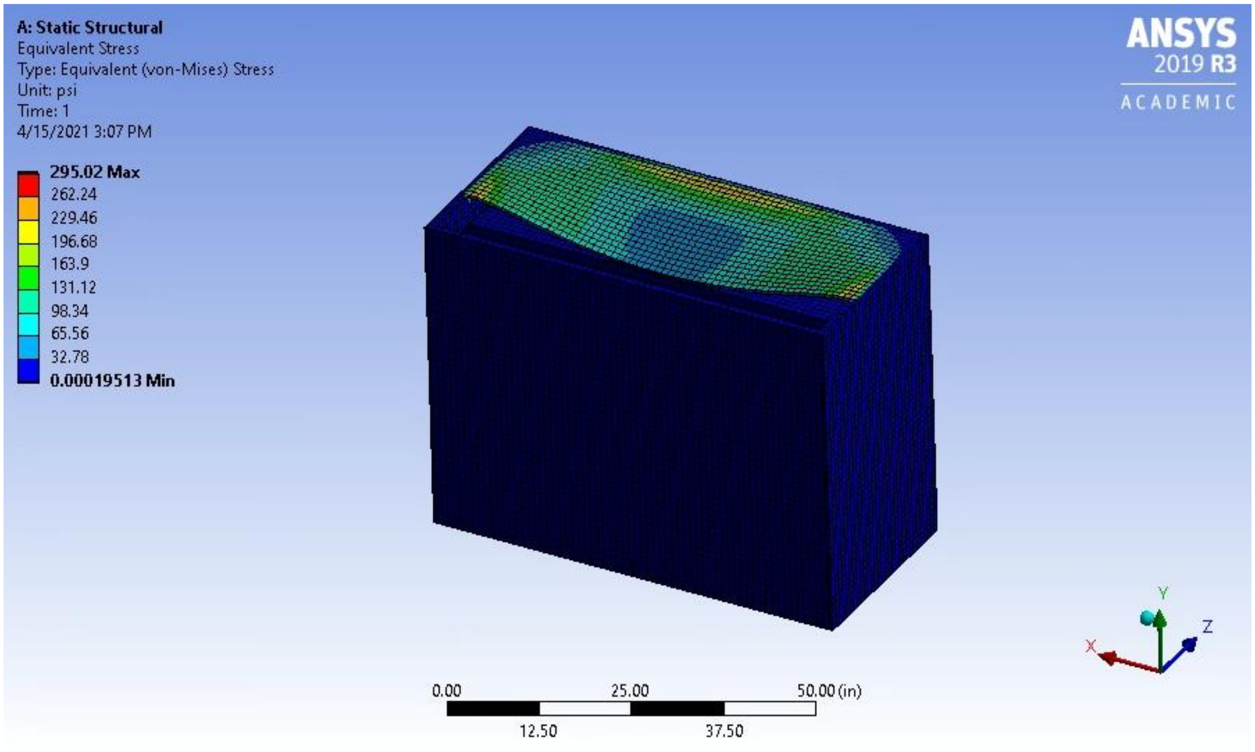


Figure 4.2 - Weight on Top Surface, Equivalent Stress

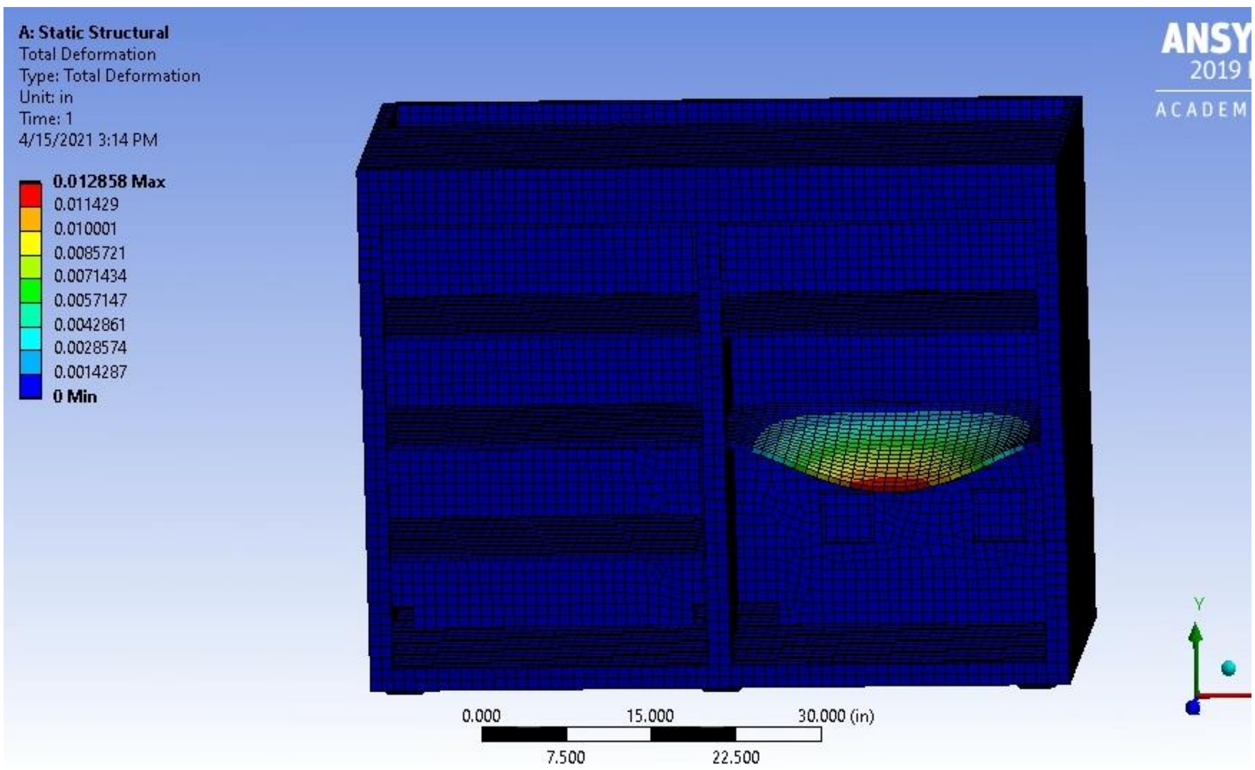


Figure 4.3 - Weight on Shelf, Total Deformation

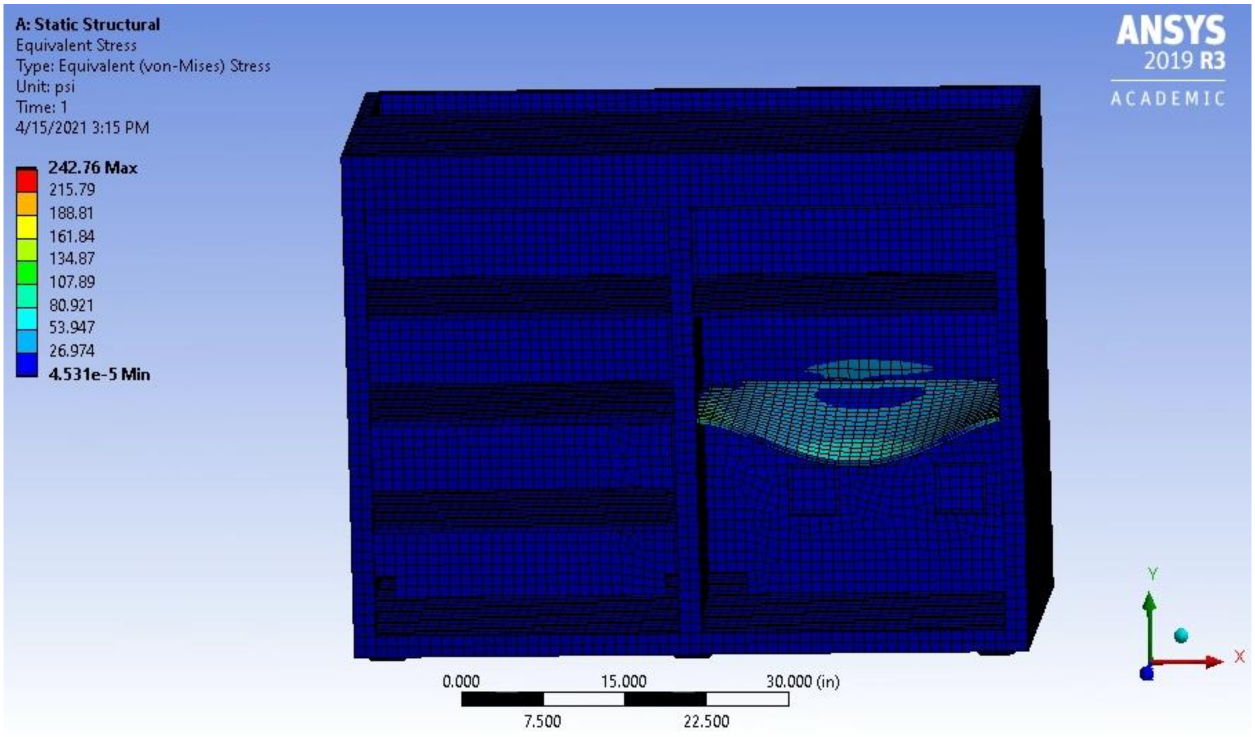


Figure 4.4 - Weight on Shelf, Equivalent Stress

4.2. Bill of Materials

Shown below in Figure 4.5 through Figure 4.6 is the bill of materials for the electronics, the wood, and the miscellaneous items respectively. A bill of materials was the system the team decided to use for recording the items that would need to be purchased for this project. The bill of material was also used to help the team create a budget for this project and each subcategory as well as determine the total cost of the project. The bill of materials was also used to keep track of which items would be purchased and as a way to log where each item would be purchased from.

The team used these bills of materials to keep track of the different parts we needed to purchase and where we planned to purchase them from as well as the price per unit and the number of units the project required. Three different BOMs were created to make it easier to organize and locate the different necessary items the team needed to purchase. This was also done to determine the different budgets necessary for each subcategory. Each of the bill of materials consists of different categories the team recorded for each part or item that needed to

be purchased in order to ensure that the necessary parts and quantities would be purchased for the entertainment system.

To properly implement the bills of materials system, the team determined it would be best to create an excel file to log the items to be purchased. For each item, the subsystem that the part will be used in as well as a description were to be logged. Then the team would list the provider as well as a link to the website where each item could be purchased. This was done to make it easier to revisit the site if necessary and to allow each team member to be able to view the description of each part. Finally, the team recorded the price and quantity per unit and the number of units required for the project as well as the shipping or tax price if applicable. From this information the team was able to determine the total cost of each part and the total amount for the project as a whole.

Bill of Materials - Electronics								
Subsystem	Part Description	Provider	P/N w/ link	Price per Pkg	QTY per Pkg.	# Pkgs.	Shipping/ tax	Total Cost
Fan	Noctua Cooling Fan	Amazon	Fan	$13.95	1	2	1.78	$29.68
TV Lift/Top Panel	Mophorn TV Lift Stand Motorized	Amazon	TV Lift	$146.99	1	1	9.92	$156.91
Lock	Micro Servos	Amazon	Servos	$1.23	1	5	0	$6.15
Brain	Arduino Uno	Amazon	Arduino	$23.00	1	1	1.55	$24.55
Power	Arduino Power	Amazon	9V Wall Plug	$5.99	1	1	0.4	$6.39
Power	Fan Power	Amazon	12V Wall Plug	$11.99	2	1	0	$11.99
Power	Power Stripe	Global Industrial	Power Strip	$9.95	1	1	0	$9.95
Brain	IR Remote	Amazon	IR Remote	$6.99	2	1	0.47	$7.46
Power	Motor Drive Board	Cytron	Motor Drive	$11.50	1	3	10.35	$44.85
TV Lift/Top Panel	Linear Actuator	Ebay	Linear Actuator	$39.43	1	1	2.69	$42.12
Testing	Testing Kit	Amazon	Breadboard	$18.49	1	1	0	$18.49
						Total amount	-	$358.54

Figure 4.5: Bill of Materials - Electronics

Bill of Materials - Wood								
Subsystem	Part Description	Provider	P/N w/ link	Price per Item	QTY per Pkg.	# Items	Shipping/ tax	Total Cost
Wood	Plywood 11/32" x 4' x 8'	Home Depot	Plywood 11/32"x4'x8'	$27.97	1	2	-	$55.94
Wood	Plywood 15/32" x 4' x 8'	Home Depot	Plywood 15/32"x4'x8'	$36.95	1	5	-	$184.75
Wood	Wood Post 4" x 4" x 6'	Home Depot	Wood Post 4"x4"x6'	$12.77	1	1	-	$12.77
						Total amount	-	$253.46

Figure 4.6: Bill of Materials - Wood

Bill of Materials - Miscelleanous								
Subsystem	**Part Description**	**Provider**	**P/N w/ link**	**Price per Pkg**	**QTY per Pkg.**	**# Pkgs.**	**Shipping/ tax**	**Total Cost**
Cable Management	Cable Box	Amazon	Box	$16.49	1	1	-	$16.49
Cable Management	Cable Clips	Amazon	Clips	$9.99	1	1	-	$9.99
Sliding Shelf	Spring	Amazon	Spring	$7.49	1	1	-	$7.49
Sliding Shelf	Bracket	3D Print	-	-	-	-	-	$0.00
Sliding Shelf	Screws							$0.00
Door	Handles	Amazon	Handles	$18.98	5	1	-	$18.98
Door	Hinges	Home Depot	Hinges	$10.48	1 pair	2		$20.96
Door	Screws							
Acrylic	Acrylic Sheet							$0.00
Acrylic	Acrylic Hooks	3D Print	-	-	1	2	-	$0.00
Acrylic	Acrylic Tabs	3D Print	-	-	1	2	-	$0.00
Rail	Rails	3D Print	-	-	1	4	-	$0.00
Rail	Screws							
Rail	Wheels	Home Depot	Wheels	$4.78	2	2		$9.56
Paint	Paint						-	$0.00
Storage	Shelf Tabs							$0.00
OPTIONAL	HDMI 2.1 Extension	Amazon	Cable	$15.99	1	4	-	-
OPTIONAL	Ethernet Extension	Amazon	Cable	$10.99	1	1	-	-
OPTIONAL	Cable Hider	3D Print	-	-	1	2	-	-
						Total amount	-	$83.47

Figure 4.7: Bill of Materials – Miscellaneous

4.3. Cost

One very important factor of this project that the team had to consider throughout the design process was the total cost of the project. The cost of the entertainment system was very important to determine early on in the designing process because it would factor into every decision that the team had to make when determining the variety of parts necessary to create each subsystem. When doing the initial research at the start of this project the team found that many of the existing entertainment systems with TV lifts on the market were quite pricey, ranging anywhere from $1000 to above $3000. Because of this the team believed that we could have a competitive advantage if the Entertainment 721 were to cost less than those currently existing on the market. After doing some initial research on the big ticket parts the team would need to purchase such as the TV lift stand, motors, cooling fans, plywood, and other necessary hardware, the estimated budget necessary to create the entertainment system was around the $700 mark. Given our target audience is upper class families, gamers, hotels, and AirBnBs, the team planned to market the entertainment center as a luxury item. The total cost of the system being around $700 allows the team to sell the Entertainment 721 for around $1500. This would

be at the lower middle end of the market while providing more features than what is available in this price range.

Many of the decisions the team had to make regarding the different subsections were made with the cost of materials in mind. For the TV lift system the team had discussed designing a homemade lift system to save money on purchasing a commercially made lift. This however would have created many issues as the design is very complex, so the team determined that it would be worthwhile to spend more on a commercial lift system. In determining the cooling system design the team wanted to use to create the cooling cabinets, the cost played a part in the decision. Ultimately the team decided to use a fan system to cool the cabinet, many factors aside from cost went into this decision however it was one of the more inexpensive designs proposed. One of the most expensive subcategories of this project included the plywood needed to build the frame of the entertainment system. When discussing the different material options the team could use, one of the major concerns was the price of the materials. Considering the size and the dimensions the team had already determined, a lot of the building material would be necessary. In order to keep the structural integrity of the system and to keep the cost of the project low, the team determined that plywood would be the best choice for the building material.

With the cost being a major factor of the project, the team needed a way to keep track of the necessary items that needed to be purchased as well as the prices of all the needed items. The team decided to do this by creating a bill of materials which would be used to log all the items purchased, the quantity and the total price. The bill of materials is shown in Tables 4.5 thru 4.7 and the method the team used to create it is discussed in more detail in section 4.2. The total cost of the electronics subcategory is $358.54. This category was expected to have the highest cost as it contains all of the electronic items, including the TV lift, motors, and fan systems which are some of the more expensive items necessary for this project. The total cost of the wood section is $253.46, which given the amount of building material, was expected to be between $250 and $300. Lastly the total for the miscellaneous section was $83.47. This section contains all of the hardware, wheels and railing system and all other additional items that were required to be purchased for this project to be built. The overall total cost to build this project was $695.47. This total cost is within the budget the team had anticipated for this project. This total cost would also allow the team to sell Entertainment 721 for a price that is significantly lower than a majority of existing systems currently on the market.

4.4. Final Dimensions

The following Figures 4.8 through 4.13 in this section will show the important dimensions of the system. In order to save time and keep this report concise, the drawings do not contain every dimension required to remake this system to the exact specifications. A tolerance of 1/16" applies to every dimension and the thickness of the boards used is ½" unless otherwise specified.

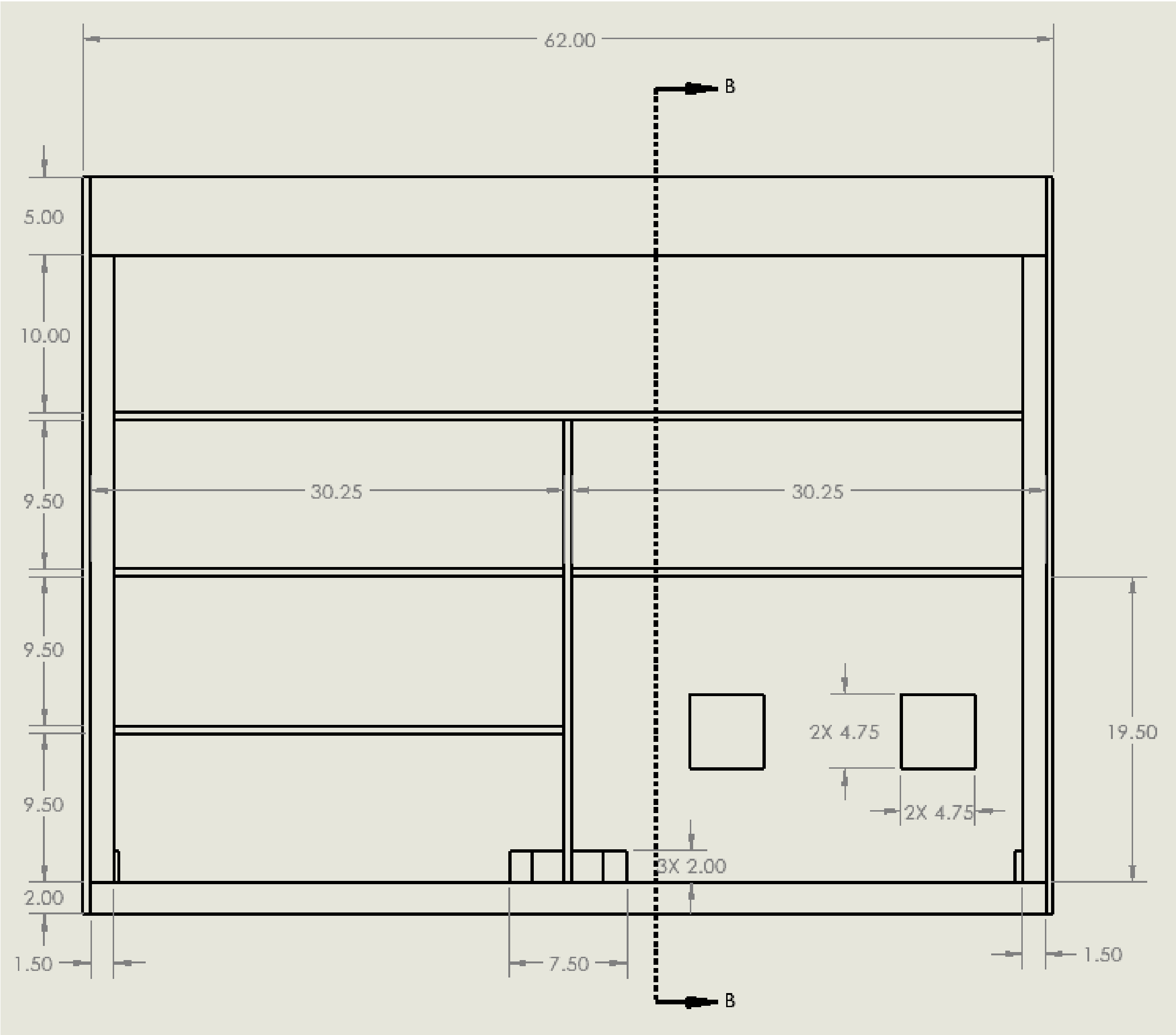


Figure 4.8: Cross sectional front view of the dimensions of the project

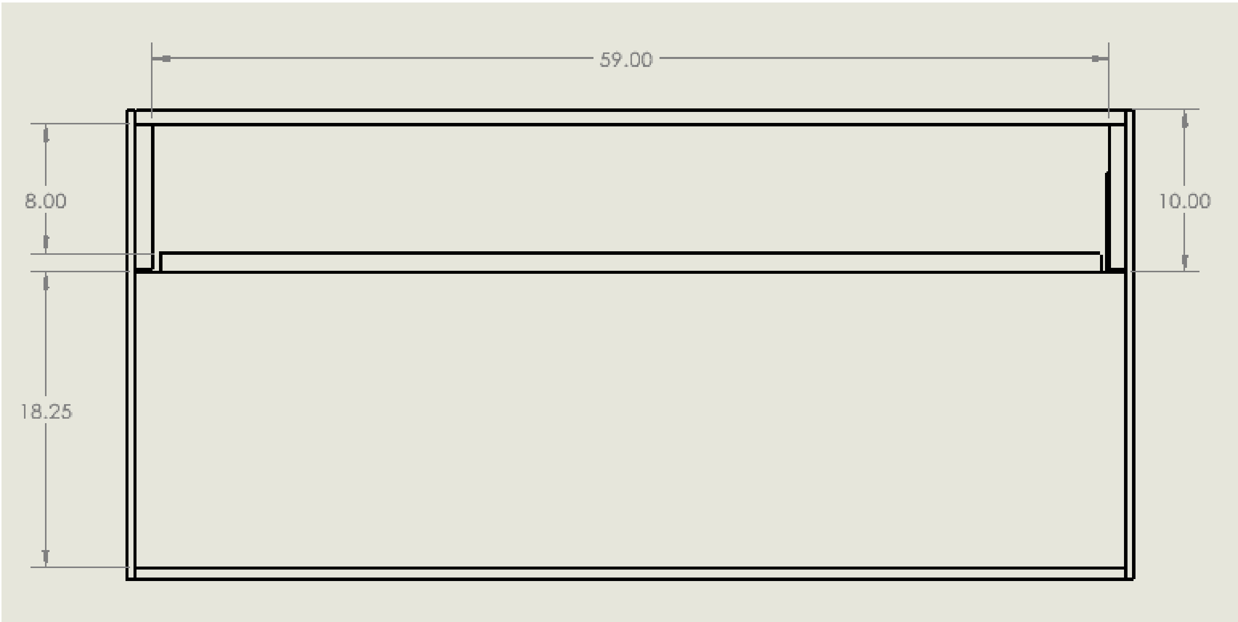


Figure 4.9: Top view of the dimensions of the project

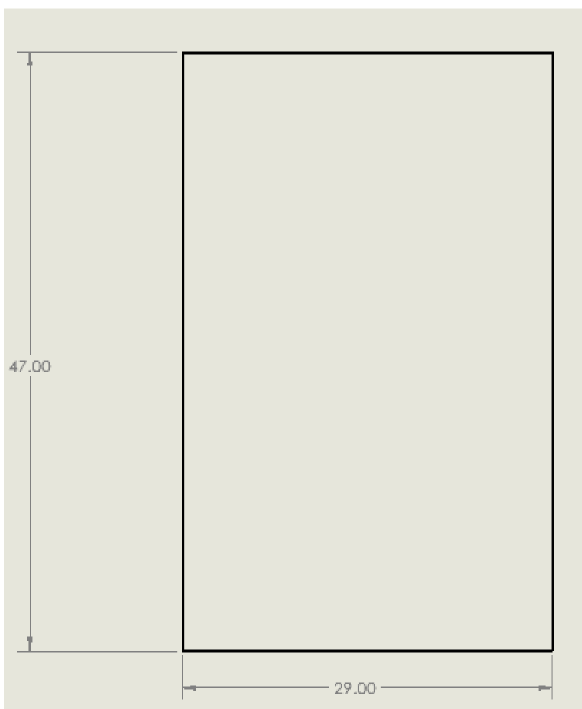


Figure 4.10: Side view of the dimensions of the project

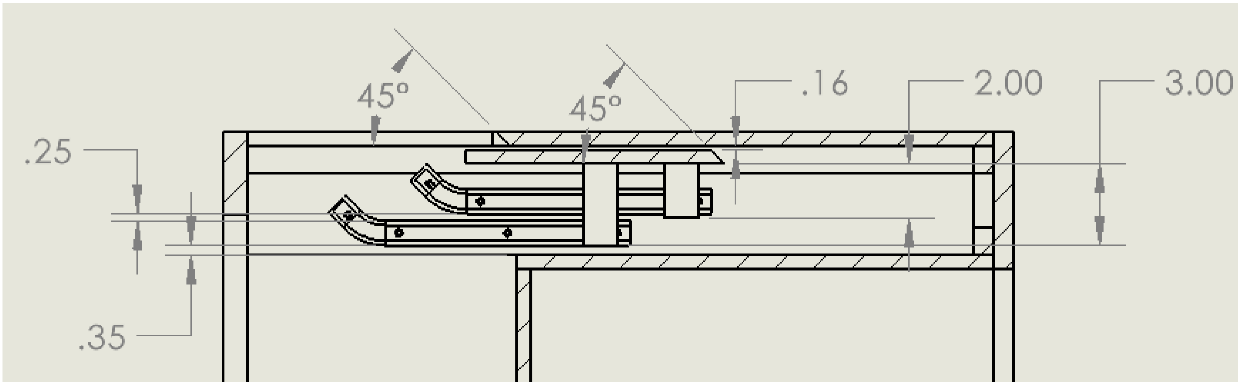


Figure 4.11: Cross section view of the dimensions of the rail system in the project

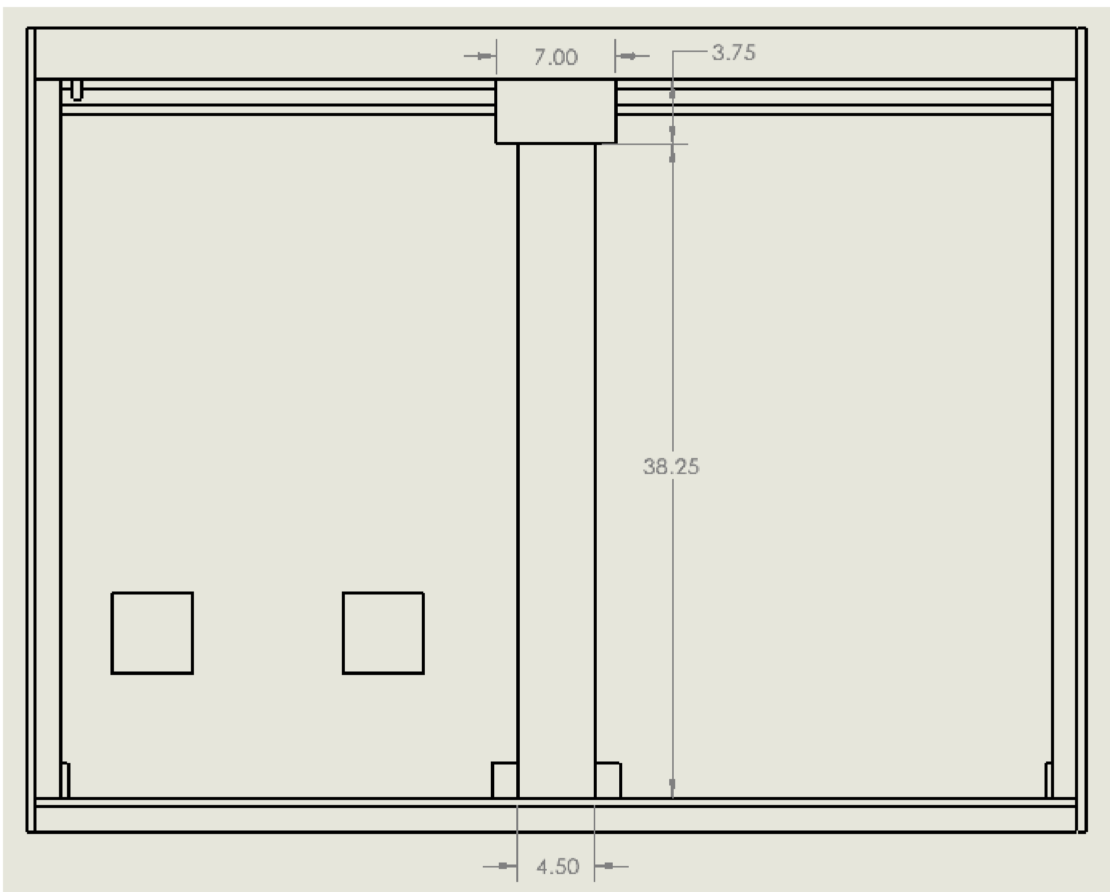


Figure 4.12: Rear view of the dimensions of the project

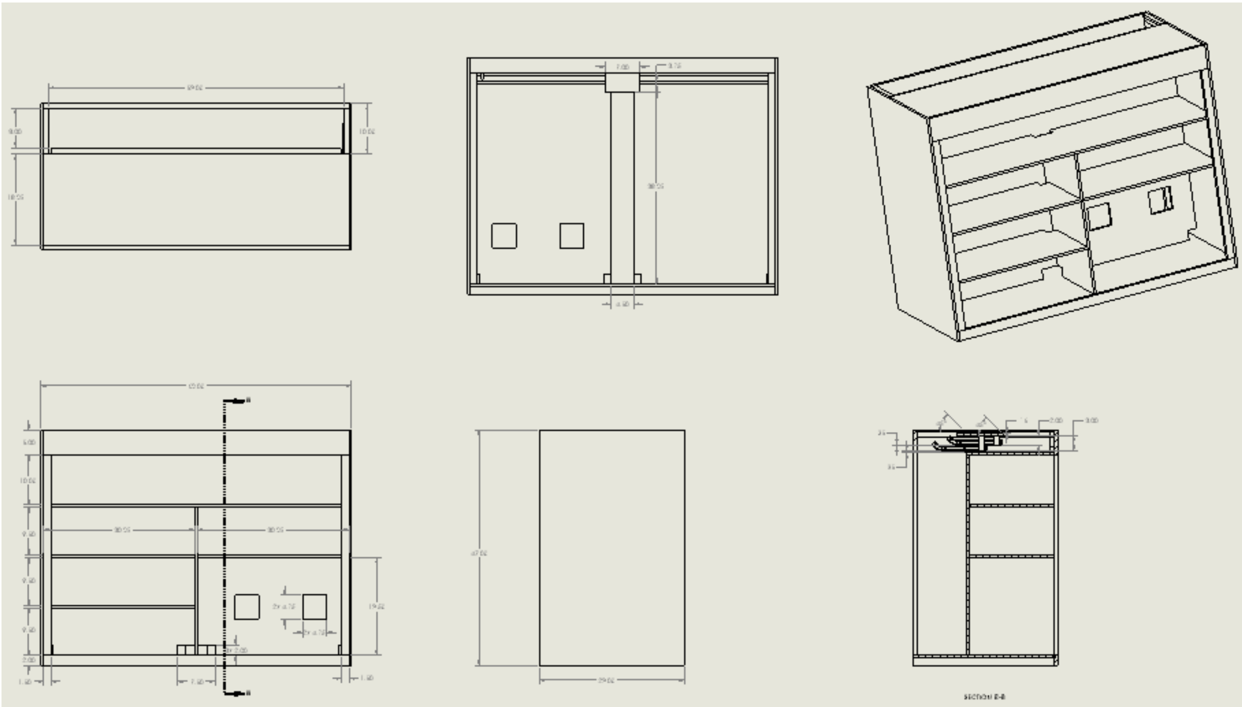


Figure 4.13: Collection of all the final dimensions for the project

5. Prototype Results and Discussion

While the team considers the first prototype to overall be a successful project, there are many improvements that could be made from this. The product ended up conforming to each of our benchmarks except for the actuation time. Due to the complexity of the project and the time and financial constraints, the team is satisfied with the work performed on the entertainment system created.

The biggest improvement could come from the overall actuation time. The time it takes for the top surface and the TV lift to actuate is 100 seconds. In a future iteration, the team would look to purchase faster actuators to reduce the overall time to 60 seconds.

Another major improvement could have come with the electrical system and programming. The infrared remote would send incorrect signals from time to time that would be irritating to end customers who want to raise or lower the system and the system is not responding. In addition, adding potentiometers to the actuators so they could sense where they were in their actuation would be helpful in coding a solution to letting the actuators stop at a certain point or allowing them to start and stop mid actuation in case there is an emergency. Finally, the fan system could be made much more accurate with a temperature sensor on the outside of the entertainment system to get an ambient air temperature. The code could be improved with this to give more accurate fan speeds to cool the cooling cabinet.

A realization that was had after the system was built is that it is too large for many people and hotels to consider buying this item. The height of the system also creates an issue where the TV would be at a tall height in the room which would cause the user to have to look up rather than have the middle of the TV be at eyesight as is the case with entertainment systems without lifts. Due to the height of the actuator, it would not be possible to reduce the height by a significant amount without reducing the size of TV that the system is able to store. In a future iteration, the team would prefer to target a 43” or 49” TV size to make the system accessible to more customers.

6. Conclusion

This project tackled several problems in the entertainment system market such as a unique solution to hiding the top surface, sufficient storage, cable management, a cooling system, and a locking system. The team feels that the project was a success and is happy with the results of the final build.

Large improvements to the system can come from the actuation time, the size of the system, and the electrical system. The actuation time is lower than the proposed 60 sec and faster actuators should be implemented. In a future build, the team would reduce the size of the system considerably by allowing only 43” or 49” sized TVs to be compatible. The 55” tv size placed large strains on the cost of the system, the weight of the system, and the overall dimensions. Improvements in the electrical system could come from allowing the system to sense where it was in the actuation as well as giving more sensors for temperature readings.

This project used several engineering principles to create. The team applied the design process learned in concepts of design to work through the project. First the team conducted market review, then researched possible solutions, then created a schedule to keep members accountable. After these basics were set up, heavy brainstorming sessions were conducted while each member of the group contributed his or her individual ideas. A conceptual design was created from these brainstorming sessions and a more detailed plan was made to get to the embodiment design. Finally, the team approached the detail design phase where the final dimensions, cost, and FEA were written out.

Many challenges existed over the course of this project. The biggest challenges to the team were the building of the wood structure and the electrical system, since the team members had little to no experience in these areas. Through extensive amounts of research and help from skilled professionals, both online and in person, the team was able to overcome these challenges. The team was able to perform engineering done in class such as FEA analysis, solid modeling and drafting, material selection, scheduling, fan calculations, and 3D printing. This work would not have been possible without the training the University has given to us over the last few years. The team will now look forward to achieving innovation in each of their respective careers.

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