University of Michigan

ME 450-Fall 2012
Final Report

Team 11: Automobile Seat Comfort

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EXECUTIVE SUMMARY

The task at hand is to design, build, and test a system, which prevents an automobile seat from increasing in temperature due to direct solar radiation loading. This system is to be 'stowed' in an off position while the occupant is present in the car seat and automatically deploy/engage when the car seat is exposed to solar radiation. This task stemmed from a sub-function of a previously broader automobile comfort scope assignment.

Engineering requirements were developed in conjunction with Johnson Controls (JCI) and their understanding of the customers' needs. Several of the more important engineering specifications are listed below:

1) No human energy input beyond a signal (automatic)
2) Regulate the thermal loading area of at least 0.075 m^2 of the backrest and 0.120 m^2 of the seat cushion
3) System must be able to retract and store into its off position in under 8 seconds

Upon completion of concept generation, a Go/No Go chart, and Pugh chart analysis, we developed a Roller Runner cover system that was later refined to a scissor mechanism that can extend a reflective cover at an angle over the seat. The scissor extension allows for a repeatable extension and retraction without causing any damage to the seat surface.

The final prototype, the Xtendr, blocks the thermal radiation by using a Temptrol heat reflecting material, extended by an aluminum scissor mechanism. The cover is stored above the scissor mechanism, wrapped around a spring loaded spool. It is located in the upper shoulder area of the backrest and is covered with foam and leather to increase customer comfort and seat 'style'.

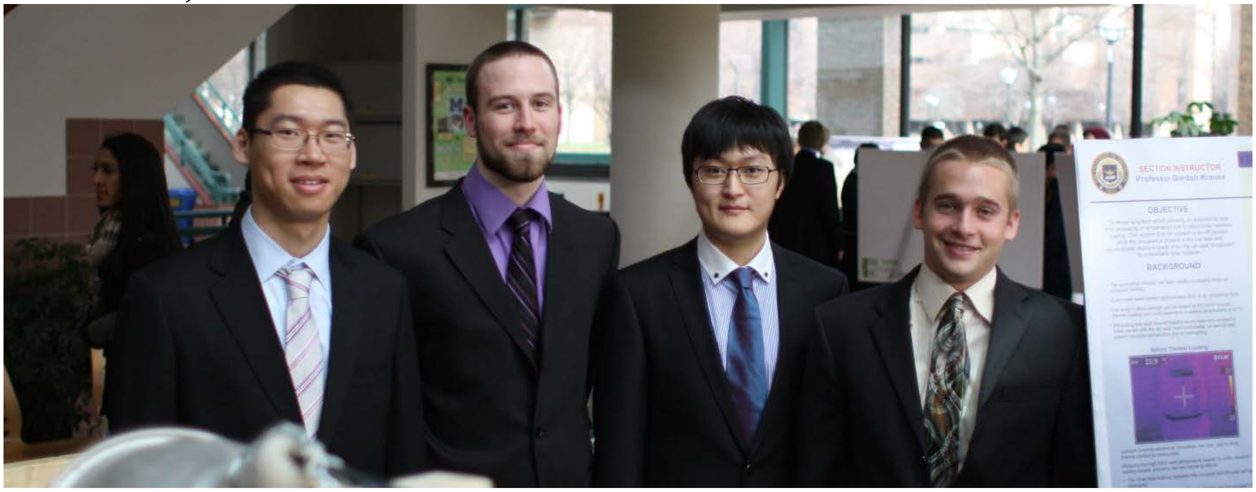
All of the linkages, as well as the load bearing portions of the frame, are 0.25" aluminum that was water jetted to the correct shape with holes and slots later milled out. All of the round elements that needed manufacturing were shaped using a lathe. All purchased components were cut down to size using a band saw or a knife. The design as it stands will cost approximately $30 under the assumption of a volume of >100,000 units per year.

Validation testing revealed that our prototype successfully met 13 of the 15 specifications. The two specifications that we failed to meet, comfort impact and durability, have been addressed with possible solutions in the Final Design and Recommendations sections.

Improving the current design could involve reducing the size of the aluminum parts and making them instead out of a lighter weight ABS/nylon material, installing a cam and lock system on the housing cover, inserting wire guides, upgrading the motor, moving the system further back in the seat, and incorporate the suggested algorithm into the seat programming.

The Xtendr is a low cost, low energy solution that can go a long way to reducing discomfort caused to customers by solar radiation loading. A few small tweaks to this proof of concept will result in a comfortable, durable answer that will increase the overall value of a car seat.

Team 11, Automobile Seat Comfort: Left to Right (Ziqi Zhu, Nathan Hartmann, Chaoji Wu, Justin Risetter)



Xtendr Installed in Seat and In Fully Retracted Position

Xtendr at Design Expo in Fully Extended Position with Heat Lamp Demonstrating Radiation Blockage

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INTRODUCTION

Project 11 – *Automobile Seat Comfort* is sponsored by Johnson Controls – Automotive Seating Department. Johnson Controls (JCI) is the global diversified technology and industrial leader to optimize energy and operational efficiencies of buildings, automotive lead-acid and advanced batteries, and interior systems for automobiles. For the Automotive Seating Department, they have supplied original equipment manufacturers (OEMs) worldwide for more than 80 years with smart automotive seat systems that offer consumers comfort, safety and style [(The Ultimate in Style, Comfort, and Safety from the Number One Automotive Seat Supplier)].

Thermal comfort is one area of the automotive seat system that needs improvement. The automotive seat has contact with approximately 30% of an occupant's surface area, creating a microclimate between the seat and the occupant. The initial focus of our project was to create a system for regulating the temperature and humidity this microclimate. After developing a possible solution consisting of three different sub-systems, JCI felt that the most effective use of our time would be spent focusing on one of these functions. By reducing the amount of energy necessary to dissipate, the cooling system will require less energy to cool to the customers' desired temperature. Therefore, the objective of this project is to develop a system capable of significantly reducing thermal loading on the seat due to the sun.

The main goal of this project is to provide JCI with a unique design that tackles this issue of thermal loading, one that does not infringe on other patents out on the market. Currently, there are no fully automatic thermal protection systems that come with car seats. Preventing thermal loading is a relatively undeveloped market with most of the current solutions being manual after market purchases. Our project is intended to be an initial stepping stone for JCI to eventually develop a unique function that allows their seats to outperform their competitors.

The design we will be producing must therefore meet the requirements of the customer, because they are the ones who will be using our product on a daily basis. Due to our very limited knowledge of automobile seat design we conversed with Johnson Controls to determine what they have found to be the requirements of the customer and those are listed in abbreviated format below.

- Thermal regulation area is to be maximized
- The surface should have a uniform temperature
- Power draw restrictions
- Total system weight minimized
- Should not take up more space than current seat envelope
- Occupant seat comfort is not negatively affected
- Cost minimized
- Survive durability requirements of a typical seat test
- Shut down/ store away quickly
- No damage to the seat surface
- Sun thermal blockage is to be maximized
- Algorithm developed to activate system
- Automatic deployment

SPECIFICATIONS

Working with JCI, we developed specifications for this solar radiation blockage system as will be detailed below (Table 1). These specifications are the result of the large redefinition of the overall project scope and further refining.

Table 1: Reason for Specifications and Requirements

Requirement Type	**Quantification**	**Reason**
Solar Radiation Regulation Area	Min: Backrest: 0.075 m^2 Min: Cushion: 0.12 m^2	The seat cover needs to cover the main portions of the seat, that being the inserts and not the bolsters, hence the minimum area chosen.
Temperature Uniformity within Cushion and/or Backrest Zones	< 2 °C difference	The seat cover is to thoroughly block the sun at all points it is covering, so that there are no hot spots on the seat. The value of ± 2°C has a greater cost to occupant comfort benefit than the perception threshold of 1/2°C due to the fact that in order to create a surface with temperature uniformity of less than a ±1/2ºC difference the cooling system would have to be dynamically controlled, so that hot spots are cooled as they appear. This type of a system would simply be too expensive for the benefit that could be achieved.
Battery Power Draw	Max of 3A, 9-16V, 36 W (allowed to draw power when car is not running)	Allowable power draw from car battery for non-critical systems.
Maximum Power Draw Time for One Cycle	< 500 J	Assumes close to maximum power draw for implementation and shut down of the system.
System Weight	< 1 kg (this is for the design to be used in industry, prototype may weigh more due to access to materials and machinability, but CAD prototype must be shown to be < 1 kg)	There is value in this system having automatic deployment and therefore more components, so that no lower of weight requirements is required.
System is to Fit within Current Seat Envelope	No portion of the system is to extend over ½" from any external seat surface originally in place.	Initial temperature reduction system must be capable of storing within the specified quantification when the occupant is present

Requirement Type	Quantification	Reason
Comfort Impact	No negative impact to comfort, to be assessed by JCI's expert panel in a 'Static Comfort Evaluation'	Customer requirements. Will not stand for poking, pinching, hard surfaces as experienced by the occupant. The expert panel will produce a report of the comfort impact this seat cover may (or may not) have on the overall seat comfort.
Cost of Manufacturability	Manufacturing cost < $35.	Based upon past standard developed for cooling system and the fact that this is an initial idea trialing system.
Durability	Design for the typical 10 year use. JCI engineering will give an evaluation of the durability of the system proposed system.	The system will be used a number of times over the course of the car's lifetime and so it must be designed a build to withstand repeated use and abuse.
Shut Down/Storage Time	System is completely in stored position in under 8 seconds	From a fully deployed position, when the system retraction is started (real life = unlocking the car door) the cover must be in the fully retracted position in under 8 seconds.
No Seat Damage	After installment, no visual wear should be present due to the system	The cover system must not damage the actual seat through its use, because it would otherwise do more harm than good.
Solar Radiation Blockage	Thermal Reflectance > 0.95	The majority of sun shades and reflective products for cars use aluminum foil covered products to reflect thermal energy. The thermal reflectance target is comparable to this value since those sun shades provide a noticeable lower of interior car temperature.
Deployment Activation	1. Car is stopped and door is locked. 2. Occupant and/or objects are off the seat. 3. The outside temperature is higher than 36 °C. 4. The light sensor determines sun light conditions.	The seat deployment need to meet these conditions to ensure that there are neither occupants nor belongings on the seat and that the car is at risk of heating up.

Requirement Type	Quantification	Reason
Automatic System	No human energy input outside of the signal.	The customer needs a reason to purchase the system over other manual counterparts.
Not to Interfere with Current Seat Manufacturing Infrastructure	Determined by JCI Engineers	The initial cooling seat design must not change fundamental manufacturing plans of current seat designs.

Customer Requirements and Engineering Parameters
With the engineering specifications determined out of the requirements of customers there was great interest in which specifications had greater impact and pertinence to the controllable engineering parameters. This section explores these connections.

We began by exploring other products aimed at preventing solar radiation from hitting vehicle seats and benchmarked them to see how they ranked against the customer requirements that have been determined (Table 2).

Table 2: Benchmarks and Comparison against Customer Requirements

1 – Poor 2 3 – Acceptable 4 5 - Excellent	Keeps Seat Cool When Car is Off and	No Negative Comfort Impact	Maximum Area of Seat Cooled	Uniform Seat Surface Cooling	Dependable	Automatic Deployment	Does Not Drain Car Battery	No Damage to Seat (Apart from System	Minimize Cost Addition to Seat	Does not have to Wait to Enter Car	Total
Weight	5	4	2	1	4	5	4	3	2	5	
Eclipse Sunshade	15	12	6	3	12	5	20	12	8	5	98
Genuine Cool Ass	15	8	8	4	12	5	20	9	8	5	94
Heat Shield	8	12	6	3	16	5	20	9	8	5	92

To determine which project specifications were of greater relative importance we were very mindful of customer desires and the ultimate function of the cooled seat. To kick this process off, we took into account JCI's focus and final design objectives for this project and coupled that with our understanding of the customer needs and desires as learned through benchmarking other designs and conversation with JCI. This allowed us to rank desires of the customers in the below order from most important to least (Table 3).

1) Keeps seat cool
2) Keeps seat dry
3) Cools Occupant Quickly
4) Uniform Surface Temperature
5) Maximum area cooled
6) Occupant Controlled

7) No negative comfort impact
8) Independent back and cushion control
9) Low power draw

Table 3: Customer Desire Ranking and Corresponding Descriptions

Rank	Customer Desire	Description
1	Keeps seat cool	Cooling potential of seat when drawing from car battery.
2	Keeps seat dry	Ability of the seat to keep the occupant dry, as it specifically wicks sweat away.
3	Cools occupant quickly	From the start of the cooling system to when the microclimate has reached its target temperature.
4	Uniform surface temperature	Ability of the cooling system to cool the microclimate evenly across cooling surface.
5	Maximum area cooled	Area of the cooling surface of the system is to be felt by the occupant over a maximum body surface area
6	Occupant controlled	The ability of the occupant to change the temperature of the cooling seat.
7	No negative comfort impact	The cooling system is to no way affect the original comfort of the seat.
8	Independent back and cushion control	The cooling system in the backrest and cushion are to be able to be independently operated.
9	Low power draw	system should not affect the performance of other systems by overdrawing power from the battery

The engineering parameters (which are in large part directly connected with the engineering specifications), shown in Table 4 below, were then rated against these customer preferences in a QFD chart (Table 5) to determine which parameters produced the largest change in the customer requirements, and were thereby the most important parameters. We then connected the parameters to their corresponding engineering requirements, which had been previously developed, and ranked them according to the importance of the parameters.

Table 4: Technical Parameters and their Explanations

Technical Parameters	Description
Variable Control	The system must allow control inputs for both the backrest and cushion independently.
Material Breathability	Surface material of the cushion and backrest must allow both air and water to pass through it for the sake of both moisture and temperature control.
Cooling Potential	Different concepts and techniques will ultimately have different amounts of cooling capacity that can be gained from them.
Heat Sink	The way the heat is ultimately ejected from the system can be varied based upon the technique chosen.
Visible to User	We can vary the positioning and size of the system so that its noticeability to the occupant is minimized.

Noise Level	Ability to control the sound level emitted *output* from the system.
Heat Transferability	Within the system itself there will be an inherent need to move heat away from the seat and to do so with uniformity, therefore the heat must be readily transmitted through the system.
Power Draw	Amount of power being drawn from the car battery to power the cooling system.
Weight	Amount of mass the cooling system consists of.
Humidity Control	Ability of the system to regulate moisture in the microclimate.
Seat Comfort	The system must not affect the comfort of the seat.
Independent Cooling	Backrest and seat cushion must be able to be controlled independent of one another.

QFD development involved a combination of research, user preference (based upon our sponsor's experience with car seats), and engineering targets developed in conjunction with JCI. Notice the customer needs, as understood by JCI and ourselves, are listed along the left side and weighted based upon the end goal of the cooled seat and customer impact. The adjustable parameters of the seat are listed and described vertically above (Table 4). The parameters and customer requirements are then rated according to their impact on one another (High: 9, Med: 3, Low: 1) in the QFD below, Table 5. The scores are tallied, normalized, and then ranked to show which parameters are most influential to the customer requirements. The parameters are in large part directly connected to the engineering specifications and so the rankings developed in the QFD can be transferred over to determine which specifications are the most important.

Furthermore, in the triangle shaped region at the top of the table, Table 5, an impact rating is given to the relationships between each of the Technical Parameters and how changing one affects each of the others. A positive mark means that they have a good relationship in that both parameters are tending towards their desired (+/- mark) directions. Likewise, a negative mark means that as one tends toward its desired (+/- mark) direction, the other one tends away from its desired direction. This allows us to see the strengths we want to utilize and the paradigms we will seek to break.

The three competitor products produced by Nocord, Gentherm, and W.E.T. are also compared against the customer requirements and technical parameters to determine how they align with our own developed specifications. On the right side of Table 5 the competitor products are compared against customer needs and on the bottom they are compared against the parameters.

Table 5: QFD Chart of Customer Needs Compared to Engineering Parameters

QFD

Project: Initial Seat Cooling
Date: 10/20/12

Impact	
High	9
Med.	3
Low	1

Survey Legend	
A	Eclipse Sunshade
B	Genuine Cool Ass
C	Save-A-Seat

	Solar Radiation Blockage (+)	Uniform Solar Radiation Blockage (+)	Power Draw from Battery (-)	System Weight (-)	Volume and Seat Integration (-)	Durability (+)	Retraction Time (-)	Human Involvement (-)
Solar Radiation Blockage (+)								
Uniform Solar Radiation Blockage (+)	+							
Power Draw from Battery (-)								
System Weight (-)	-	-	-					
Volume and Seat Integration (-)			-	-				
Durability (+)	+	+	-	-	-			
Retraction Time (-)	-		+	-		-		
Human Involvement (-)			+				++	

Customer Needs	Customer Weights	Solar Radiation Blockage (+)	Uniform Solar Radiation Blockage (+)	Power Draw from Battery (-)	System Weight (-)	Volume and Seat Integration (-)	Durability (+)	Retraction Time (-)	Human Involvement (-)	1 Poor	2	3 Acceptable	4	5 Excellent
Keeps Seat Cool When Car is Off and Unoccupied	5	9			1						C	AB		
No Negative Comfort Impact	4	1	3			9					B	AC		
Maximum Area of Seat Cooled	2	9	3									AC	B	
Uniform Seat Surface Cooling	1	3	9									AC	B	
Dependable	4			1			9					AB	C	
Automatic Deployment	5			3	1				9	ABC				
Does Not Drain Car Battery	4			9				3	3					ABC
No Damage to Seat (Apart from System Installment)	3					1		1				BC	A	
Minimize Cost Addition to Seat	2			1		1	3	1	1				ABC	
Does not have to wait to enter Car	5			3	3			9	3	ABC				

	Solar Radiation Blockage (+)	Uniform Solar Radiation Blockage (+)	Power Draw from Battery (-)	System Weight (-)	Volume and Seat Integration (-)	Durability (+)	Retraction Time (-)	Human Involvement (-)
Raw score	70	27	72	25	41	42	62	74
Scaled	0.95	0.36	0.97	0.34	0.55	0.57	0.84	1
Relative Weight	17%	7%	17%	6%	10%	10%	15%	18%
Rank	3	7	2	8	6	5	4	1

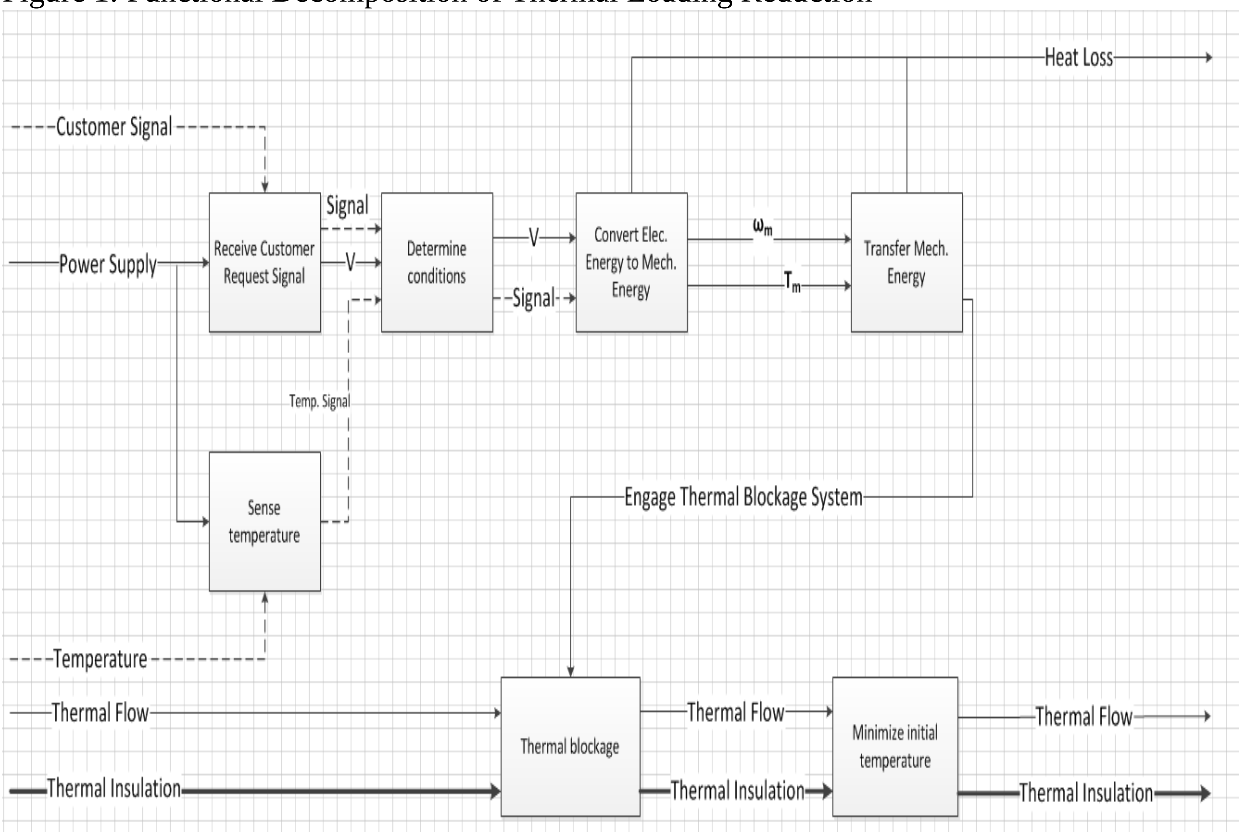
Technical Requirement Units	#	#	W	#	#	db	#	W
Eclipse Sunshade	3	3	3	2	1	3	1	1
Genuine Cool Ass	3	3	3	3	2	3	2	1
HeatShield	3	3	3	2	2	3	1	1

CONCEPT GENERATION

This section details the process we followed in both creating initial concepts and then in how we worked to choose the best concept from which to pursue as a final design.

The first step was to determine all the functions necessary to meet the previously stated specifications. To do this we created a functional decomposition diagram (Figure 1), and from that we were able to visualize all of the functions with their inputs and outputs as well as how they interact in the overall system.

Figure 1: Functional Decomposition of Thermal Loading Reduction



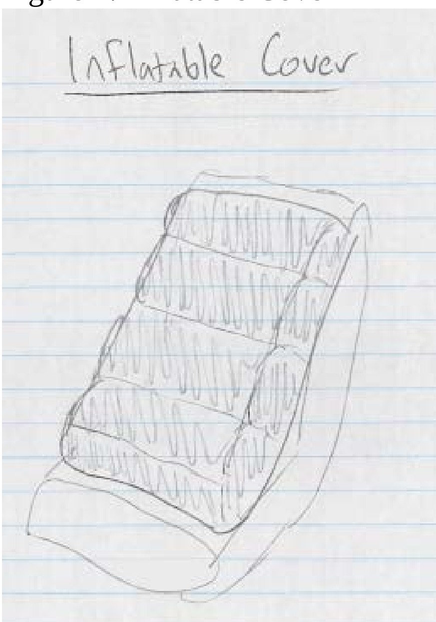
We then developed designs for solar radiation blockage and for controlling/guiding the system as it moves between the stored and the activated positions. Each person was tasked with coming up with a minimum of five designs, regardless of their feasibility.

Most of our designs consist of a physical covering of some sort, although the type and the application of the cover vary significantly. The first three designs mentioned below are attempts at developing ways to apply a cover over a seat. The last two on the other hand are ideas to help guide the cover into the correct position and possibly correct the path if the cover begins to stray. All other concepts we have generated are illustrated in Appendix A-1.

Inflatable Cover

The inflatable cover design relies on air to both inflate and insulate the seat from the thermal loading. The cover would initially be condensed near the top of the seat. An air compressor would then be used to inject air into the cover causing it to inflate. As the cover inflates it will expand outward until it reaches its full size. As this occurs, gravity will be pulling the cover down so as to cover the entire seat diagonally (Figure 2). The top layer of the cover will serve to reflect away heat, but if some is absorbed by the outer layer, then there will be an insulating layer of air to protect the seat. To retract, it would have to be deflated and rolled up back into the seat.

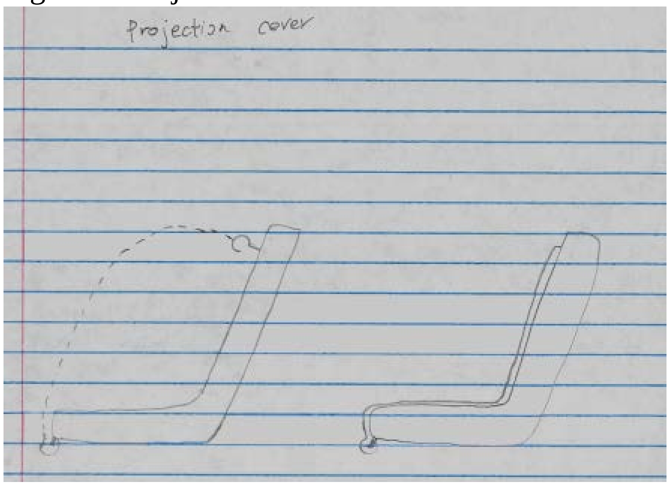
Figure 2: Inflatable Cover



Projection Cover

By using a super lightweight material, a cover could be deployed by using a fan to blow the cover away from the top of the seat (Figure 3). The cover would go out to beyond the front of the seat and then drape down to sink next to the seat. A motor would then retract the cover back to the seat taking any thermal loading with it.

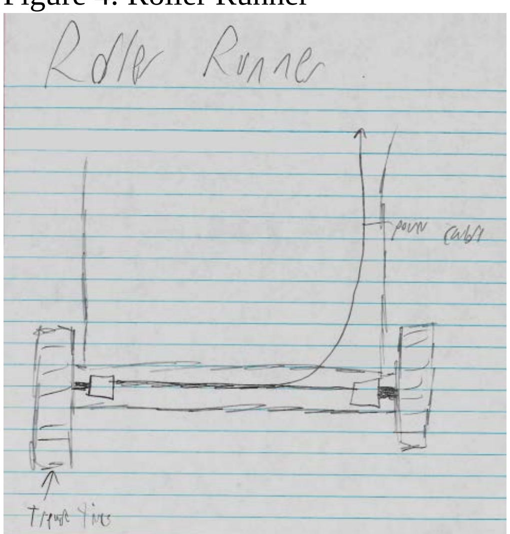
Figure 3: Projection Cover



Roller Runner

The roller runner is an idea (Figure 4) primarily for extending and retracting the thermal protection. On the end of what would be a cover sheet, there would be two wheels powered by motors that would be capable of driving the cover down the seat. Another motor would be located on top of the seat to assist the wheels in pulling the cover up. In the stored stage, the wheels would be housed in a box on top of the seat.

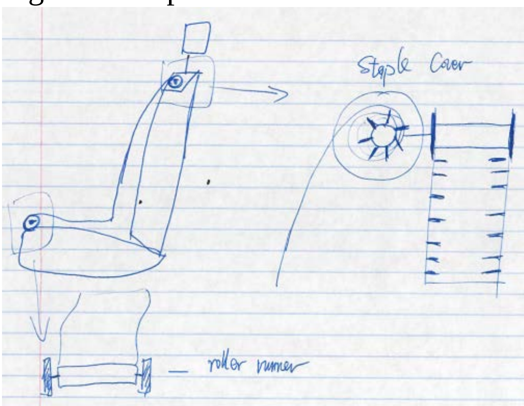
Figure 4: Roller Runner



Staple Cover

The staple cover system is a control design that is meant to keep a cover from becoming crooked as it is retracted. A wheel with spokes would be sitting on the deployment end of the system, helping to keep the cover even (Figure 5). The spokes would be aligned with holes along the sides of a cover. As the cover moves, the spinning spokes release the cover at the same pace at both ends of the cover, preventing them from becoming crooked upon deployment. They can do nothing once the cover leaves the encasement.

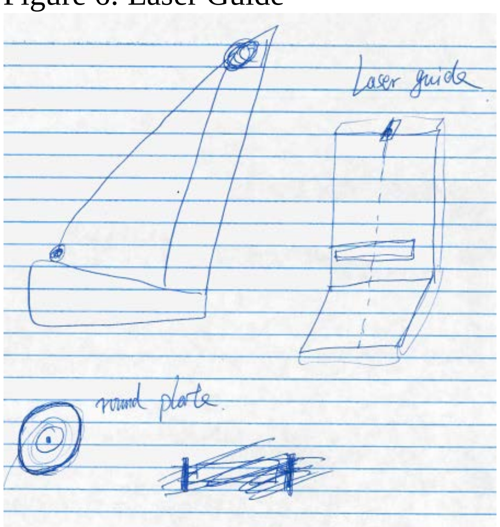
Figure 5: Staple Cover



Laser Guide

This idea is also a control design, albeit this one is more of an active control whereas the previously mentioned Staple Cover is a passive one. The Laser Guide works by using a laser to project straight line down the center of the seat (Figure 6). A sensor will be mounted on a cover and will constantly be seeking to keep the laser within its sights. If it loses the laser it will adjust how the cover is being moved, left or right accordingly so that the cover both extends and retracts correctly aligned with the retracting spool.

Figure 6: Laser Guide



CONCEPT SELECTION

This section details our process for determining which concept(s) are feasible and 'better' than others, ultimately ending with the final design concept chosen to pursue and refine.

The first step was to run a technological readiness, go, no-go, and feasibility analysis on all of our concepts to both start the iteration process and weed out those ideas that will simply not work. The results of our analysis are shown below in Table 6.

Table 6: Initial Concept Readiness and Iteration

Concept/ Revision	**Specs**	**Tech**	**Feas**	**Explanation**	**Go/No Go?**
Separate Seat Cover Retraction	Y	Y	Y		Go
Party Horn	Y	Y	Y		Go
Memory Metal	Y	Y	N	It's a lab-level material	No Go
Spring Roll Retraction	N	Y	Y	Not automatic system	No Go
Motor Roll Retraction	Y	Y	Y		Go
Inflatable Cover	Y	Y	Y		Go
Projection cover	Y	Y	N	Low durability and retraction is an issue	No Go
Staple Cover retraction	Y	Y	Y		Go
Accelerator sensor	Y	Y	Y		Go
Round Plate over spindle	Y	Y	Y		Go
Light Sensor	Y	Y	Y		Go
Roller Runner	Y	Y	Y		Go
Track Guided	Y	Y	Y		Go
Automatic shrinkable antenna retraction	Y	Y	Y		Go
Magnet guide	Y	Y	Y		Go
Magnet holder	Y	Y	Y		Go
Laser Guidance	Y	Y	Y		Go
Cover Pump	Y	Y	N	Durability and retraction not good	No Go
Waterfall	Y	Y	N	Water is an issue	No Go
Cold air seat cover	N	Y	Y	Drawing too much power	No Go
Light cover with air blow	Y	Y	Y		Go
Roof retraction cover	N	Y	Y	Not fit into the seat	No Go
Automatic sun shade	N	Y	Y	Not fit into the seat	No Go
Hollow shield glass	N	Y	Y	Not fit into the seat	No Go
Polyvision glass	N	Y	Y	Not fit into the seat	No Go
Bottom up track system	Y	Y	Y		Go
Up & shield	Y	Y	N	Iteration issues	No Go
Up & down	Y	Y	Y		Go

Concept/ Revision	**Specs**	**Tech**	**Feas**	**Explanation**	**Go/No Go?**
Antenna from bottom	Y	Y	Y		Go
Umbrella	Y	Y	N	Not fit into the seat	No Go
Ropes to side	Y	Y	Y		Go
Mini umbrellas	Y	Y	N	automatic is an issue	No Go
Side umbrella	Y	Y	Y		Go

From this initial screening we developed three Pugh charts that the individuals of the team would use to personally evaluate every 'Go' design from the technological feasibility review above. The weights and criteria incorporated into those Pugh charts are detailed below in Table 7 and Table 8.

Table 7: Pugh Chart Selection Criteria for Thermal Loading Prevention

Thermal Loading Prevention		
Selection Criteria		Weight
Low Thermal Loading	Minimize thermal loading	15
No Negative Comfort Impact	Doesn't negatively affect previous comfort	10
Max Area Blockage	Maximize the cooling area	5
Uniform Surface Cooling	Keep seat surface the same temperature	10
Durability	Long lifetime	10
Automatic Deployment	Minimize Human Input	10
Low Power Draw	Consume low power	5
Within the seat volume	Can be stored within or attached to the seat	5
No Damage after Installation	Doesn't put additional wear on the seat surface	7.5
Cost	Low manufacturing cost	5
Manufacturability	Easily applied to seat given current manufacturing methods	7.5
Retraction Time	Small time to retract	10
Total		100

Table 8: Pugh Chart Selection Criteria for Control

Control		
Selection Criteria		Weight
No Negative Comfort Impact	Doesn't negatively affect previous comfort level	10
Durability	Long Lifetime	20
Repeatability	Works in a consistent manor	20
Low Power Draw	Consume < 500J per cycle	5
Within Seat Volume	Can be stored within or attached to the seat	5
No Damage After Installation	Doesn't put additional wear on the seat surface	10
Cost	Low manufacturing cost	5
Self-Adjustment	Corrects alignment or prevents system from getting misaligned	10
Retraction Time	Small time to retract	15
Total		100

Using the garnered results each member of the team developed 2 unique designs that they believed would satisfy all of the requirements. Once all this was completed, we came back together to see what each person developed. All comprehensive designs are detailed in Appendix A-2. These designs were put into another Pugh chart and compared using the weights shown in Table 9 below.

Table 9: Selection Criteria for Individual Comprehensive Designs

Selection Criteria	Weight
Solar Radiation Blockage	14
No Negative Comfort Impact	7
Max Area Blockage	5
Uniform Surface Temp.	2
Durability	7
Repeatability	7
Automatic Deployment	14
Low Power Draw	5
Within the seat volume	5
No Damage after Installation	7
Self-Adjustment	5
Manufacturability	7
Cost	5
Retraction Time	10
Total	100

In Table 10 and Table 11 below the results from the team Pugh chart evaluation are summarized, with the top five winners being more detailed further below. Note: only seven designs are shown in the tables below because several comprehensive designs featured all of the same concepts and would have score the same in the Pugh chart.

Table 10: Design Concepts

Design #	**Concept**	**Score**
1	Roller runner, staple cover, round plate	300
2	Drawer slide, roller, motor	324
3	Antenna Guide, Motor	305
4	Antenna, cover extended by antenna	336
5	Side Rope	307
6	Light cover with air flow	288
7	Roller Runner, Round plate, light sensor	302

Table 11: Team Pugh Chart Evaluation Results

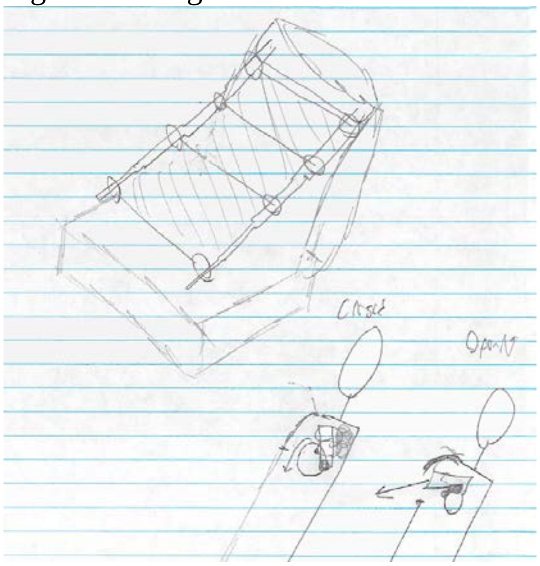
Selection Criteria		**1**		**2**		**3**		**4**		**5**		**6**		**7**	
	Weight	Rate	Weight	Rate	Weight	Rate	Weight	Rate	Weight	Rate	Weight	Rate	Weight	Rate	Weight
Keep Seat Cool	14	3	42	3	42	3	42	3	42	3	42	3	42	3	42
No Negative Comfort Impact	7	3	21	3	21	3	21	3	21	3	21	3	21	3	21
Max Area Cooled	5	3	15	3	15	3	15	3	15	3	15	3	15	3	15
Uniform Surface Cooling	2	3	6	3	6	3	6	3	6	3	6	3	6	3	6
Durability	7	3	21	4	28	3	21	4	28	2	14	3	21	3	21
Repeatability	7	3	21	4	28	2	14	4	28	4	28	1	7	4	28
Automatic Deployment	14	3	42	3	42	3	42	3	42	3	42	3	42	3	42
Low Power Draw	5	3	15	3	15	4	20	4	20	4	20	2	10	2	10
Within the seat volume	5	3	15	3	15	3	15	3	15	1	5	3	15	3	15
No Damage to the seat after Installation	7	3	21	4	28	4	28	4	28	4	28	4	28	3	21
Self-Adjustment	5	3	15	3	15	3	15	3	15	3	15	3	15	4	20
Manufacturability	7	3	21	2	14	3	21	3	21	2	14	3	21	3	21
Cost	5	3	15	3	15	3	15	3	15	3	15	3	15	1	5
Retraction Time	10	3	30	4	40	3	30	4	40	3	30	3	30	3	30
Total	100														
Total Score	500	**300**		**324**		**305**		**336**		295		288		**297**	
Rank		4		2		3		1		6		7		5	

From the concepts our team had generated, the clear winner was some sort of antenna design because the top three designs use an antenna concept somewhere within it. The runner up idea was our roller runner concept which came in fourth, fifth, and seventh. The only other concept that was included in the comprehensive design was a rope guide and this came in 6^{th}. Shown below is each of the top five concepts in further detail accompanied with sketches to provide a visual reference.

Design 4

The winning design (Design 4) shown in Figure 7 below utilizes what we are terming antenna retraction. Antenna retraction is similar to the antennas on older portable radios or to the extension of toy light sabers. This allows there to be a track for the cover to extend on that can then retract in on itself and take up comparatively little space. This design would have the antenna guides sit inside the shoulder rest. When the system is activated, they would be motor driven to rise up and angle down to cover the seat diagonally (from the upper back to the front bottom of the cushion). The cover would be attached to the tops of the antenna with guide loops going around the rest of the antenna to allow for easy extension and retraction of the cover.

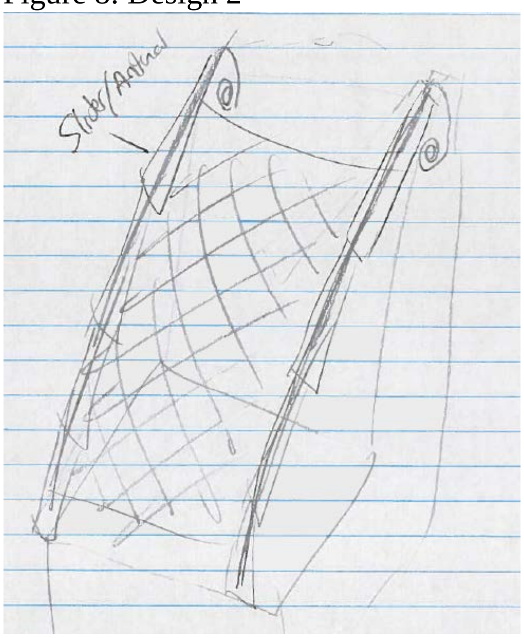
Figure 7: Design 4



Design 2

In second place, also with a form of antenna retraction is Design 2 (Figure 8). Rather than being strictly antennas, this would be more like the rollers in drawers. They can still be extended to a great length compared to the relatively short storage length. They would also use a motor to raise and rotate it into position. The drawer sliders would rely on gravity to move out to length, but then would be pulled back up with a rope or cord before the motor once again rotated it back into a storage position.

Figure 8: Design 2



Design 3

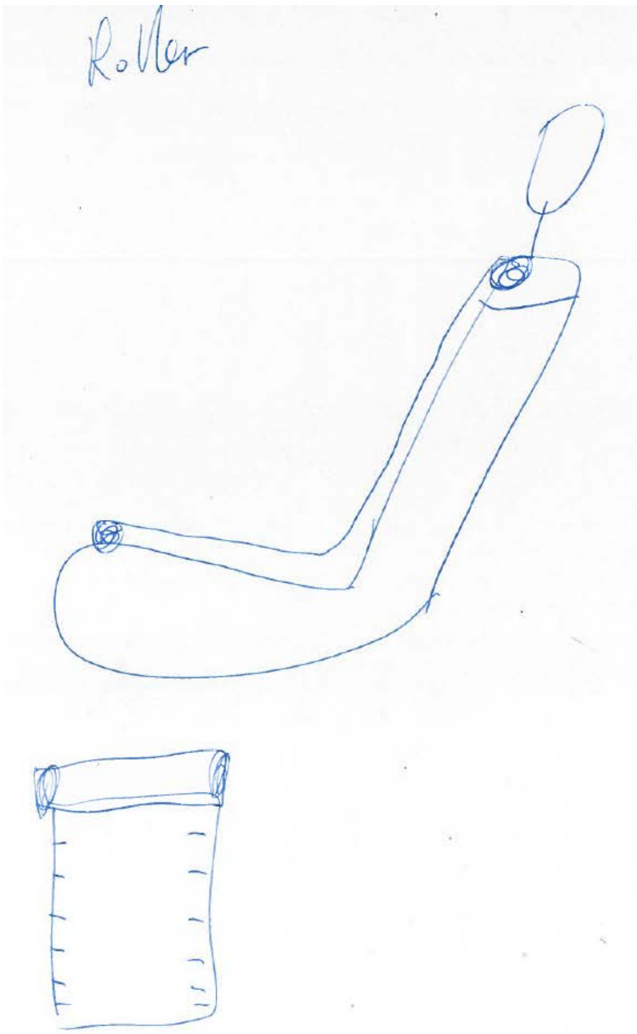
Design 3 (Figure 9), the third place finisher and another antenna concept, is very comparable to Design 4. The only difference being how it expands and retracts. Initially the antennas would extend out to position. Afterwards, powered by a separate motor, the cover would slide down the guide antennas into its fully deployed position.

Figure 9: Design 3

Design 1

The fourth place finisher, Design 1 (Figure 10), is different from the three design raking higher than it on our team Pugh chart. This is also stored in the shoulder area of the seat, but it uses a different technique to extend out the reflective cover. This uses wheels attached to two motors on one end of the cover to drive the design down the backrest and up the slight incline on the cushion. When it goes back into storage, there will be a motor driving the spindle for the cover to wrap around. To guide the cover in, there will be spokes on either end that correspond with holes in the side of the cover.

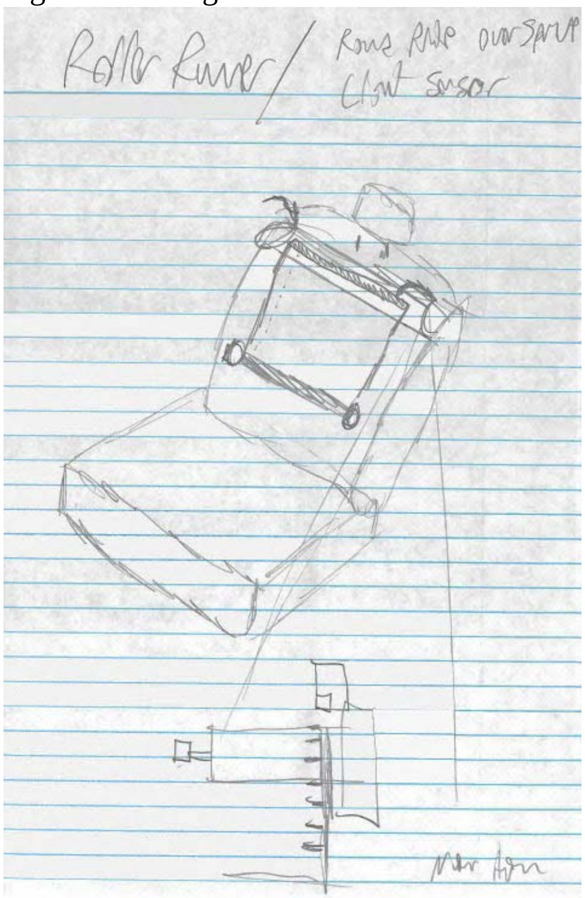
Figure 10: Design 1



Design 7

The fifth place finisher is very similar to Design 1. Instead of using spokes to guide the cover upon retraction, Design 7 uses a laser to draw a straight line down the center of the seat. A sensor at the front of the cover will follow this line by adjusting the two wheels driving the cover out (Figure 11).

Figure 11: Design 7

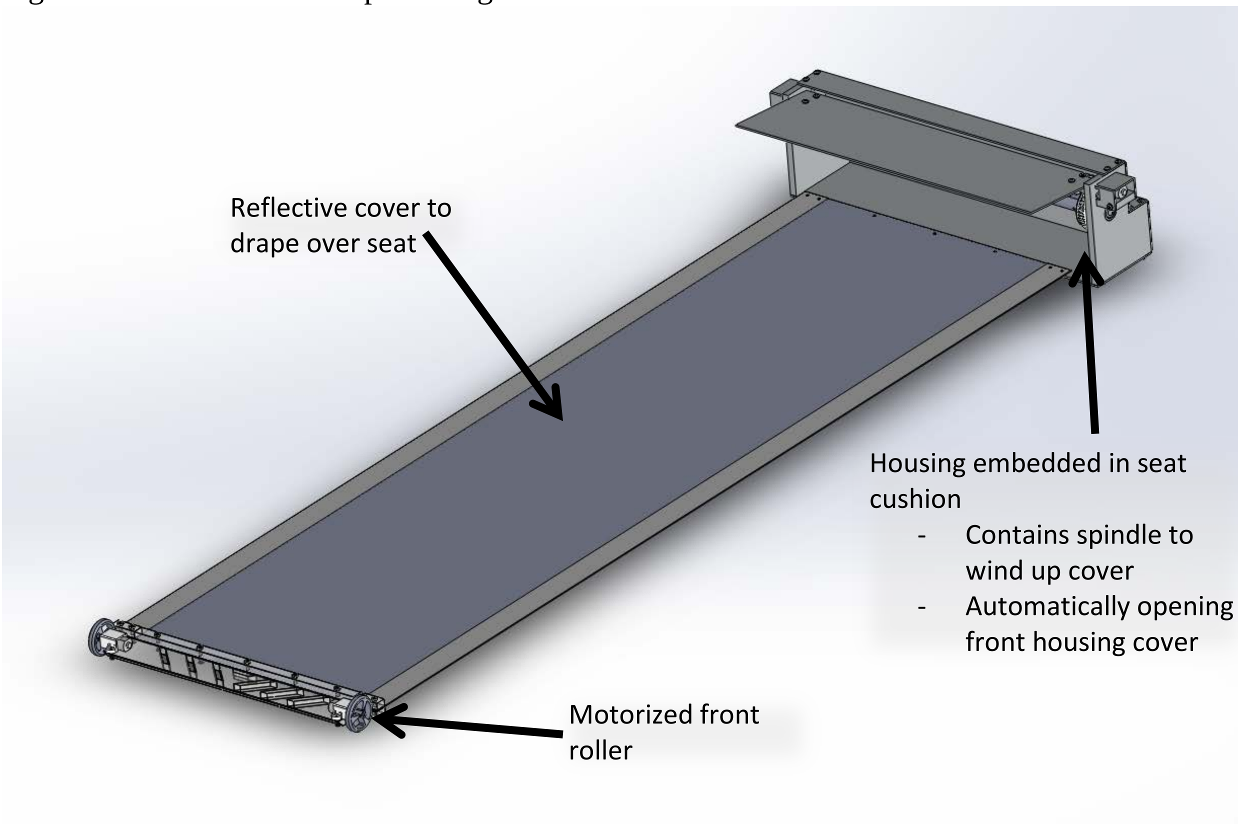


Selection and Progression

After this initial analysis we decided to move forward with the extending antennae design and began to look into the most important aspect of that design, the automatic antennae mechanism itself. After many searches and explorations into custom construction we determined that the linear telescoping extension mechanisms would either be too expensive or too large for our design needs. This prompted us to have to leave that design and move forward on the 2^{nd} best design we determined from Table 10 above.

This second best design was the ‘Roller Runner concept’ which consisted of creating a front rolling ‘robot’ of sorts, which would automatically roll down the backrest and up the cushion of the seat, dragging a reflective cover. This would have allowed the seat to be automatically covered and retracted via a similar method, albeit in reverse. We moved forward and created an Alpha Design from this concept as pictured below in Figure 12.

Figure 12: Roller Runner Alpha Design



After presenting this design and reflecting on the current direction various concerns concerning the roller runner design were voiced, not the least of which was the issue of repeatability and keeping the runner straight, as well as the speed of retraction. After further discussion as a team and with our supervisor (Krauss, Professor, 2012) we decided to seriously reconsider the current direction. We engaged another slight brainstorming session as to other possible ideas/concepts that have not been considered and the idea for a 'scissor' mechanism surfaced. This concept was lightly explored, sketches and concept CAD drawn, and after deliberation and a rough pro/con sheet made up we decided as a team that the repeatability and speed of this design would be far better than the current roller runner while not being affected by any large negatives. A full CAD design, engineering analysis, and part sourcing was then pursued.

Why the Scissor Mechanism was Chosen

There were several reasons we chose the 'scissor' mechanism design (Xtendr) as being our final and best design. As stated above the repeatability of this system, since it is on a standard path that is limited by rigid joints, is far superior to the roller runner design, that coupled with the scissor mechanism itself means it is more compact in the horizontal direction than the original antennae system would have been, making it more practical to use in the confined environment of the seat.

Cost was also another large driving factor. The antennae system was largely ruled out for both size and cost, and the roller runner was slate to use four motors, a large jump in cost compared to the Xtendr's one motor. Furthermore if a dynamic control system would have ended up being needed in the Roller Runner then this difference in cost would have only been magnified.

Finally, simplicity, the Xtendr design seemed to be the simplest of the Antenna and Roller Runner designs. Thus a quicker manufacturing process and shorter troubleshooting timeframe. For the Antennae system would have required a linkage inside the seat to allow the antennae to store vertically and then move to a horizontal position, and the Roller Runner design was to employ four motors, two of which would have likely been dynamically controlled. The Xtendr, however was to employ three (originally four) similar 'X' based linkages controlled by one motor, so that the most complicated portion was in how to make the joints and reduce friction.

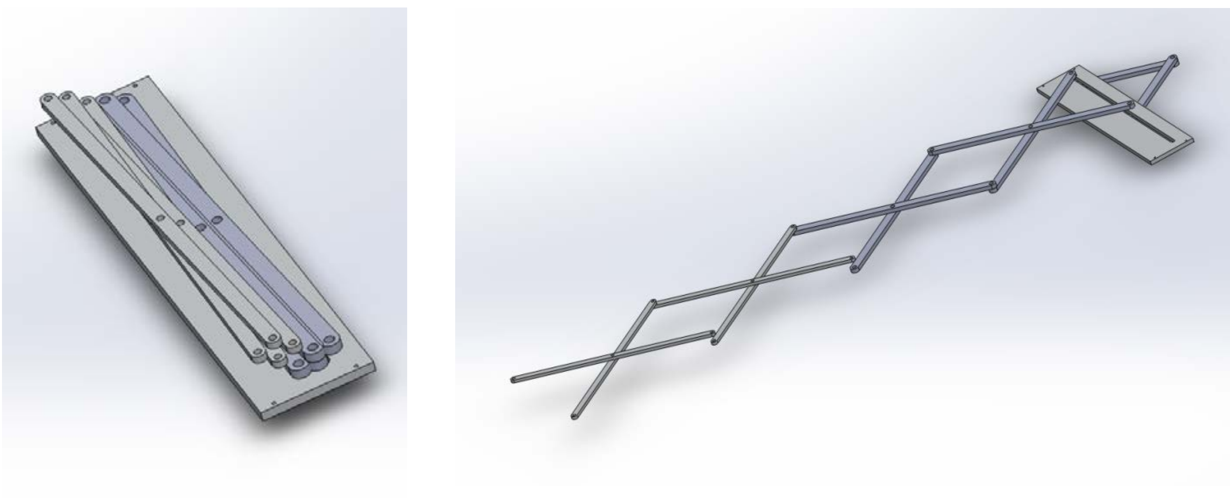
These factors combined to make our decision rather clear. And so after several design switches the Xtendr was the final design concept chosen and pursued.

CONCEPT DESCRIPTION

This section will detail the original final Xtendr concept and initial alpha prototype design. Due to the large time constraint we faced, having suffered a large scope change and this large design concept change, we never formally had an 'Alpha Prototype' of the Xtendr design concept. Rather we had improving versions and so the first largely completed version will be taken as the 'Alpha Prototype' model and looked at in a bit more detail.

Below in Figure 13 the original proof of concept CAD model was developed. It allowed us to visualize the scissor extension concept and begin to look into what problems will be encountered and how to overcome them through good design.

Figure 13: Xtendr Concept in Retracted and Extended Positions Respectively



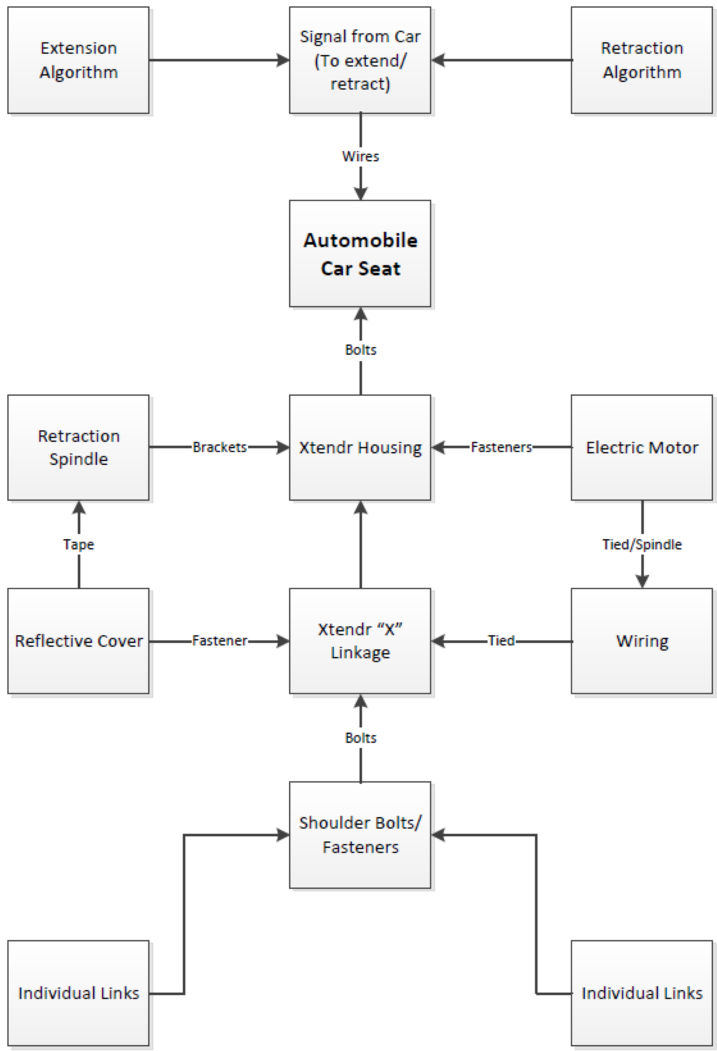
It can be seen above that the mechanism overall length is dictated by the angle of the links with respect to each other (within a single 'X' system). So that when the 'X's look more like two parallel lines the extended length is very short (as shown in the left picture of Figure 13 above). Then as the angle increases and as the two links connected to the baseplate move away from each other the link extends and the overall length increases drastically (as shown in the right picture of Figure 13 above).

With the extension a reflective cover, which would have originally been stored inside the seat would be pulled out and held over the seat via the above displayed scissor linkage mechanism. In like kind the cover and linkage would be brought back into the seat via an extension of the back most bolts.

Concept Layout

There are a number of subsystems that work to make the whole concept of the Xtendr a possibility. They are shown in the layout drawing below in Figure 14.

Figure 14: Layout Drawing of Xtendr Subsystems



To draw attention to the main subsystems it should be shown that the Xtendr housing holds all the necessary physical components to make the Xtendr work. While the signal to extend or retract come from the car and its programing in response to the environment. The linkage attaches to the housing via shoulder bolts. Those shoulder bolts also act as the connection point for the wiring which then connects to the wiring spindle which is connected to the motor and in that way through winding up or releasing the wire the whole mechanism is either extended or retracted.

The reflective cover itself is attached to the linkage via a leading rigid plate which is then connected to the front most point of the linkage via a screw and nut. The other end of the cover is wrapped around a spindle with a torsional spring and directly connected via a strand of tape. In this way the cover always has tension on it and therefore is held straight and does not get caught in the linkage when being retracted.

PARAMETER ANALYSIS

After we had finalized our design concept, we began to perform a detailed engineering analysis. Our analysis is based on the Xtendr final design and the information learned from this analysis below will be put towards further development of this design. We came up with the necessary equations fundamental to the design functions. Using these equations and further analysis, we verified our system size, material used, motor chosen along with other design components. We focused on the key factors affecting the principles of the overall design. Other more basic material choices, such as housing and linkage material, will not be focused on here, for they were chosen based upon machinability and ease of working with standard sized hardware. A final consumer ready design would undergo more detailed material analysis and optimization (The actual Matlab code used to calculate the following conclusions can be found in Appendix E).

Spindle Diameter and Cover Thickness

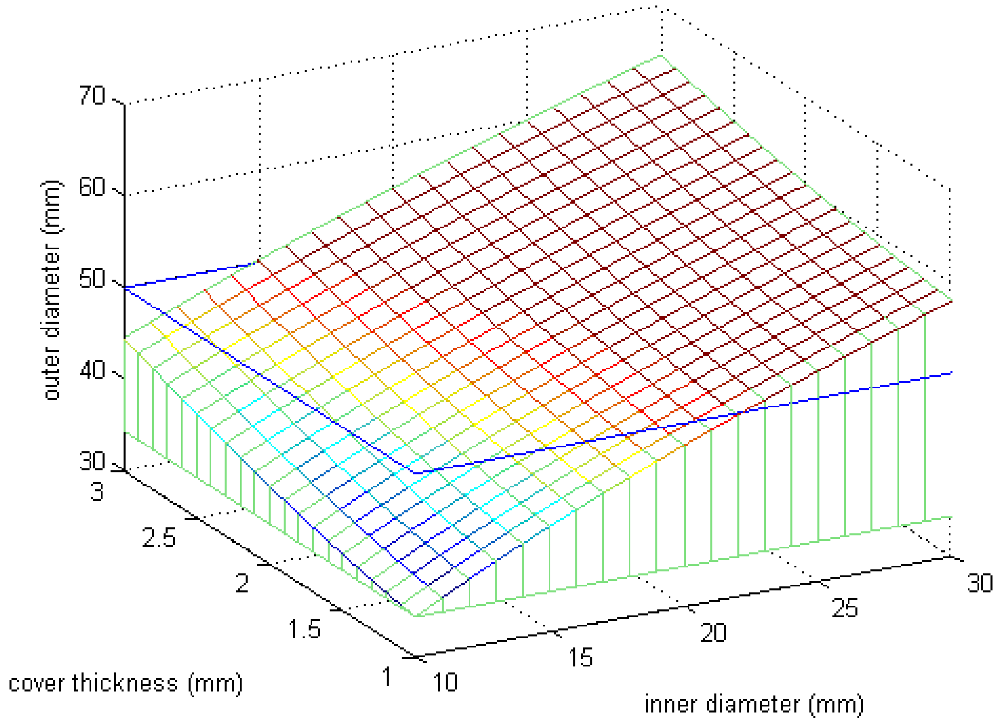
We began by determining how much space we had to work with inside the shoulder area of the car seat and found that the open area was approximately $330 \times 55 \times 100$ mm cuboid. Our design consists of rolling the reflective cover on a spindle inside the seat, therefore it's important for us to know the dimension of our spindle with relation to cover thickness. The maximum available to use depth is only 55 mm, so our final retraction spindle diameter must be less than that. The rolled up diameter relation is defined below in Equation 1.

$$\boldsymbol{L \cdot t = \pi \cdot (D^2 - d^2)/4} \qquad \text{(Equation 1)}$$

Where 'L' is the length of the whole cover, 't' is the thickness of the cover, 'D' is the final outer diameter after retraction and 'd' is the outer diameter of the spindle. Based on this equation, we used Matlab to figure out at what range the spindle would be safely within the 55mm depth limit.

As shown in Figure 15 below, we checked the cover thickness from 1 mm to 3 mm, spindle diameter from 10 mm to 30 mm and the resulted outer diameter is shown as a mesh in 3D. We don't want our design to be exactly at the limit point, so we added some clearance and found that when the spindle diameter is around 20 mm and the cover thickness is less than 2 mm, the final outer diameter will be about 50 mm. Since the purchased retracting cover is approximately 20 mm in diameter the largest thickness the reflective cover can be is 2 mm.

Figure 15: Relationship Among Final Outer Diameter, Inner Diameter and Cover Thickness



Cover Analysis

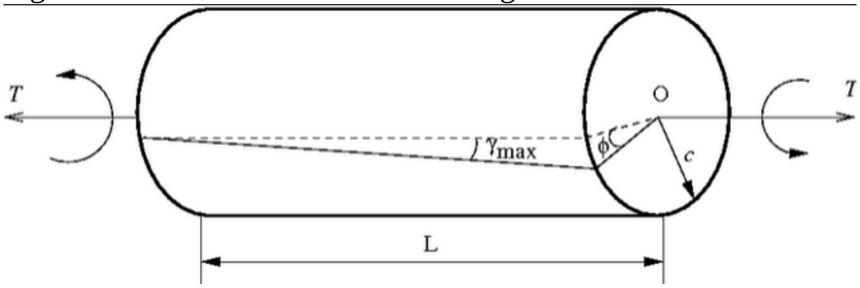
The cover in our design is of great importance. It should be flexible enough to roll over around the spindle when collected but thick enough to reflect more than 95% of the solar radiation, thin enough to fit in the given space, and light enough to meet our total system weight requirement. By considering all these factors and researching the existing product, we found a cover material that could be used in our design. It is Temptrol® Heat Reflecting Fabric supplied by Innovative Insulation Inc. It has 95% reflectivity, 0.28 mm (10.9 mils) thickness, and 84.5g/m^2 (17.3 lb/Msf) density, which satisfied all our requirements.

Spindle Rigidity Analysis

The spindle in our design is about 30 cm long and has a relatively small diameter, so it's important for us to consider the rigidity of the material we will be using. We will focus on the deflection angle throughout the spindle under the torque generated by the motor to collect the cover. The deflection angle equation for a tube is defined in Equation 2 and Figure 16.

$$\boldsymbol{\theta = \frac{TL}{JG}} \qquad \text{(Equation 2)}$$

Figure 16: Definition of Deflection Angle

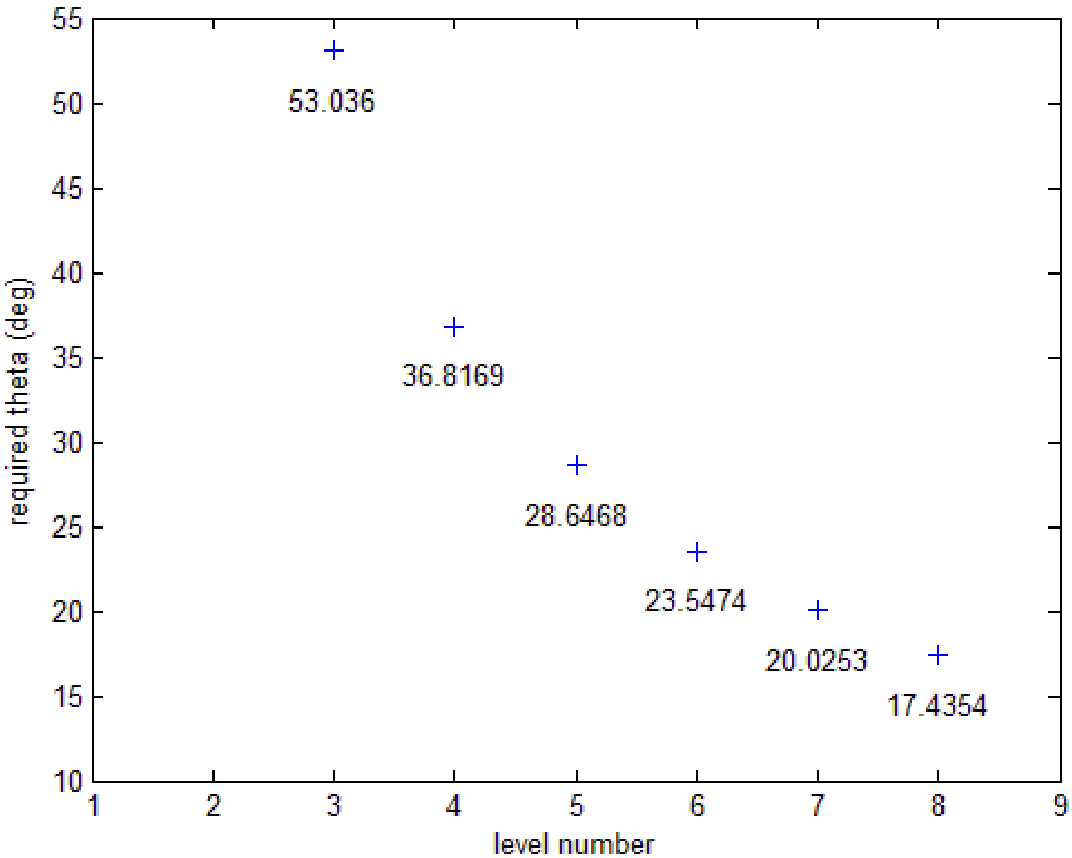


Where 'θ' the angle deflection, 'T' the applied torque, 'L' the tube length, 'J' the moment of inertia of the tube, 'G' the shear modulus of the material. Since we want to avoid a large deflection throughout the spindle, we assumed the deflection at the outer diameter of the spindle should be less than 1 mm, The 1 mm deflection at the outer diameter resulted in a 3.6° angel deflection of the spindle. From Equation 2, we calculated that the shear modulus of the material should be larger than $42.1\ MPa$.

X-Structure Analysis

Since we had limited space in the seat from which to place our entire system, we needed to balance the extended length with the compacted length. This meant that there would be a balance between the number of 'scissor' 'X's employed, since with each additional 'X' the overall extension length would increase, while the minimized retraction length would also increase. We sought to demonstrate this relationship with a function shown below in Figure 17. The number of 'X's employed is to be known as 'Level Number' so that a level number of 2 means 2 'X's are in use. The required final angle of the linkage is in reference to the final angle between the two bars in any given 'X' needed to extend to the full 720mm.

Figure 17: Required Final Angle of the Linkage at Different Level Numbers

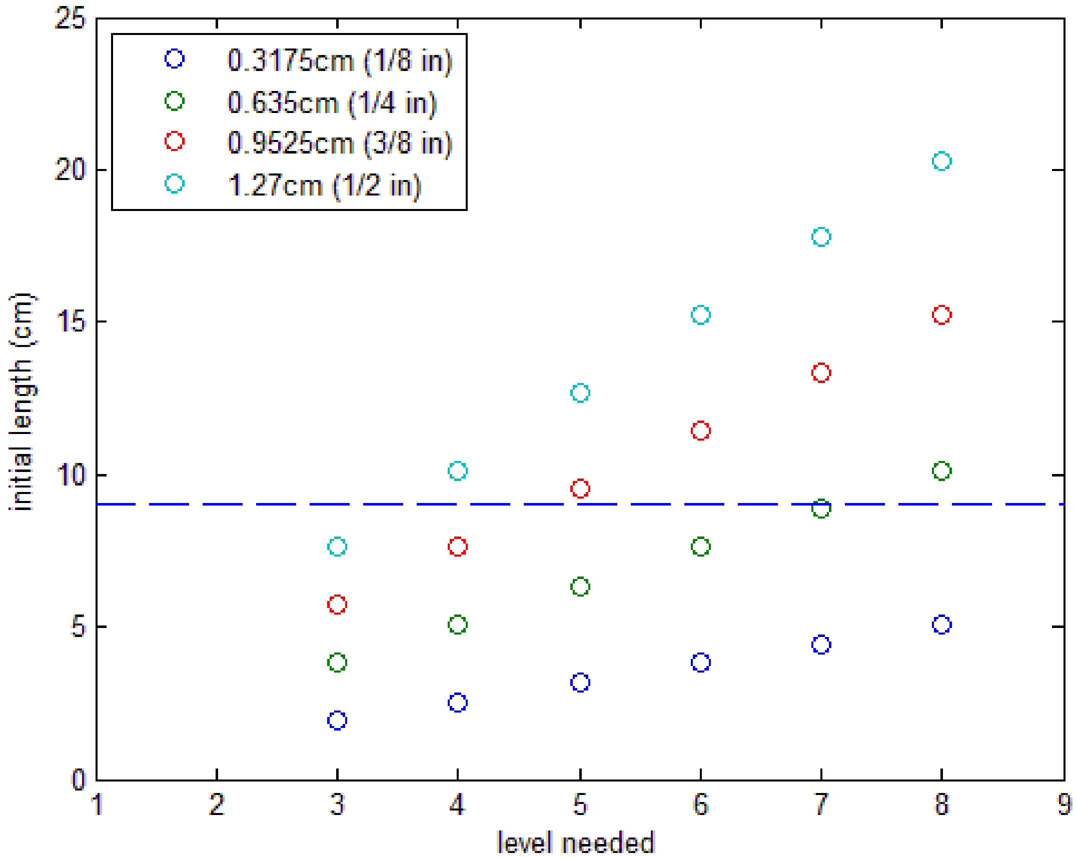


From Figure 17 above it can be seen that with the addition of more 'X's the final required angle decreases, for every 'X' in the setup would need to extend less since there are more extending. It is important that we understand this relationship for it affects the overall weight of the system and the moment forces on the linkages as the level number increases.

This also means that with the lower level numbers there is a larger angle required, which means our motor would need to run a longer time in order to move the linkage through that larger angle for both the deployment and retraction motion. However, the larger final angle would reduce the force required to move the linkage through its full angle of motion. This is because there is a constant retraction force being exerted on the mechanism from the reflective cover, and due to a higher final angle in the mechanism, the motor would need a smaller torque to move the linkage to its final extension point. Therefore, a balancing act of the smallest level number which the motor can still fully retract in under 8 seconds should be chosen.

Another limit is the depth of space when fully retracted. We have approximately 9.5 cm in depth for the linkage mechanism to fit in when retracted. Due to allowable width and strength requirements, we should must again choose the appropriate level number and bar width, this relationship is detailed below in Figure 18. From this figure we can see that with larger width a lower level number is allowed, for the 9.5 cm is the cut-off dashed line. From this analysis we determined that a 3-4 ‘X’ type linkage with possibly narrowing linkages would be a safe design to proceed with.

Figure 18: Initial Length (Depth) of Retracted Structure with Different Level Numbers and Widths

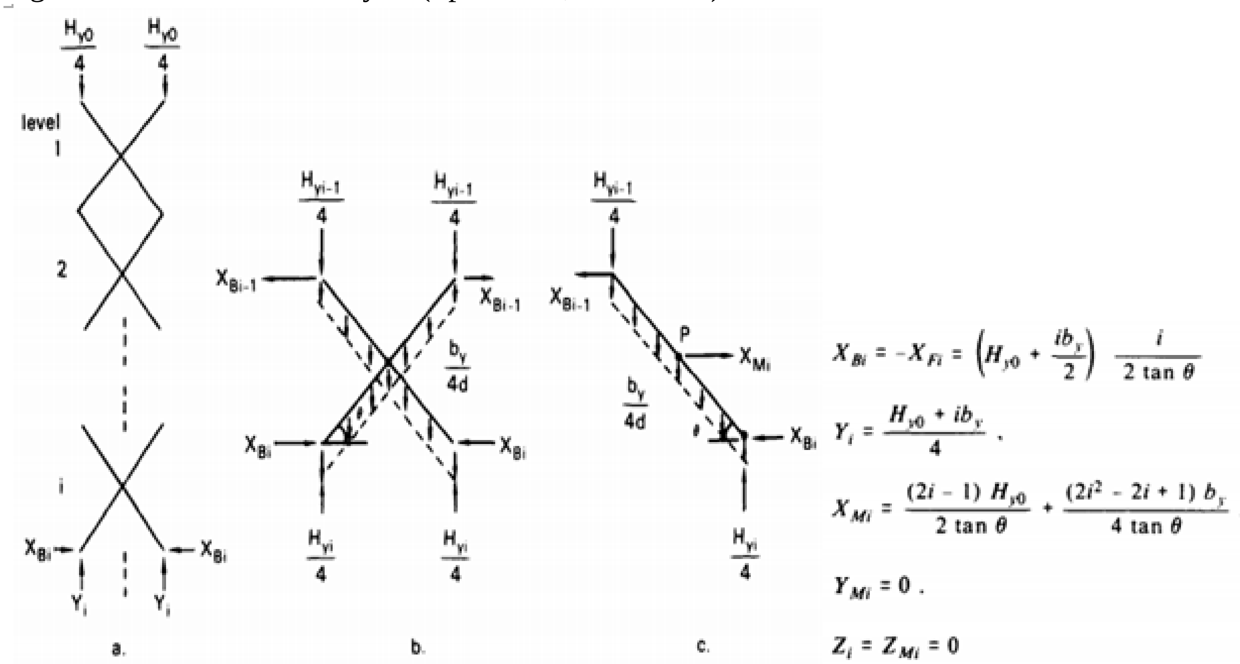


Motor Analysis

The motor is the driving power in our system for deployment and retraction. Since our design is using a scissor ‘X’ structure our motor is to pulling the line attached to the bolts at the end of the linkage perpendicular to the extending motion (See Figure 19 with regards to the ‘x’ direction motion for clarification on how the motor will move the scissor mechanism that it extends/retracts).

First, we tested the cover spindle to see what the largest force was at the end point of the fully extended position. The largest force from the cover was determined to be $31N$ $(7\ lbs)$ at a full extension of 850 mm. We used the scissor lifts analysis shown in Figure 19 below to determine the expected force on the motor.

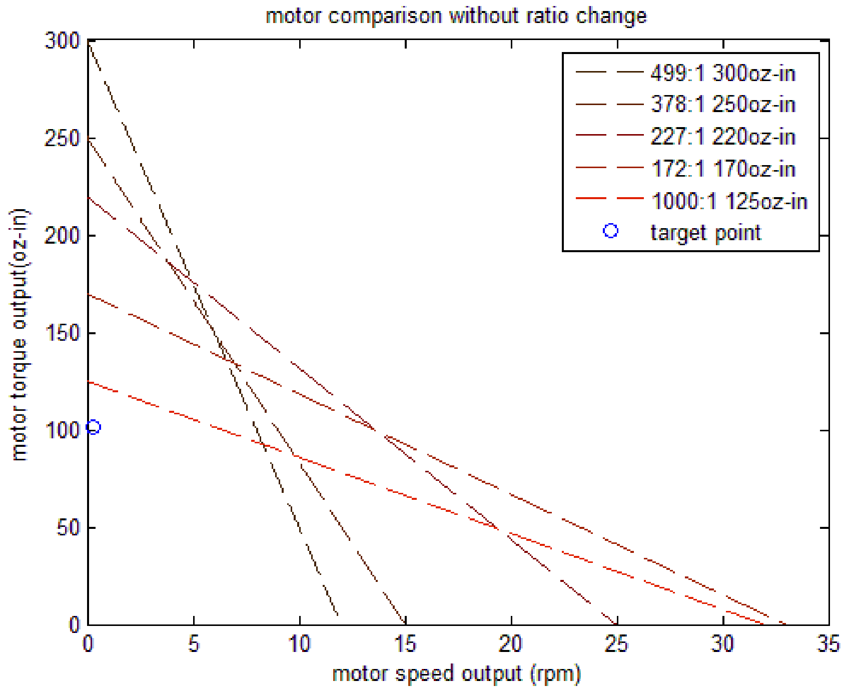
Figure 19: Scissor Lift Analysis (Spackman, June 1989)



Using these equations in Figure 19 we found the expected force at the linkage ends was to be approximately 71 N. We assumed the wire spindle attached to the motor would be approximately 1 cm in diameter and calculated the required maximum torque for the motor to move the linkage ends: $716\ N \cdot mm\ (101.4\ oz - in)$.

From previous analysis we determined that we wanted to choose the lowest level number possible, therefore the bolts would move about 5 cm each. So the RPM for the motor should be 0.26 rpm when considering the time of retraction is to be 6 sec (2 seconds less than the required 8 seconds for some safety factor allowances). Inserting this required point into the speed/torque motor curves we could see how the various motor sizes aligned with our estimated requirements shown below in Figure 20.

Figure 20: Motor Comparison Without Ratio Change



Since our calculation was ideal in that it didn't consider the friction in the joints nor the resistance due to beam bending, we decided to choose a motor with a larger stall torque than ideally calculated. It is also good practice to choose a motor with 2x the required stall torque for longer motor service life, so we decided to use the 300 oz-in 499:1 gear ratio motor from Pololu.

<u>Material and Manufacturing Process Selection (Appendix D-1)</u>

When it comes to selecting materials we learned that you have to have a very good understanding of the technical requirements of the material coming into the selection process or else it can be overwhelming with all of the different materials that are out there. What makes one material better than another? It all depends on what you are looking for in terms of Young's modulus, density, cost, conductivity, etc.

Similarly for manufacturing, it is very important that coming in you have an idea of the shape, roughness, or quantity among other criteria. The nice thing about manufacturing is that if the material has already been chosen, somewhat dictating the possible manufacturing processes.

<u>Design for Environmental Sustainability (Appendix D-2)</u>

SimaPro was a challenge to get started but was interesting once a basic understanding was developed. It is amazing how much detail there can be in quantifying emissions. Each of the plastics we analyzed were broken down to the most minute of details that was then broken up into waste, air, raw, and water emissions. We hadn't realized how much pollution is emitted from producing one simple part, although the program seemed to be biased towards emphasizing air pollution when we used the EI99 comparison method.

Design for Safety

It isn't enough to simply design for an application in an ideal scenario because life isn't idea. Product designers expect their products to withstand abuse and design a safety factor accordingly. It is very reassuring to know that devices that are operating in potentially dangerous applications have more than enough safety factored in to keep us safe even when things go wrong. On the other hand, as the designer, we are faced with the challenge of meeting all of the specifications times whatever factor of safety we have built in while still minimizing the usual factors such as cost and weight.

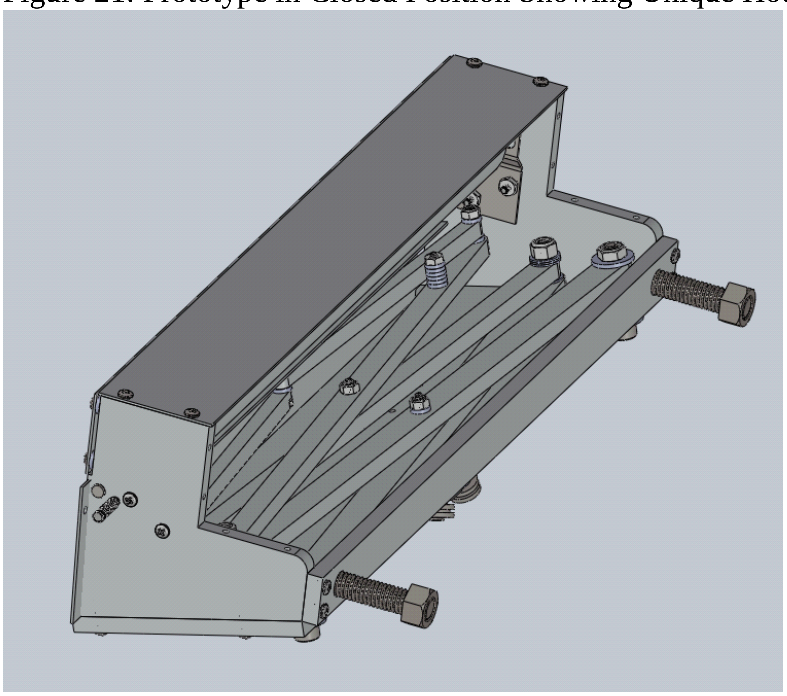
FINAL DESIGN

This section will detail the constructed prototype's design and operation, as well as discuss the differences between this present design and what we envision a mass-manufacturing, consumer ready, final design to be.

Prototype Design Description

The prototype was created to fit inside the upper 1/3 of the seat back rest. The mechanism housing was shaped in such a way that it would actually fit 'around' the internal seat frame. Thereby allowing us both maximum volume and full internal mounting of said housing (Figure 21 below shows the shape of the housing). It can also be seen in Figure 21 that the housing was mounted to the seat frame rails using two large rear bolts, thereby firmly securing the entire mechanism in the seat.

Figure 21: Prototype in Closed Position Showing Unique Housing Shape



The housing served several purposes. It protected the mechanism when in retracted position, mounted the entire mechanism to the seat, and most importantly provided a rigid platform from which the linkage, reflective cover spindle, and housing door could be readily mounted.

The linkage is connected to the base plate as shown in Figure 22, via two rear cut slots in which two low friction shoulder bolts slide. This sliding motion changes the angle of the two respective links connected to the slots thereby changing the angle of the rest of the links in the assembly and in like kind causes the overall mechanism to either extend or retract in overall length. The base plate also serves as the point of connection for the motor and wire pulleys as shown in Figure 23 below. The baseplate must be rigid so as to handle the forces generated from the extending link and the turning motor.

Figure 22: Baseplate and Linkage Mechanism

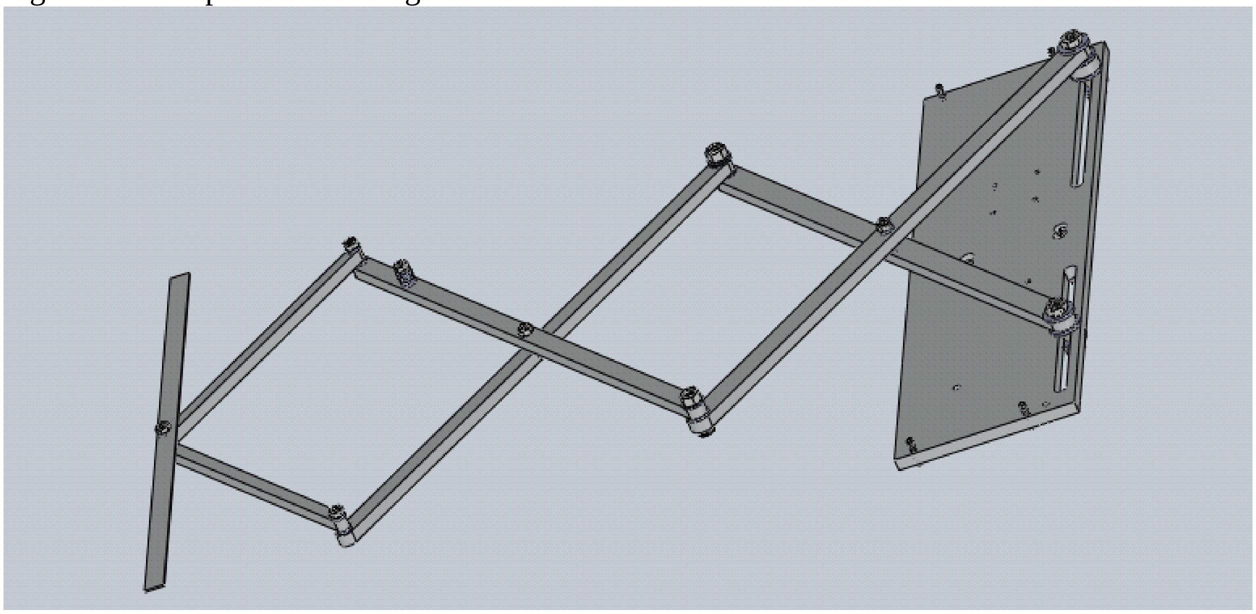
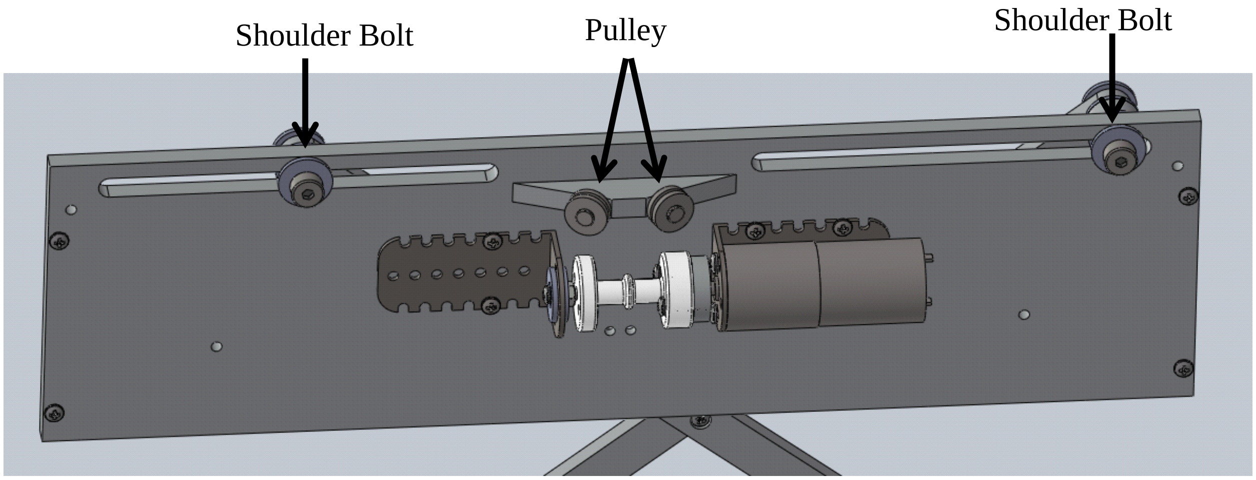


Figure 23: Baseplate Rear View Showing Motor and Pulley Connections

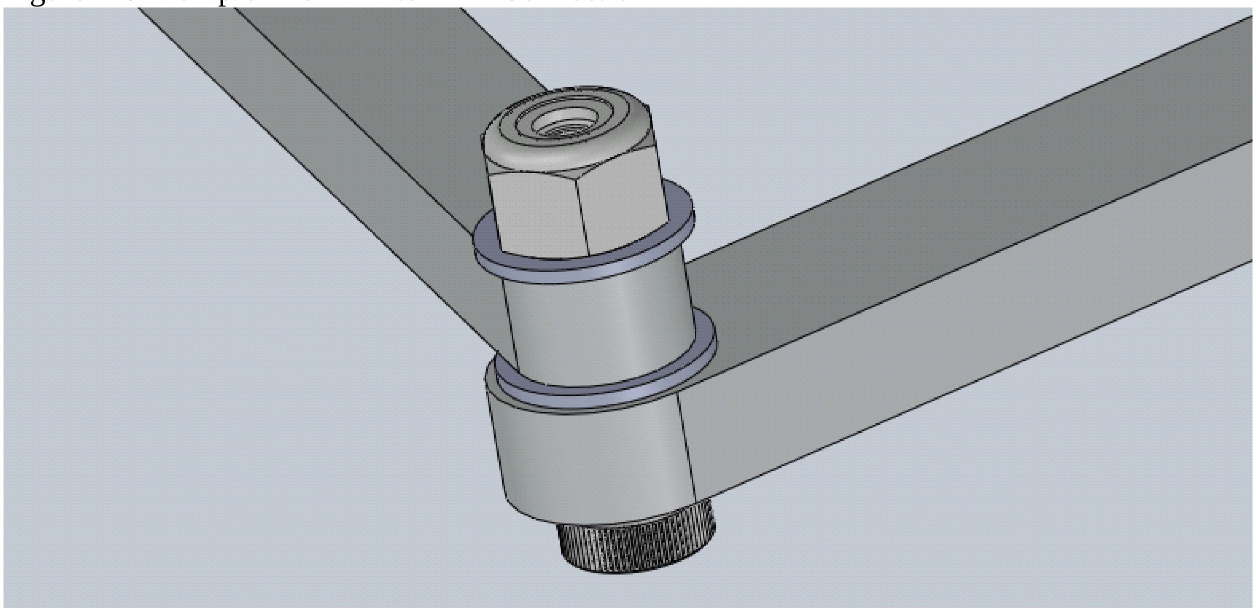


To expound on the motor driving mechanism shown in Figure 23 above it can be seen that the two shoulder bolts would be connected to the white motor spindle via wires run around the pulleys and wrapped around the white spindle, so that as the motor turns it would wind the wire around the spindle, thereby shortening the wire length and drawing the shoulder blots in towards the middle. This changes the linkage angle, extending the overall mechanism.

The spindle is supported via a motor hub and connected to the motor shaft and screwed into the spindle. The other side of the spindle is supported via a 'free to rotate' screw. This screw helps to minimize spindle deflections from the wire tension.

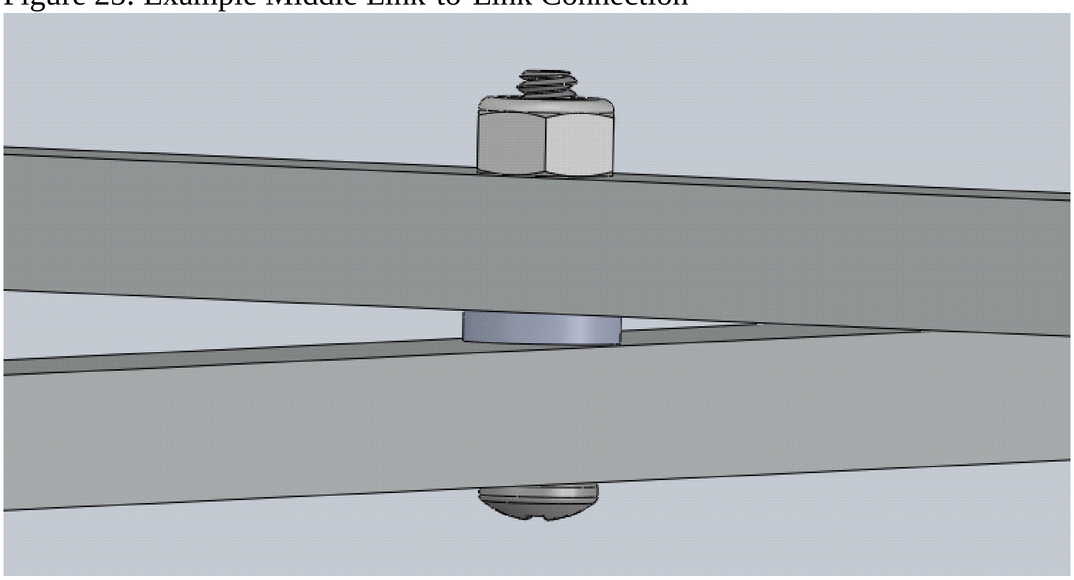
The baseplate-to-link connection consists of a two low friction shoulder bolts, once for each link, coupled with the appropriate washers and lock nut. The right link connection in Figure 23 above utilizes a large plastic spacer so as to provide clearance for the left link to fold in under it. The link-to-link connections, shown in Figure 24 below, use a similar principle. That being a shoulder bolt with appropriate washers and lock nut (Note, some of the links have counter bored holes so that the bolt head does not catch on other links nor the baseplate during its range of motion).

Figure 24: Example End Link-to-Link Connection



The middle of the links are also connected to one another, for this is what creates the 'scissor' mechanism. This connection consists of a thru hole drilled in both links, by which a 4-40 Screw is placed, washer in the middle and lock nut on top.

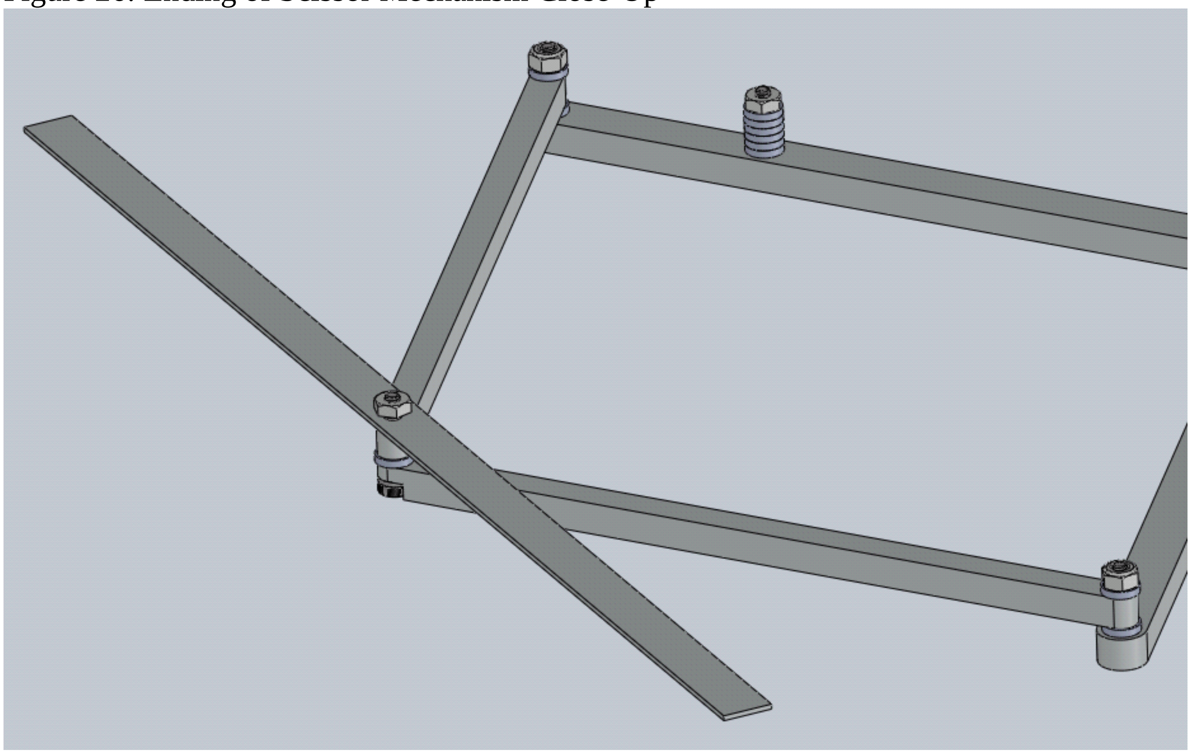
Figure 25: Example Middle Link-to-Link Connection



The final two links are merely half links, thereby ending the 'x' pattern at a single point. It is from this point that the leading edge of the reflective cover is connected (as shown in Figure 26 below). The means of connection consists of a thin aluminum rectangle with a center drilled hole. The reflective cover wraps around this aluminum rectangle and a hole is drilled out where the aluminum center drilled hole is, thus allowing the 4-40 Screw to fit through and have a nut attach to the end thus securing the reflective cover and still allowing to it stay parallel to the front edge of the housing through the rotating motion of the links.

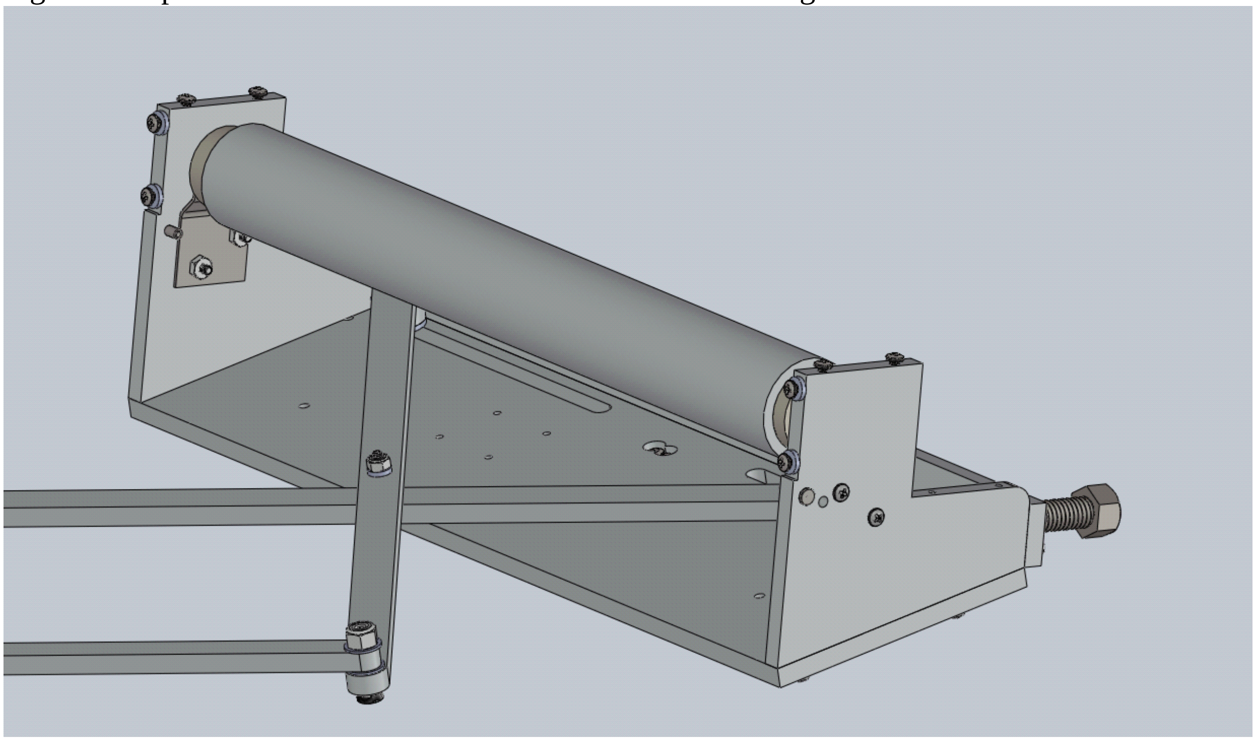
On the upper link in Figure 26 below one can see a stack of washers with a top nut. This stack prevents the front most half links from moving to be parallel with one another, thereby preventing any change point issues which could result from manufacturing imperfections.

Figure 26: Ending of Scissor Mechanism Close-Up



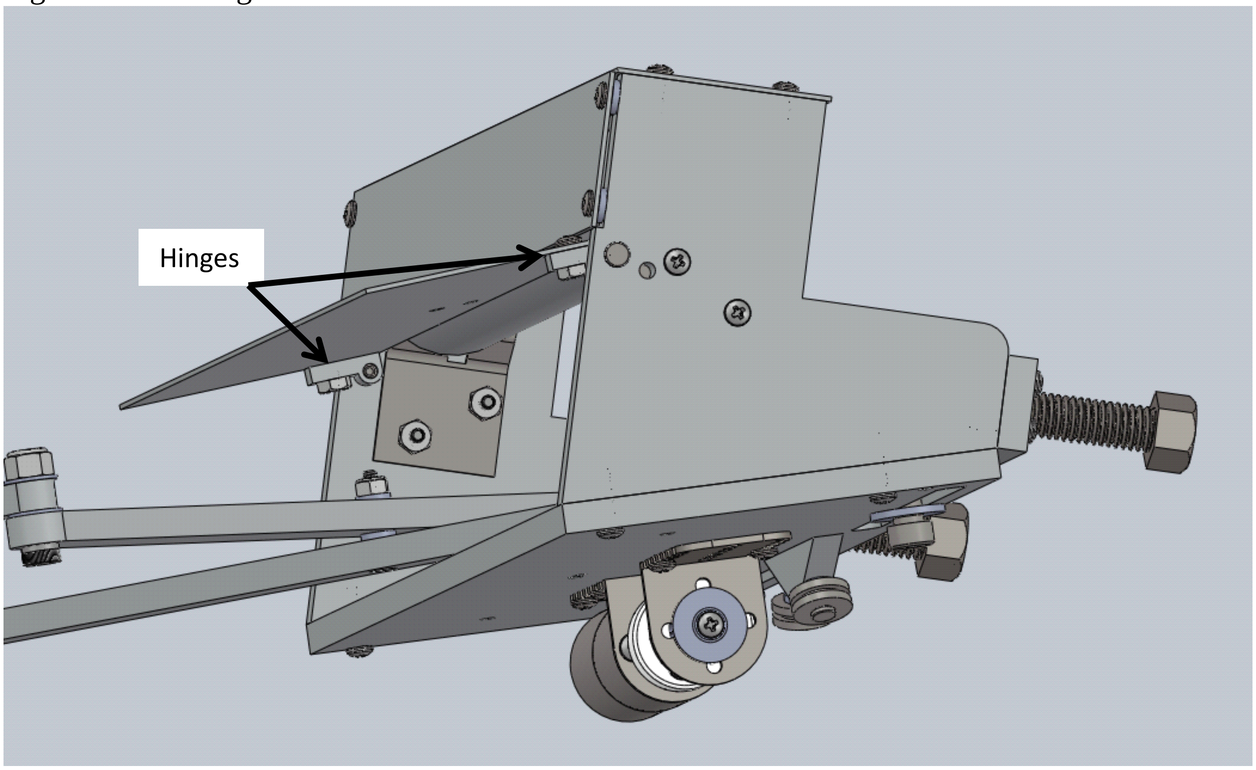
The side plates are screwed onto the baseplate and from there the spindle brackets are attached to the side plates (as shown in Figure 27 below). These brackets support the spindle with holds the reflective cover and internal torsional spring for automatic retraction and holding the cover taunt through the whole operation.

Figure 27: Spindle with Reflective Cover Mounted To Housing



The side plates also hold the housing cover (shown in Figure 28 below) via two small hinges. The cover is free to rotate about those two hinges and is pushed open by the leading edge of the cover during extension and drops closed under the force of gravity once the cover has fully retracted.

Figure 28: Housing Cover and Cover Plates Mounted



Thin aluminum sheets are then attached to the upper front and top most portions of the side plates as a means of protecting a stored mechanism from damage (see Figure 30 below). Figure 29 shows the fully assembled and fully extended prototype (excluding the reflective cover and connecting wires).

Figure 29: Fully Assembled and Extended CAD Prototype

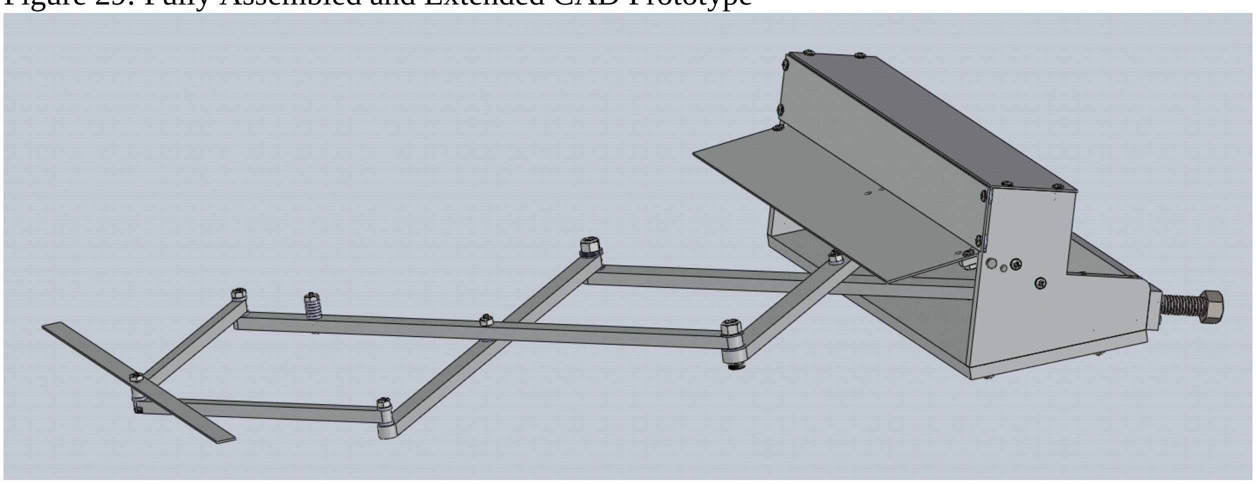
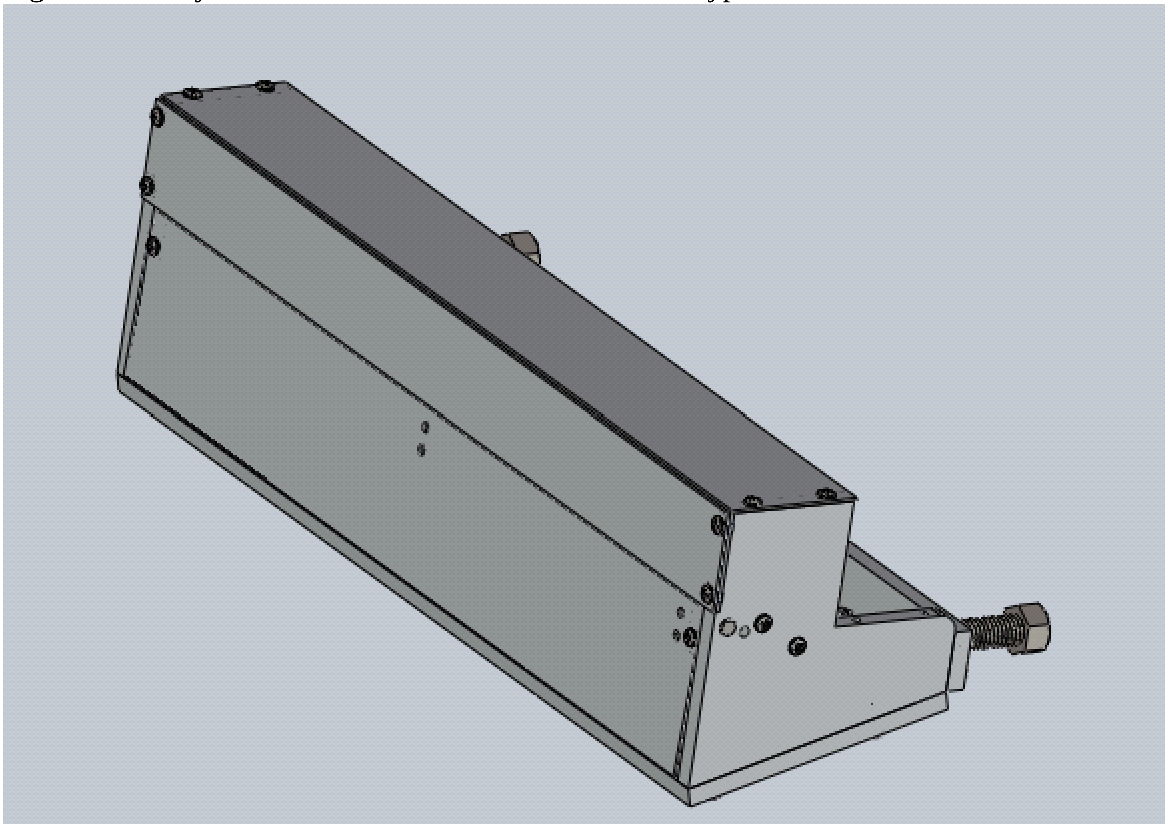


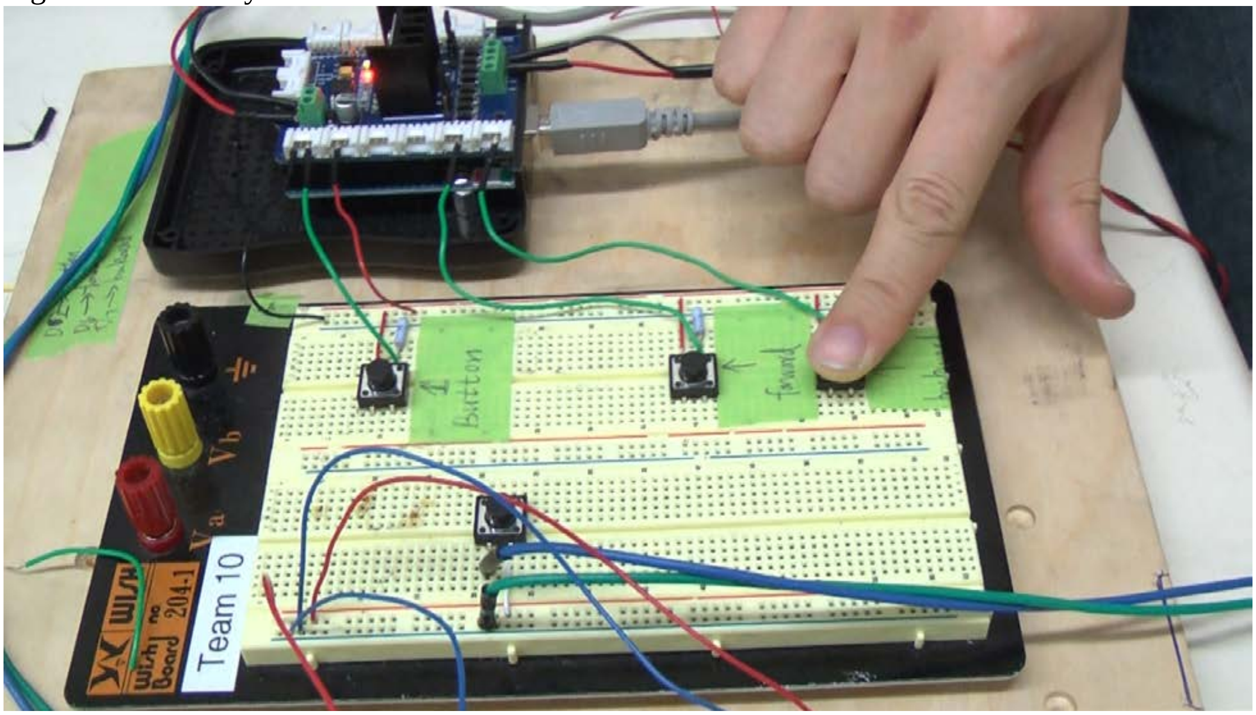
Figure 30: Fully Assembled and Retracted CAD Prototype



Design Operation

The whole mechanism is designed to operate at the pressing of a single button. The prototype simply needs a signal to extend and a signal to retract, both of which are sent via the button labeled ‘button’ in Figure 31 below. The other two labeled buttons (labeled ‘forward’ and ‘backward’ respectively) allow for fine-tuned, operator controlled, actuation of the Xtendr mechanism, not to be included in the final design, but were used for troubleshooting and testing. The fourth, unlabeled button allows for control of the automobile seat itself, specifically the backrest tilt control. This allowed us to simulate the function of the seat moving to an optimum Xtendr position and then returning to the user’s predefined settings upon retraction.

Figure 31: Circuitry for Xtendr



At the first press of the button (labeled 'button' in Figure 31 above) the Xtendr automatically starts the motor and runs for a designated period of time. As the motor turns the motor spindle turns, and in like kind wrap the right and left link wires around the spindle (Figure 32). This in turn pulls the shoulder bolts toward the center thereby opening the housing cover through frontal force and extends the mechanism out over the seat.

At the second press of said button the Xtendr motor begins to unwind the wires that had been wrapped around the wire spindle and the extended linkages are pulled back into the housing via the force of the reflective cover spindle torsional spring (works like a pull down house shade…). The limit to the retraction is the speed at which the motor can let out wire to allow the shoulder bolts to slide to the far ends of the housing.

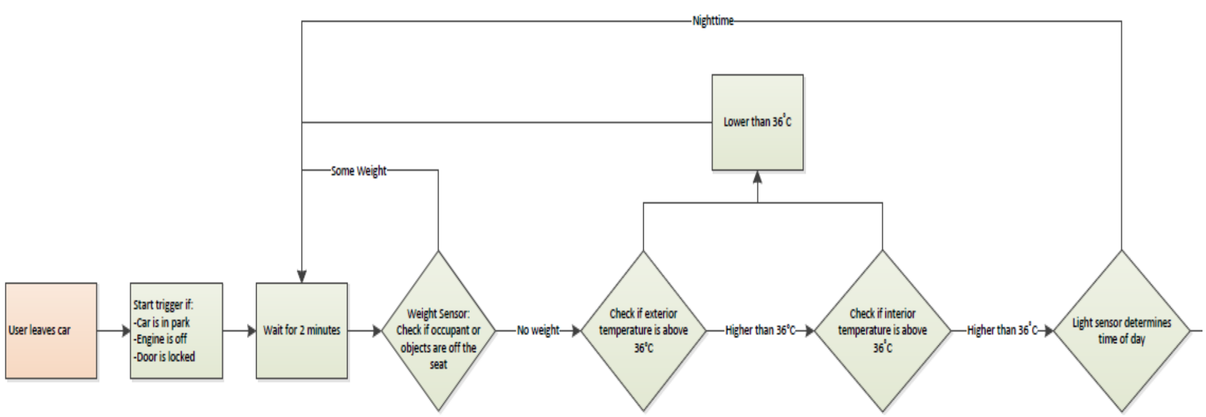
Figure 32: Motor and Wire/Spindle Assembly

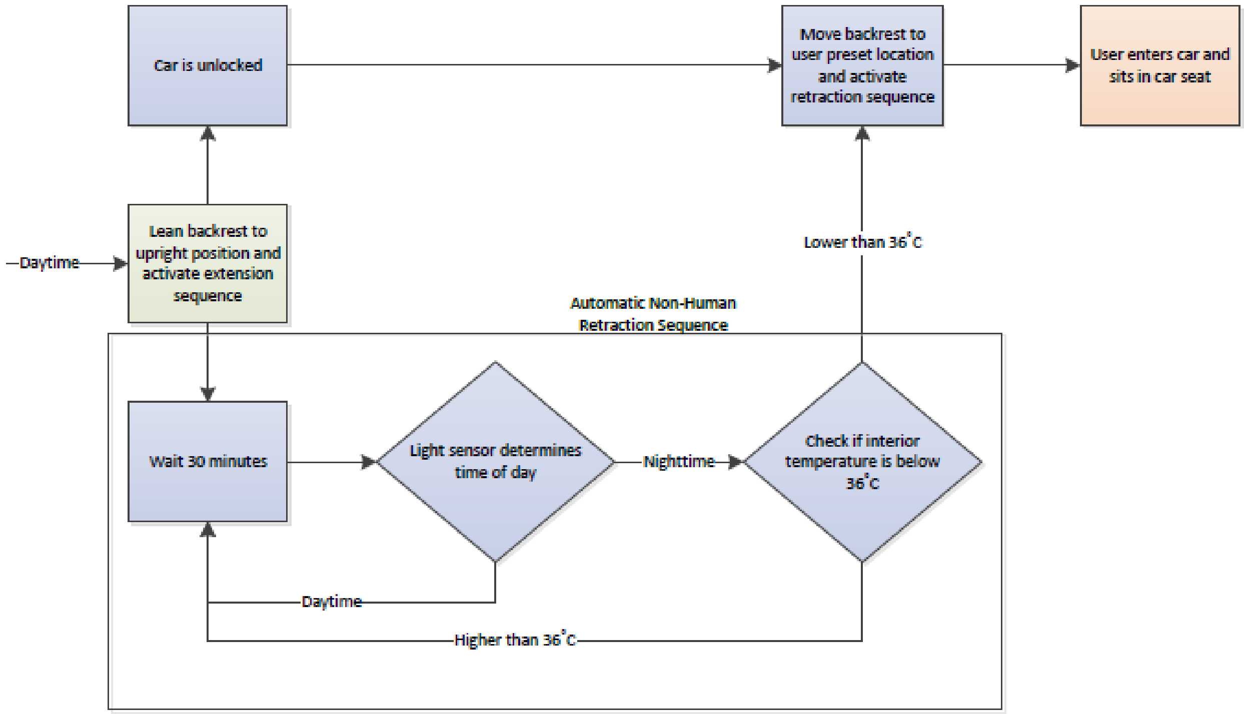
In a mass produced consumer ready design, an algorithm (detailed in Figure 33 below) would be employed in the car processors which would be used in determining when the Xtendr extends/retracts.

For example, this design would likely only be installed in higher end vehicles. These vehicles now come standard with outside temperature readings, automatic light sensing headlights, and pressure detecting seats (for the sake of air bag deployment). These standard sensors would be utilized in determining the environment in which the car is sitting and then if the Xtendr should be deployed. Basically, if when the car senses the engine is off and the occupant is gone it will begin to monitor the outside environment and if it senses it is both hot and sunny the Xtendr would be deployed.

The Xtendr would remain deployed until the unlock button is pressed or the Xtendr is no longer needed (ie. Night time or it becomes very cloudy). At whichever point is determined happens first the car would send a signal to the Xtendr and the whole mechanism would be automatically retracted.

Figure 33: Xtendr Deployment/Retraction Algorithm Overview



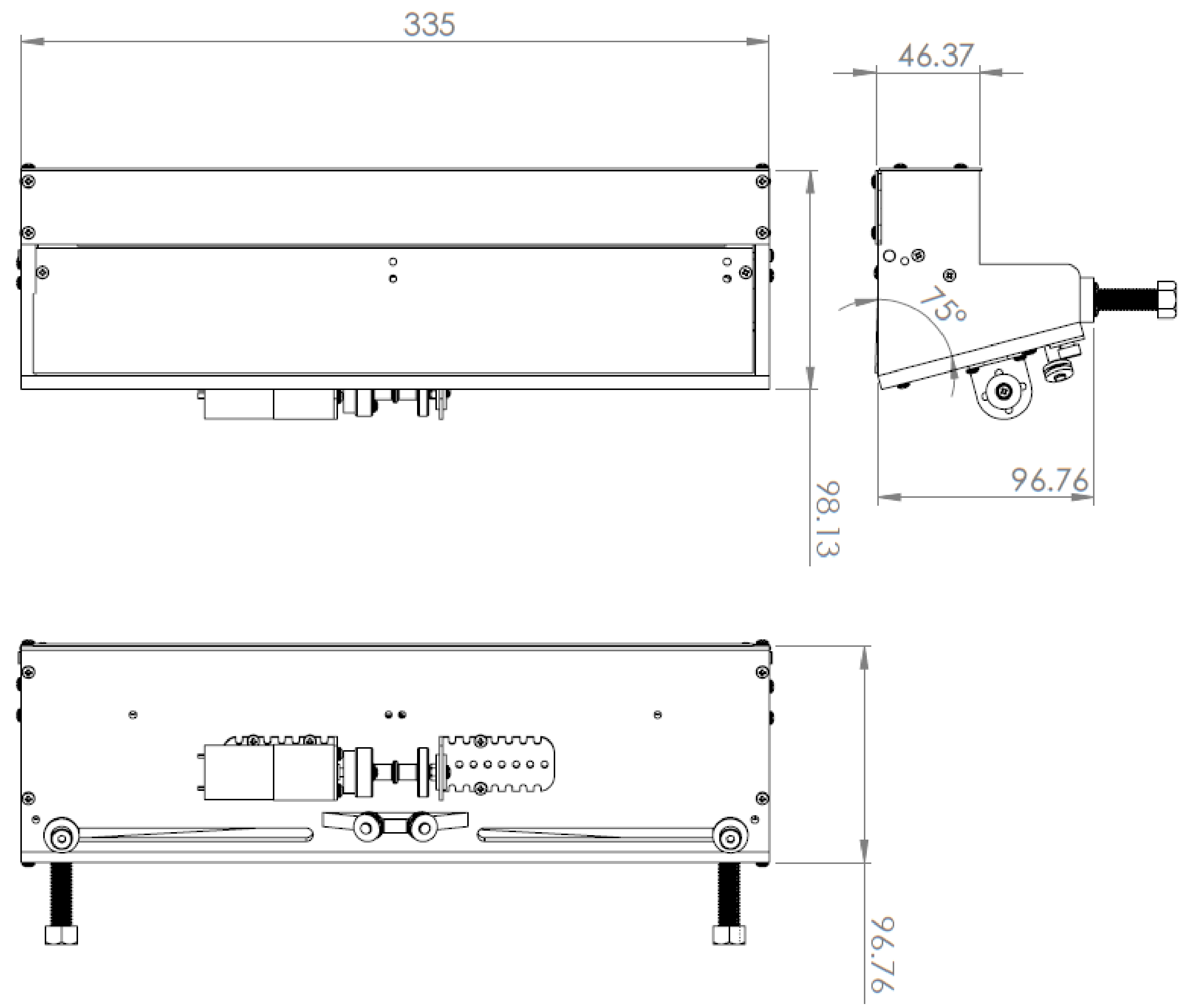


Engineering Drawings and Part List

This section will give an overview of size of the prototype and major parts, detailed drawings of individual parts can be found in the Fabrication Plan section below, and a complete bill of materials list can be found in Appendix B.

In Figure 34 below the Xtendr is in retracted position. This gives the overall prototype housing dimensions as it would fit in the automobile seat (Detailed engineering drawings of all parts can be found in Appendix G).

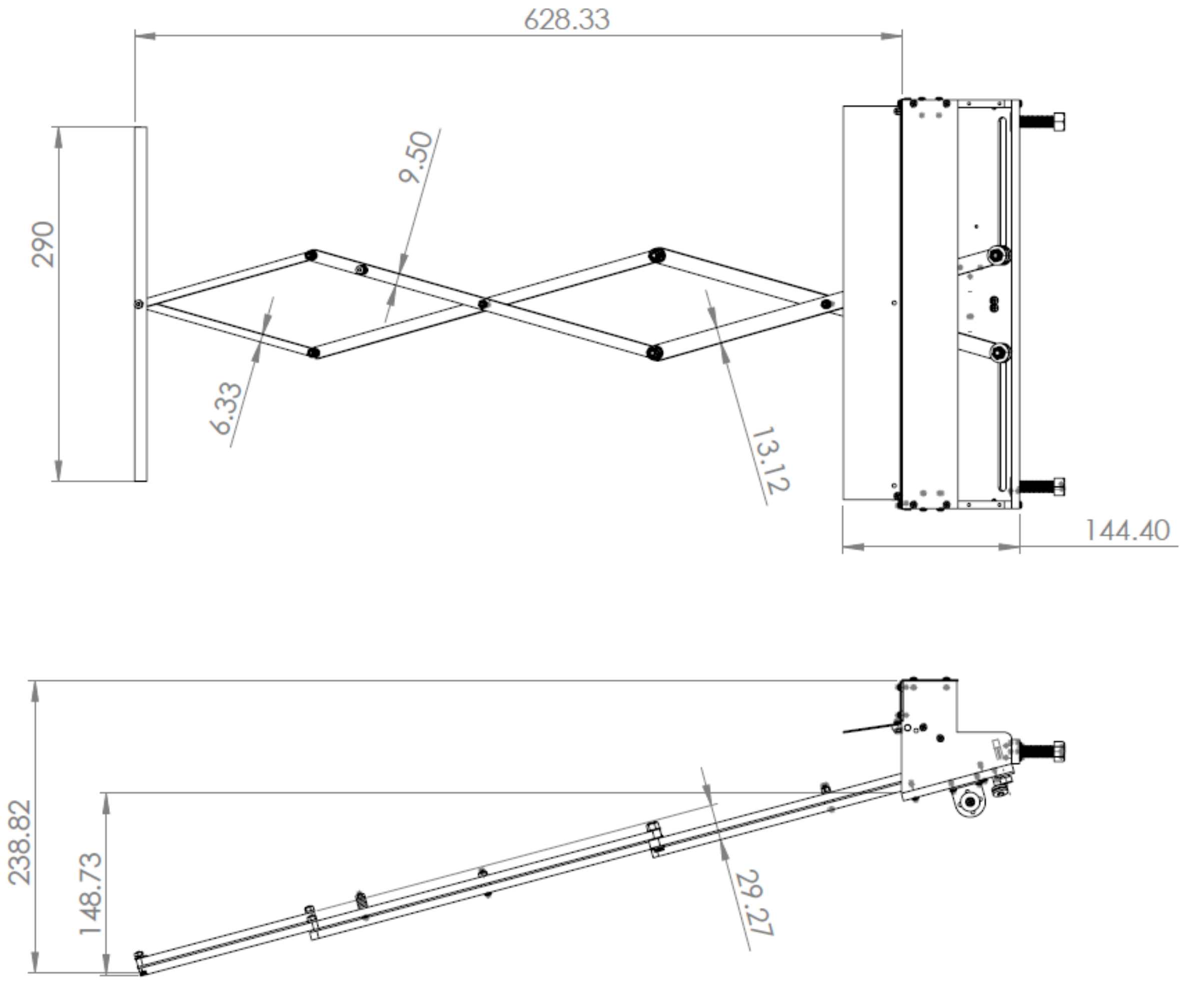
Figure 34: Retracted Xtendr Drawing (dimensions in mm)



A mass produced customer ready design would have optimized linkage sizes and the housing would consist of thinner material. The smaller linkages would allow the overall housing to shrink in size. This would allow the housing to fit further back in the seat, and allow for a greater angle down towards the front cushion of the seat, thereby moving the cover closer to the seat surface and therefore the cover would better be able to block any sunlight coming in on an angle.

The below drawing in Figure 35 shows a dimensioned drawing of the Xtendr in extended position.

Figure 35: Extended Xtendr Drawing (dimensions in mm)



Again, there will be several key differences between this prototype design and a consumer ready model. As stated before the angle of decent with which the cover extends will be increased so as to get the Xtendr closer to the seat surface. Furthermore, the linkages, who's widths are given in the top-down view of Figure 35 show that they are considerably thicker than optimally needed to support the notably light reflective cover. The progression of the links in stacking position, where the links in each progressing 'x' configuration are 'on-top' of the links previously may not be necessary, but rather have them attach both above and below the previous links, so that there is not net change in height from the first to the ending link. This would further reduce overall linkage volume and allow the housing to be shrunk even more so.

<u>Major Component Part List</u>

This subsection will give information as to supplier and fabrication of key parts in the Xtendr design.

Component	Material	Supplier	Mfg. Part #	Price	Qty	Manufacturing Comments
Reflective Cover	Temptrol	Innovative Insulation Inc.	N/A	47.96	1	Cut to size and attached to spindle/linkage
Linkages Baseplate Side Plate	¼" Aluminum Plate (18"x18")	McMaster	89155K27	86.57	1	Water jetted shape, milled out holes/slots/taps
Reflective Cover Spindle	Levolor Roller Shade	Lowes	393923	10.57	1	Cut spindle to length and mounted it in the housing
Motor	N/A	Pololu	1591	19.95	1	Mounted motor to mounting bracket and motor hub to shaft, by which the spindle was then connected
Housing Covers Cover Attachment	0.04" Aluminum Plate (12"x24")	McMaster	89015K22	23.55	1	Cut to size then drilled holes to specification

Validation Potential

Nearly all of our specifications can be directly validated for a final consumer ready design with the constructed prototype. This is because it was designed full scale and to be directly compatible with an automobile seat, meaning that the prototype was fully installed in an automobile seat and worked from that position.

The fact that the prototype worked within the envelope of an automobile seat, meeting many specifications gives us great confidence that a consumer ready final design, with some of the improvements mentioned above (such as smaller links, smaller housing) would meet all of the specifications, including the few that the prototype did not meet.

As an example, the comfort and the durability specifications were not met with the prototype. Though we have great confidence a final design would easily meet them because of the utilization of optimized, smaller, links and housing made of plastic. This combines to drop the mass. Rigorous testing with the plastic links could easily increase the lifetime and durability and the smaller housing would allow it to be fit further back in the seat, thereby making room for more covering foam, hence increasing comfort.

FABRICATION PLAN

This section will go into detail about the steps we took to machine each part, as well as the steps necessary for assembling the prototype. Also, we have included briefly how all of this will change in the final design for manufacturing.

Manufacturing Plan

Most of the parts in this section follow very similar manufacturing processes. Therefore we will discuss in detail the process that we followed for each type of part, so that you may apply it to the individual part drawings included in Appendix G.

<u>0.25” Aluminum Plate</u>

Parts Included: All ‘Beam’ parts, the ‘Bottom Base Plate’, the Left and Right ‘Side Plates’, the ‘Back Mounting Plate’, the ‘Lower Pulley Support’, and the two housing cover hinges.

Each of these parts were initially a part of a single 18” x 18” x 0.25” 6061 aluminum plate which was then cut to size using a water jet. The appropriate holes and precision cuts were performed using a mill.

Steps for Milling:

- Place part in mill using 1.5” parallel plates to hold flat
    - For the parts with holes on angled sides (Side Plates and Lower Pulley Support), we used 1” parallels for support and then used a level before clamping the piece in, so that the drilling surface would be perpendicular to the drill.
- Use an edge finder at approximately 800 rpm to locate the datum points
- Center drill all of the holes first
- Drill the appropriate hole to the specified depth at the drilling speed specified in Table 12 below.
- For threated holes: remove the drill bit and replace with a conical center for alignment purposes and then thread the hole for the correct screw (4-40 or 8-32)
- For the Slots in the ‘Bottom Base Plate’: use a 1/8” end mill and mill across the surface going 0.02” deeper with each pass until the slot is all the way through at 2400 rpm
- For reaming: first drill a hole that is 1/64th smaller than the ream size. Then ream the hole at 80 rpm
- For counter boring: Use an end mill to drill to specified depth at speed given in table below
- Remove part from clamp and file down any sharp edges

Table 12: Drilling Speeds for Aluminum

Diameter	Speed (rpm)
0.125	3600 or less
0.250	3600 or less
0.375	3600 or less
0.500	2865
0.625	2292
0.750	1910
1.00	1432

0.040” Aluminum Sheet
Parts Included: ‘Top Upper Cover’, ‘Top Most Cover’, ‘Cover Extension Holder’, ‘Spindle Support’, and the ‘Housing Cover Opening’

All of these pieces were taken from a 12” x 24” x 0.040” aluminum sheet. The sheet was taken to the metal cutter where it was sheared into rectangular pieces. The holes were drilled into the sheets using a drill press with a #30 drill bit at 3600 rpm or less.

Lathed Parts
Parts Included: ‘Spacer Aluminum,’ ‘Wire Spindle,’ and ‘Spindle Support’

Each of these were manufactured using the lathe machine although the spacer and spindle support were made out of aluminum (2000 rpm) while the wire spindle was made from a delrin rod (1300 rpm).

Steps for Lathing:

- Insert part into chuck and tighten in
- Use a facing tool on the end as well as the outer diameter to get the part down to the proper size and shape
- Use parting tool for the internal grooves in the wire spindle as well as to separate the part from the rod
- Flip part around and face off the other end of the part

Miscellaneous

Cover Spindle
The cover spindle was actually a levolor roller shade (#393923) that we purchased and modified. Start by removing the shade cover. Then remove the end cap from the side without the torsional spring. Cut the spindle to size and attach the end cap to the resized spindle.

Spindle Mount Brackets
The spindle mounts are purchased with the spindle and are used as intended, but you need to remove some material so to allow them to fit inside the prototype. Take a bandsaw (300 fpm) and cut the pieces down to their appropriate size.

Reflective Cover
For shaping the reflective material, use an x-acto knife to cut the cover to a rectangle of 290 x 850 mm.

Leather Outer Cover
Once the body of the prototype has been built, cut the leather and the foam so that it will cover all of the aluminum exposed to the seat surface. Use a laser cutter to etch in the ‘Xtendr’ logo.

Assembly Plan

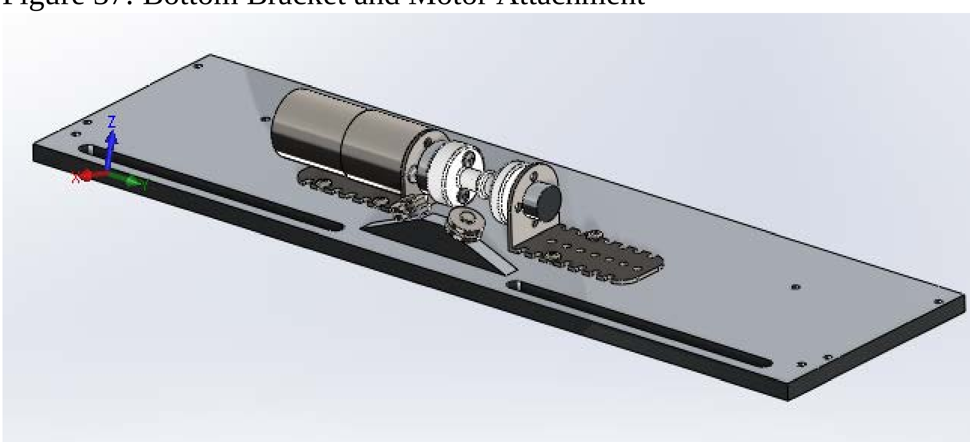
Here is a step by step guide to assembling all of the purchased and manufactured parts together to create your very own ‘Xtendr’!

Figure 36: Final Prototype Image (Xtendr Logo)

<u>Bottom Base Plate and Motor</u>

The bottom plate of the casing is where the motor and many of the cord pulleys are going to be positioned. This sub-assembly shown in Figure 37 will be broken down into more detail below.

Figure 37: Bottom Bracket and Motor Attachment



Steps necessary to put together this subassembly

1. Place a pulley onto a pin followed by a thrust washer (Figure 38).

Figure 38: Pulley Mount

2. Press fit the bushing into the corresponding hole on the bottom base plate
3. Repeat steps 1 and 2 for the other pulley that is placed directly into the bottom base plate.
4. Place a steel pulley onto each of the pins (Figure 39), followed by a thrust washer

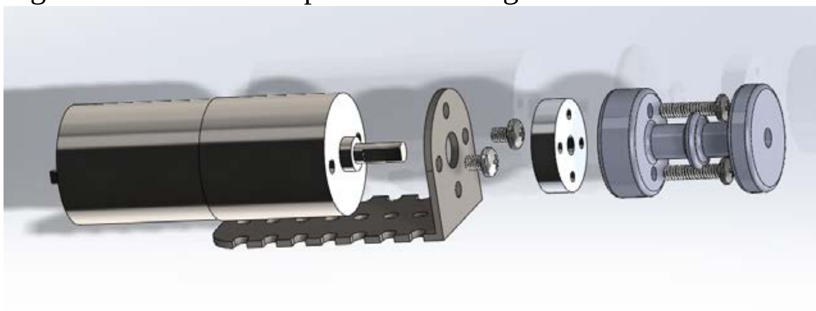
Figure 39: Lower Pulley Support

5. Press fit the pulley sub assembly into the holes on the slanted ends of the lower pulley support.
6. Secure the lower pulley support onto the bottom base plate using two 0.25" long 4-40 thread screws

The following steps detail the motor aspect of the bottom base plate, as well as the spindle attachment to the motor.

7. Place the motor through the center hole of the motor bracket (Figure 40)

Figure 40: Motor and Spindle Mounting



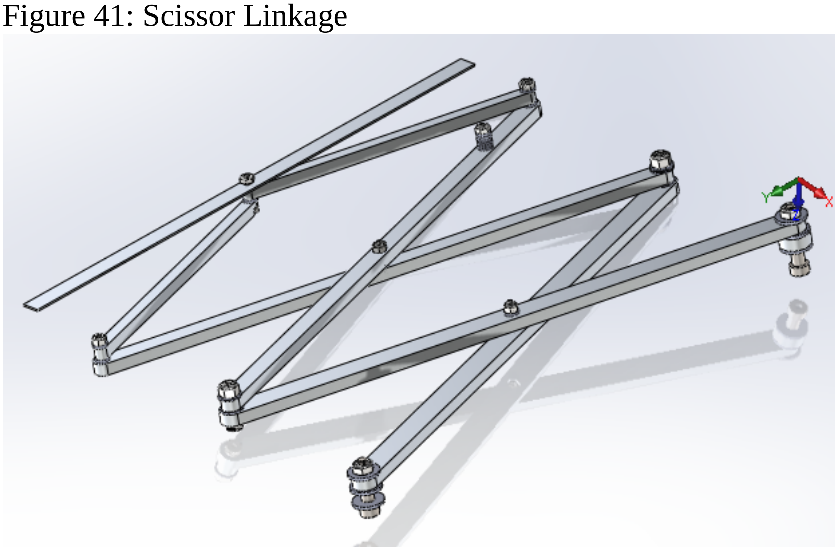
8. Secure it into place using two M3 4mm machine screws
9. Place the mounting hub over the drive shaft of the motor
10. Screw the spindle onto the mounting hub using two 0.5” long, 4-40 machine screws
11. Screw the motor on to the bottom base plate using four 3/16” machine screws
12. Insert the spindle support into the other motor bracket and then the wire spindle
13. Tighten the motor bracket down with two 0.5” long, 4-40 machine screws

The bottom base plate is now assembled. The scissor linkage assembly will be assembled next.

<u>Scissor Linkage</u>

This linkage is the mechanism which extends and retracts the cover. The alignment of the joints must be of high precision in order to minimize friction and therefore the force necessary for motion. An overall view of the linkage is shown below in Figure 41. The assembly’s steps will start with end where the cover will attach continue until where the assembly will attach to the bottom base plate.

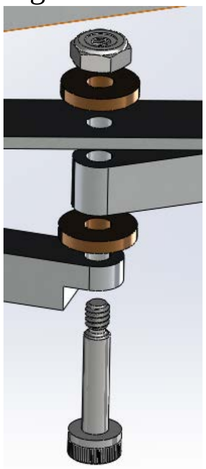
Figure 41: Scissor Linkage



Steps required to assemble the scissor linkage are as follows:

1. Align and then tighten the 1/8” diameter, 0.5” long shoulder bolt with the lower beam, a thrust washer, the upper beam, the cover extension holder, a thrust washer, and Nylon locknut in that order.

Figure 42: Cover Extension Holder Assembly



2. Next we will take each of the longer pairs of linkage bars and create a pivot point around their middles by placing a washer in between the linkages held together with a 0.75” long, 4-40 machine screw, another washer, and a 4-40 nylon lock nut (Figure 43).

Figure 43: Pivot Points in Scissor Linkage

3. Repeat for the other linkage pivot point.

Now that these have been established we can connect the bars into the scissor mechanism shape. This will be done at the ends of each of the bars with slight differences in the sizes of the shoulder bolts used for each one.

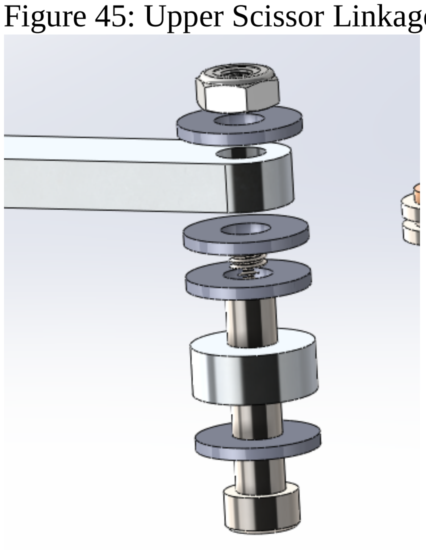
4. At the first set of connection points, closest to the cover extension holder the 1/8” diameter, 0.5” long shoulder bolts will be placed into the bored out holes on the bottom links.
5. Next we will place a thrust washer, a linkage bar, another thrust washer, all secured on by a nylon nut (Figure 44).
6. At the next set of connection points, steps 4 and 5 will be repeated, but with 3/16” diameter shoulder bolts rather than 1/8”.

Figure 44: Linkage End Connections

Finally, with the two remaining bar ends, we will create the adaption to allow the linkage to attach to the bottom base plate.

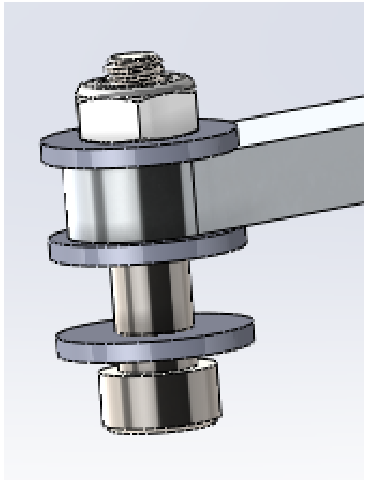
7. First we are going to look at Figure 45 where you will see the upper linkage arm. On a 1” long shoulder bolt, you must insert a washer, followed by an aluminum spacer, two washers, the linkage arm, another washer, all tightened by a thin nylon nut

   Figure 45: Upper Scissor Linkage Arm to Bottom Base Plate Connector

8. For the lower linkage arm (Figure 46), you will place two washers, the linkage arm, a washer, and a nut onto a 1” shoulder bolt.

Figure 46: Lower Linkage Arm to Base Plate Connector



Cover Spindle

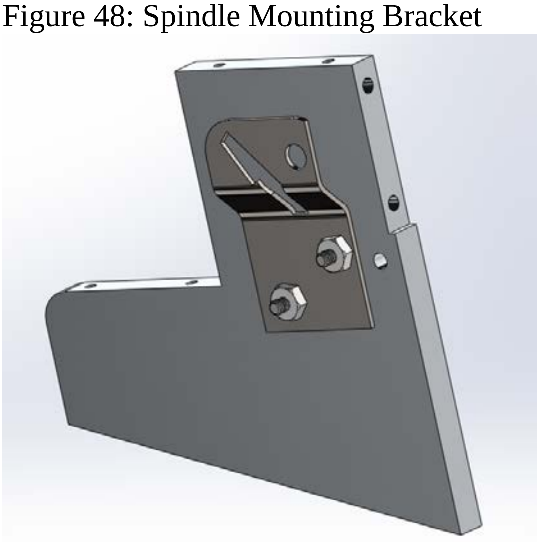
In this section, we will describe how to attach the cover to the spindle and the housing.

1. First you should tape the end of the reflective cover to the spindle
2. Next wrap the cover around the spindle until it is completely rolled up

Figure 47: Spindle with Cover Wrapped Around

3. Next you should attach the spindle brackets to each of the side walls using two machine screws ash shown in Figure 48.

Figure 48: Spindle Mounting Bracket

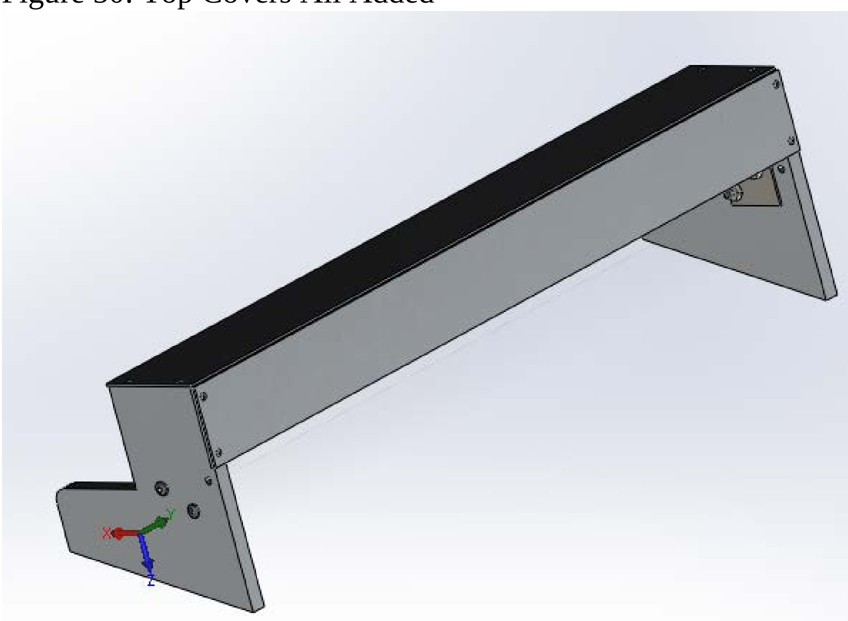


4. With each of the brackets in place, place the cover spindle in between the brackets as shown in Figure 49.

Figure 49: Spindle Mounted Between Brackets

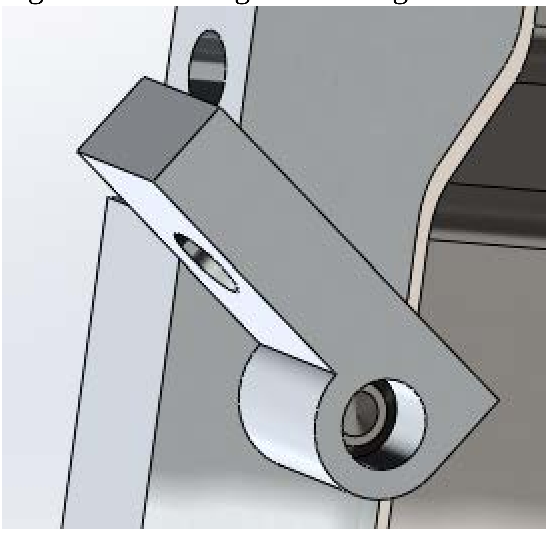
5. Use 0.25” long 4-40 Machine screws to attach the Top Most Cover at each corner to the Side Plates
6. Repeat step 4 but for the Top Upper Cover

Figure 50: Top Covers All Added



7. Add hinges to each Side Plate by inserting a pin through the side holes and then placing a hinge over that as seen in Figure 51.

Figure 51: Housing Cover Hinges



8. Attach the Top Upper Cover using four machine screws
9. Attach the housing cover opening to the hinges using a 0.25” long 4-40 machine screw and a hex nut

Figure 52: Cover Opening

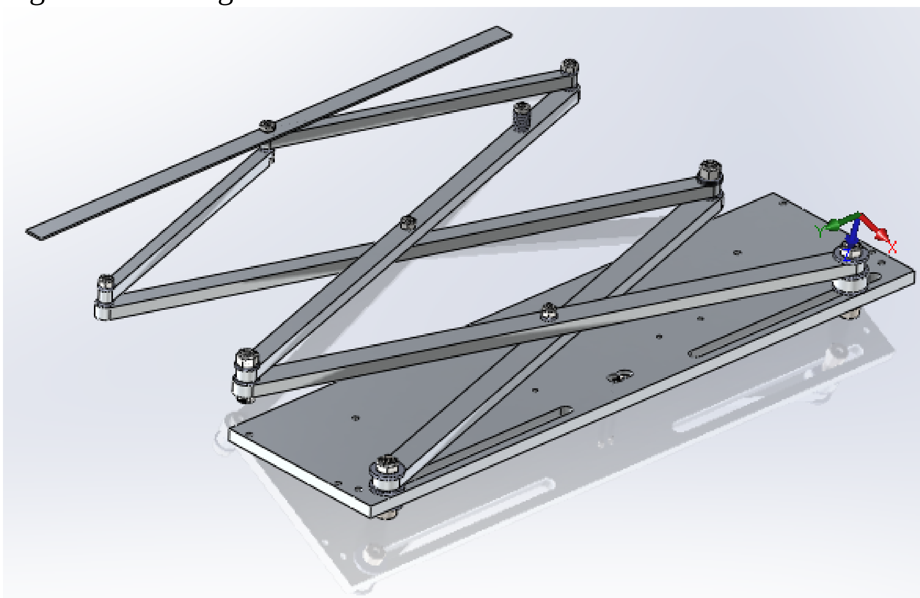
<u>Complete Cover System</u>

This is where we will attach the previously assembled subassemblies together with the housing and the cover spindle. Upon completion of these steps, a mechanically functional prototype should be present.

1. First step is to attach the scissor linkage to the bottom base plate. The shoulder bolts at the ends of the linkage arms go in the bottom base plate slots, with the plate positioned

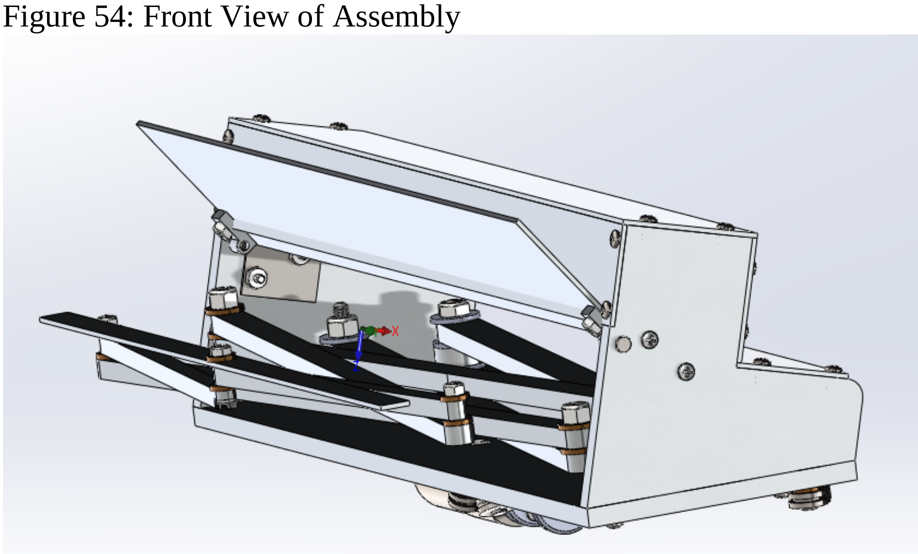
between the two subsequent washers (Figure 53).

Figure 53: Linkage Attached to the Bottom Base Plate



2. Attach the Bottom Plate to the Side Plates using 0.5” Long, 4-40 Machine Screws as shown in Figure 54.

Figure 54: Front View of Assembly



3. Wrap the fishing line around the spools and pulleys up to the end of the linkage arms as shown in Figure 55.

Figure 55: Bottom View of the Motor and the Fishing Lines

4. Attach the end of the cover to the Cover Extension Holder by removing the top nut at the end of the linkage, wrapping the cover around it and securing it with masking tape
5. Press the screw through the cover and reattach the top nut
6. Hot glue the foam to all of the surfaces facing the seat in a way that would still allow the cover to open
7. Hot glue leather to the outside edges of the aluminum frame
8. Hot glue leather to the cover and the top of the prototype.

You now should have a working prototype as shown in Figure 56 that you just need to connect to a power supply and an appropriate controller which can send 9 volts of power to the motor for a specifically determined amount of time in both directions (depending upon seat style and steering wheel position).

Figure 56: Extended View of Prototype

Final Design Manufacturing Considerations

If our design were to actually go into full scale production there are many changes that would have to take place to improve performance, safety, and manufacturing costs. The prototype detailed above, is more of a 'proof of concept' for a potential consumer ready design.

As it is, the production cost of this prototype would be approximately $30 (Buch, 2012). This is including all of the aluminum linkages and housing as well as steel fasteners. At an estimated volume of 100,000 Xtendr's sold per year, materials and parts will be significantly cheaper than what we had to pay for one prototype. As we see it, we would be able cut down significantly on manufacturing costs by switching all of the main components from aluminum to injection molded nylon. This will allow for thinner and lighter walls and linkage arms, providing numerous functional benefits that will improve the comfort as well as the angle the device extends at. The linkage arms will have more of an I-beam shape, which will further reduce the necessary material, while maintaining functional strength. Also, many of the fasteners will be thermoplastic snap-fits, which will also cut down on total cost. With these simple improvements we believe the total manufacturing cost can be brought down further.

Safety is one aspect of this project that was never truly addressed. Before this design is put into production it will have to endure rigorous rear impact testing. The Xtendr as is has aluminum corners on it that could cause harm if the occupant is forced back into their seat. Beyond that, our experience with designing for impact safety is limited, but we assume that it should be designed to collapse upon collision to prevent any sort of back or spinal injury to the occupant. Making it out of nylon will help to move it further back in the seat, away from the occupant, which will help with safety.

Performance on the final design will be comparable to the performance of the Xtendr which successfully passed 11 of the 13 validation tests. In the improvements section, we have further highlighted changes we would make to allow for the final design to pass all of the given specifications. Additionally, the addition of a housing cover lock will prevent the housing cover from dragging on the reflective cover, extending its life. Further details on the results we obtained from testing as well as our methods for performing tests can be found in the Validation section.

VALIDATION RESULTS

After we made our prototype, we wanted to show that our design would meet the specifications put forth. We developed a validation plan for each of the specifications and performed the necessary experiments/measurements/expert consultations to validate our design.

Validation Plan

First we developed a detailed all-encompassing plan to validate our prototype according to all of the specifications shown below in Figure 57.

Figure 57: Validation Plan for Each Customer Specification

Requirement Type	**Quantification**	**Validation Plan**
Solar Radiation Regulation Area	Min: Backrest: $0.075m^2$ Min: Cushion: $0.12m^2$	Using a tape measure to measure the seat surface area under the cover when fully extended.
Temperature Uniformity within Cushion and/or Backrest Zones	< 2℃ difference	Using FLIR Infrared Camera E30bx, provided by JCI, to take thermography and determine the temperature over the seat surface.
Battery Power Draw	Max of 3A, 9-16V, 36 W	Using multimeter, provided in Mechatronic Lab, to monitor peak current and voltage on the motor and calculate the maximum power.
Maximum Power Draw Time for One Cycle	< 500 J	Using the same experiment results to calculate the total maximum power draw with average cycle time.
System Weight	< 1 kg	Weighing the prototype as reference and changing the prototype CAD design to be final design type materials Nylon and subtract the weight estimated difference from Solidwork to get our final design weight.
System is to Fit within Current Seat Envelope	No portion of the system is to extend over ½” from any external seat surface originally in place.	Using meter and visual check to determine the retracted system within the original seat envelope or not.
Comfort Impact	No negative impact to comfort, to be assessed by JCI’s expert panel in a ‘Static Comfort Evaluation’	Planning to have the seat assessed by JCI's expert comfort panel. Due to time conflict, non-involved individuals test instead.

Requirement Type	Quantification	Validation Plan
Cost of Manufacturability	Manufacturing cost < $35.	Work with JCI to determine the cost of manufacturability
Durability	Design for the typical 10 year use. JCI engineering will give an evaluation of the durability of the system proposed system.	Running 100 consecutive tests with prototype to ensure repeatability. Can run more if time allowable.
Shut Down/Storage Time	System is completely in stored position in under 8 seconds	Using a stopwatch to measure retraction time from the fully extended position
No Seat Damage	After installment, no visual wear should be present due to the system	Visual inspection that there are no moving components touching the car seat during a cycle. As well as check the seat condition following durability testing.
Solar Radiation Blockage	Thermal Reflectance > 0.95	Using heat lamp to heat the seat with and without the prototype cover extended. Taking thermography by Infrared Camera and calculating the difference between the unblocked and blocked temperature rates over 10 min.
Deployment Activation	1. Car is stopped and door is locked. 2. Occupant and/or objects are off the seat. 3. The outside temperature is higher than 36 ℃. 4. The light sensor determines sun light conditions.	Prototype begins extension from a signal, and start extension with a signal... written final design algorithm will be proposed in final report.
Automatic System	No human energy input outside of the signal.	Ensure that the system does not need any input other than a signal.
Not to Interfere with Current Seat Manufacturing Infrastructure	Determined by JCI Engineers	Work with JCI during next meeting to discuss manufacturability.

Validation Results

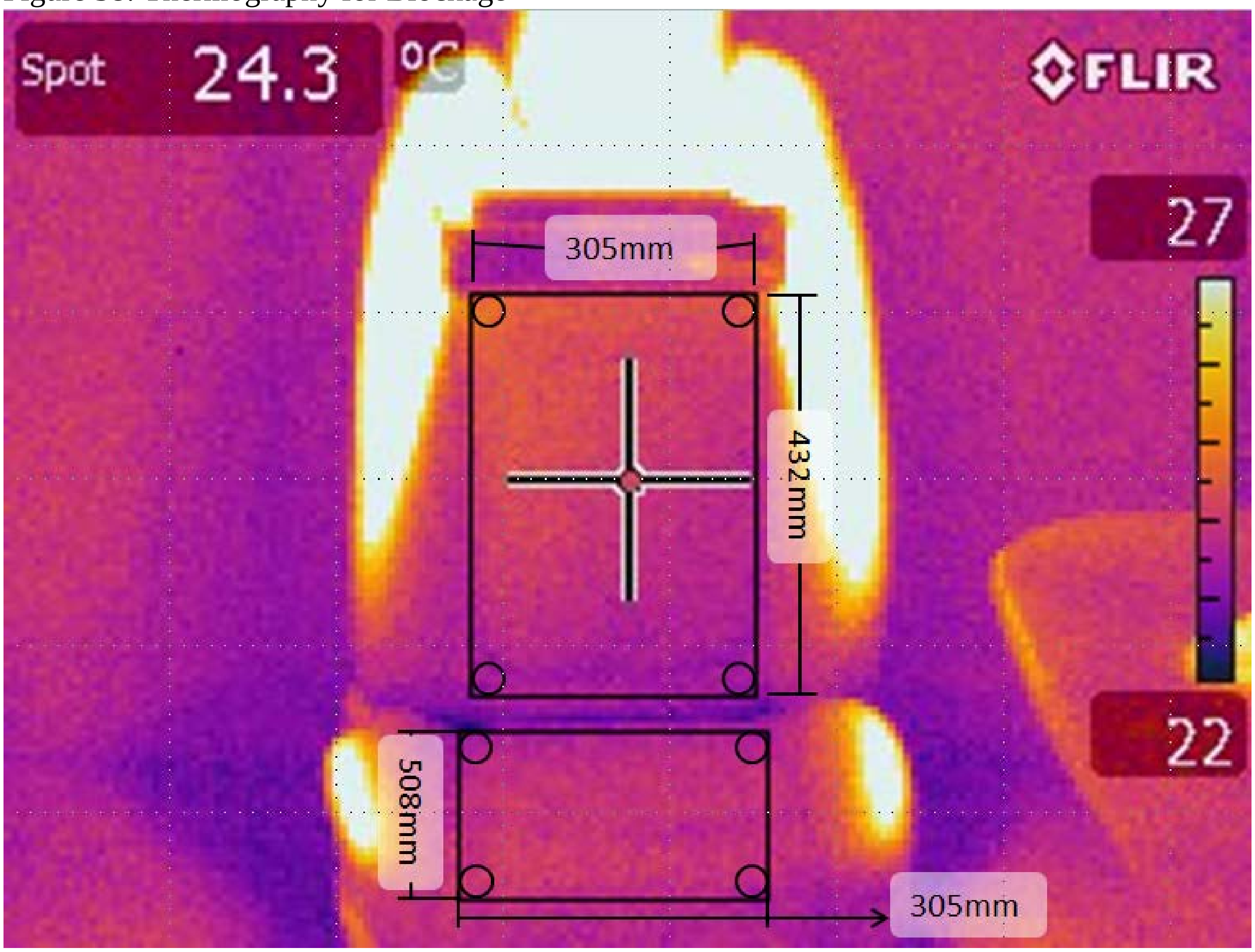
This section includes a more detailed explanation of the validation results we obtained as well as the results themselves compared to the necessary specifications.

Solar Radiation Regulation Area

The solar radiation regulation area was determined to be the area underneath the reflective cover assuming the thermal radiation was coming from above or directly in front of the vehicle. For this we measured the width of the cover to find the width of the areas regulated by the cover for both the cushion as well as the backrest. The height for the backrest was measured from the bottom of the Xtendr frame to the bottom of the backrest where it comes in contact with the cushion. The height of the cushion is from the leading edge of the Xtendr to the base of the seat (as long as the Xtendr doesn't extend past the seat).

We used an infrared camera to verify that the effective area, which is shown in Figure 58 below, was indeed where we measured it to be underneath the thermal reflection cover.

Figure 58: Thermography for Blockage



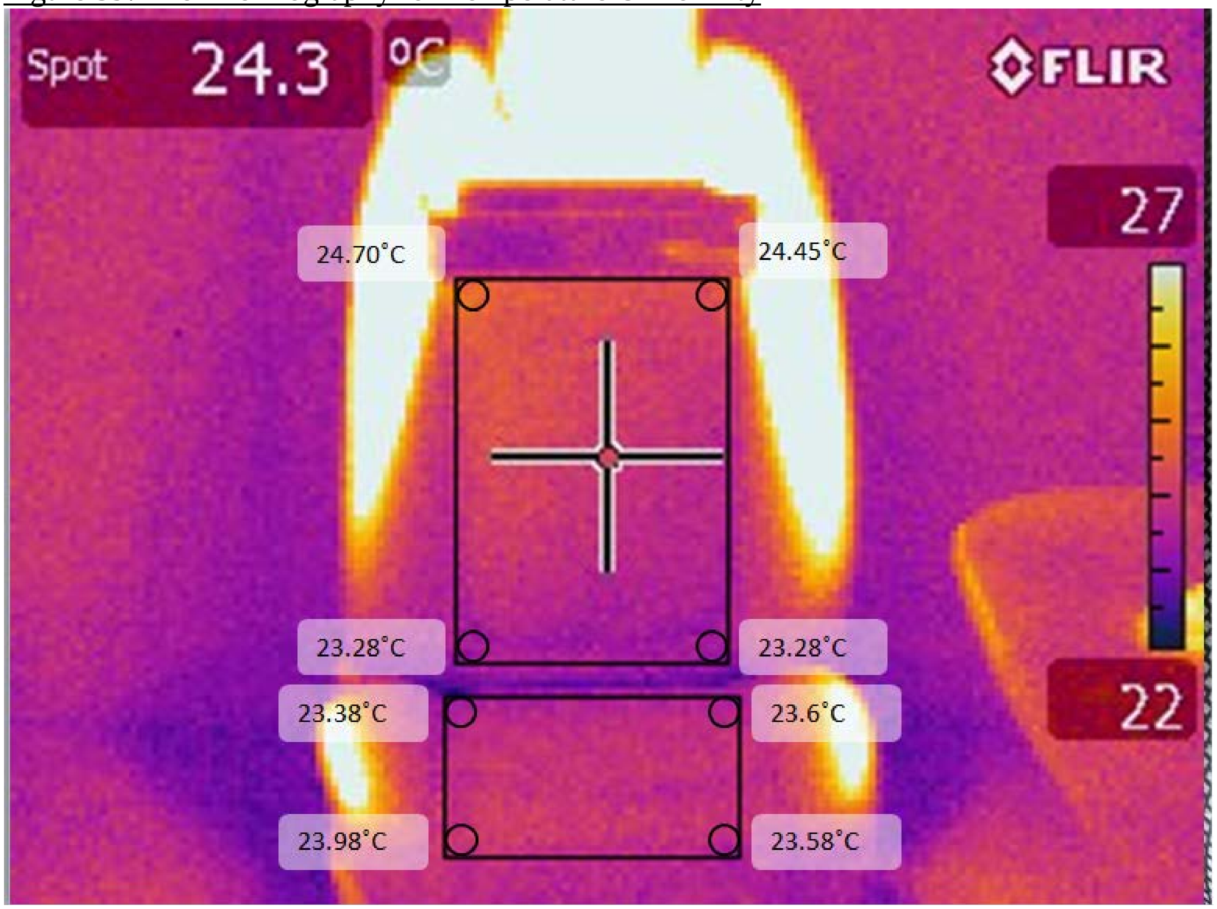
From these measurements we determined that the backrest area is $432\ mm \times 305\ mm = 0.132\ m^2$, and the seat cushion area is $508\ mm \times 305\ mm = 0.155\ m^2$, thus the total blockage area is $0.132\ m^2 + 0.155\ m^2 = 0.300\ m^2$.

Each of these matches and exceeds the necessary regulation area of 0.075 m^2 for the backrest and 0.120 m^2 for the seat cushion.

Temperature Uniformity

Using the thermography as before, we sought to find the temperature differences across the thermal regulation area. For this, we took three different points within the circles shown in Figure 59 below at the corners of the regulation area. Taking temperatures from just theses corner areas was suitable because it is clearly shown from the image, that the hottest and coolest points are located at the corners of the regulation area. The values obtained were taken using the scale on the right hand side of the screen by matching up the pixel colors. These three values were then averaged to get the values seen below.

Figure 59: The Thermography for Temperature Uniformity



After finding all of the temperatures of the sampled locations we compared the largest and the smallest temperatures to find a temperature difference of 1.42℃.

This is below our target temperature difference of 2℃. Therefore, we met this specification.

Battery Power Draw

We used a multimeter provided by the University of Michigan Mechatronic's Lab to monitor peak current and voltage at the motor during 30 cycles. The details of the recorded experiments can be found in Appendix H Table 23. We did tests on voltages varying from 9 V to 12 V provided by the power supply. And we found the maximum power is 2.3 W, which is lower than 36 W.

Cycle Power Draw
For the total cycle power draw, we used above found maximum power and multiplied by the average cycle time of our system. This gave us the maximum total power draw for one cycle, 39.6 J, which is lower than the 500J requirements. Since what we used here is the peak voltage and current, the maximum power draw calculated here is also the maximum energy usage of the system.

System Weight
For the system weight, we first weighed our prototype on the weight scale in Mechatronic lab. The prototype mass is 1.73 Kg, this is with the prototype materials of aluminum and non-optimized linkages and housing supports. Using the created CAD model of the prototype the materials for the linkages and housing pieces were changed to ABS plastic. This allowed us to get a rough estimate for the true weight of the final design which would be consumer ready. The estimated mass came out to be 0.72 Kg, this is below the specification of 1Kg.

Fit Within Seat Envelope
First we visually inspected the surface of the seat to check for any extrusions from the surface. At no point, does the prototype extend past the seat surface. Where the Xtendr is placed in the seat, it was harder to judge, because the original foam had been removed and the leather moved back, so we were forced to approximate where we believed the surface would be. The leather surface of the Xtendrr was flush with the existing leather and foam leading us to believe the system is completely within the seat envelope, and certainly under the 0.5 inch specification. This satisfies our requirement.

Comfort Impact
Between prototype completion and design expo we didn’t have enough time to setup a meeting with JCI’s expert comfort panel, so it was recommended to us, by JCI, that we conduct a study ourselves with students who have had experience riding in car seats. Our test sample came from random people in Mechatronic lab who were willing to test out our seat. We asked 10 male and 3 female students, whose heights varied from 1.57m (5’2”) to 1.90m (6’3”). Upon being seated, we allowed them to incline the seat to their own personal preference as they would when driving. We asked them to first push their shoulder into the seat, and rate the feeling on a 1 to 10 point scale: 1 as ‘feathery soft’ and 10 as ‘cactus pricks’. Then we asked them to put their hands as if they were on a steering wheel and to sit as they would when driving a vehicle and answer the questions again. After both of these questions we then had them rate the overall comfort of the seat with the Xtendr from 1 meaning ‘Best Chair You Have Ever Sat In’ to 10 being ‘Worst Chair You Have Ever Sat In’. The survey results can be found in Table 13 below.

Table 13: Comfort Impact Survey Results

Result	Pushing against the seat	Normal Driving position	Overall comfort of the seat
Male Average	4.6	2.7	4.3
Female Average	5.67	1.33	3.33
Total Averages	4.85	2.38	4.08

From Table 13 above, we can see that people still feel the prototype in the back of the seat when they push against the seat with their shoulder, but this feeling is significantly reduced when the occupant is at normal driving position. Most people asked said they couldn't even feel the Xtendr when in the driving position. We can conclude that our system still needs improvements to meet the overall comfort specification but it is reassuring that although some negative comfort is felt when pushing back, very few (if any) of the passengers experienced a comfort impact in the normal driving position.

Manufacturing Cost

Manufacturing cost was determined by consulting an engineer at JCI (Buch, 2012) who specializes in calculating production costs. We sent him our Bill of Materials, CAD files, and a description of the overall product function and he replied with a cost estimate of $30 which meets our goal of less than a $35 manufacturing cost (Note: this the manufacturing cost of the prototype, not the final consumer ready design, which would be considerably cheaper to manufacture than the presently designed prototype). This is calculated assuming a volume of 100,000 products per year.

Durability

For the durability test, we continuously ran the system 100 times. We had several failures occur during the testing. A detailed result of the failure types and causes is shown in Table 14.

Table 14: The Durability Test Failure Mode and Reasons

Problems	Number	Reason	Failure Rating
Failed Retraction	2	Friction on the back of Bolts	Non-Critical
Failed Housing Cover Close	3	Leather/Foam Effects	Non-Critical
Cannot Open	1	Cover is stuck from prior force	Non-Critical
Fishing Line Off Pulley	2	Over Retracted	Critical

From the above table, we can see that we have 8 failures in 100 tests. And 6 of them are not critical, meaning they can be easily fixed by simply running the cycle again without the need to perform any internal maintenance on the device. But there were two critical failure which would have resulted in a system malfunction and would need to be fixed by removing the system.

This is far too many failures over 100 tests to reasonably believe our prototype will be able to consistently perform over a 10 year lifetime of approximately 8,000 cycles. Additional improvements will need to be made to improve the repeatability and therefore durability of the system.

Storage Time

For storage time, we used an iPhone stopwatch to measure deployment and retraction times for 34 tests. All of the deployments were under 9 V and the retractions varied from 9 to 12 V supplied power. The detailed results are shown in Appendix H Table 24. The average retraction time when the device was between 11V and 12V (21 tests) was 7.4 seconds, which meets the 8 second requirement. When run with a power supply at 12V the fastest storage time recorded was 6.2 seconds.

Seat Damage

Since mounting the Xtendr into the seat there has been no visual seat damage despite having run over 200 cycles. We do not expect to wear nor damage the car seat throughout the lifetime of this device because there is no point in the cycle where the linkage or the linkage cover come in contact with the seat surface. From this we can conclude that the system won't have seat damage after installment.

Solar Radiation Blockage

For the solar radiation blockage, we used the test data from thermography. We took thermography of the seat at 2 min intervals while under a 250 W heat lamp with/without the system cover. Since the seat cover surface has a temperature difference at the end of 10 minutes, based on thermal equation $Q = Cm\Delta T$, we knew that the temperature difference is the effect of the thermal load on the surface, which means that the temperature difference at the end is the same as the thermal load received by the seat. So we calculated the temperature difference using Equation **3** below.

$$\boldsymbol{Reflectivity = 1 - \frac{T_{covered} - T_{Initial}}{T_{Exposed} - T_{Initial}}} \qquad \text{(Equation 3)}$$

Where $T_{covered} = 24.3$ ℃ (is the highest point within the blockage area), $T_{Initial} = 23.9$℃ (is the original temperature of the seat cover), and $T_{Exposed} = 35.4$℃ (is the highest point at the center of the seat). The calculated reflectivity is 96.5%. It's higher than the 95% minimum requirement, therefore we have met the specification.

Automatic System

Since the purpose of this design is to provide the customer with added value, it was important that the customer would not have to manually exert any energy to activate the system, since a big unique point of this cover is that it is automatic. Our system is purely electric and is able to extend and retract solely based upon on a signal received from the deployment activation mentioned in the section below.

Deployment Activation

As mentioned above this must be an automatic system, and so we were tasked with creating a flow chart of logic for a deployment/retraction algorithm that the vehicle would follow to both extend and retract the without the user having to think about it. This algorithm has been developed in a way so that it will only activate when it makes sense given the surroundings. See the Final Design section for a greater explanation of what this algorithm entails.

Algorithm:

1. Car is parked and the door is locked
2. Occupant and/or other objects are off of the seat
3. Outside temperature exceeds 36° C
4. Sunlight is hitting the vehicle

Seat Manufacturability

For this specification we consulted with JCI engineers, and they confirmed that our system won't interfere with their current manufacturing processes. While adjustments will have to be made in the upholstery of the seat the steps that go into the manufacturing process, the processes themselves, will not have to be altered to allow for our device to be installed in the seat.

DISCUSSION

If we could have done one thing differently, we would have spent more time planning and designing in the beginning of the term. The scope change on the project about half way through the semester was a bit of a setback, but regardless, we didn't spend enough time planning out all of our possible solutions. A perfect example of this was the Roller Runner design. At a point in the semester when we were pressed for time, we quickly brainstormed ideas and landed on something that we liked. After investing a ton of time developing the roller runner concept for Design Review 3, we were then realized that although this would work, there were far better solutions that we hadn't considered upon initial brainstorming. After this point, we were able to recover and develop a very quality design in the Xtendr, but most of the semester was spent playing catch up.

In taking a closer look at the Xtendr, there are several weaknesses that can be immediately observed. First, our prototype is designed to block solar radiation coming through the windshield and not necessarily the side windows. Radiation coming in the side would be able to angle in underneath the cover without being completely blocked. This could be improved if the cover were 1) closer to the surface of the car seat and if 2) there was a side sheet that fell down as the cover extends, protecting the seat from side radiation. Another issue that could possibly come up is the angle at which the cover extends. Ideally it would reach the front cover edge of the cushion, but at the moment it is extended out over the seat in a way that could possibly interfere with the steering wheel. We believe this will be solved in a redesign where thinner components will be utilized allowing for a housing to be mounted with a greater angle in the limited space internal car seat space. If this issue of cover angling were indeed solved it would also move the overall cover closer to the seat surface, thereby helping block the side radiation.

Despite those weaknesses, there are many advantages to using the Xtendr. One is simply the convenience of it. Unlike manual radiation covers that can be placed under the windshield or over the seat, the user experiences the blessing of the cover without having to worry about setting it up or taking it down every time they leave/enter the vehicle. Another strength of the Xtendr, is the large extension area provided by the scissor linkage system. A large area of cooling can be provided at the expense of a very small storage volume. This storage volume is small enough that it is capable of fitting in the upper third of the seat where there is minimal negative comfort impact to the driver. A slight modification of the design could allow the cover to also extend out over the steering wheel so that the driver will not have to worry about burning their hands. The distance capability is there with the present linkages, but a slight angle adjustment would be needed.

Other future modifications should be made to address the two specifications we struggled to meet, namely, comfort and durability. Solving the comfort issue is just a matter of putting additional padding between the hard outer walls of the prototype and the seat surface where the customer exerts pressure. If we can make the linkages smaller, the entire design will be able to sit further back in the seat, allowing for a thicker layer of foam to be placed over the top of the housing, thus eliminating the negative comfort impact.

The other issue, durability, was something we were constantly improving leading up to expo. With the addition of guides over the wires we could have prevented all of the critical errors present in the durability validation, since the wire falling off of the pulley track was the cause of the two critical failures. Another durability issue we encountered was with the strength of the wire. After an extended number of runs, it was observed that the 50lb fishing line would snap under the strain of initially trying to move the shoulder bolts. By creating the linkages out of lighter materials, increasing the angle of extension, and upgrading the tension strength of the wire, coupled with a more powerful motor, we believe that we would both have less friction/resistance to overcome and the whole system would more readily extend.

RECOMMENDATIONS

This section will detail suggested areas of improvement, specifically in conjunction with making the prototype consumer ready.

Component Level

This section will explore the improvements and changes that should be done to individual parts and components should a consumer ready design be pursued.

<u>Linkages</u>

The prototype design had far oversized linkages for the loads they were experiencing. Should another prototype be constructed the linkage cross sections should be altered and optimized for the light loading they will be experiencing. The shoulder bolts will need to be sized accordingly, and in face many of the larger shoulder bolts are also far oversized and so could be shrunk in similar proportion to the linkage size change.

For a final consumer ready design plastic would be employed in the linkages. During one of the final JCI meetings there was a focus on possibly using high density nylon as the main material for the linkages, we therefore would suggest considering that material first if such a design is to be pursued. If plastic were to be employed a drop in friction and needed initial torque to start the linkage movement, due to the lighter weight of said plastic material (versus Aluminum), would be needed.

The plastic linkages would also allow for the integration of molded axels from which the linkages could be connected to each other with. It would basically be a snap fit/rotation system. With this design it could be made so that there would no longer be a need for any shoulder bolts/fasteners within the linkage mechanism.

<u>Housing Cover System</u>

The housing cover is currently opened by the pushing of the linkage onto its backside and then remains open by resting on the taunt reflective cover as the whole mechanism extends out. Then as the mechanism retracts the housing cover continues to rest on the reflective cover until the front bar has passed by and entered the housing. Then the housing cover closes under the power of gravity.

To make this system more robust and consumer ready several improvements must be made. The first is that the housing cover should not be riding on the reflective cover, for this will only decrease the lifespan of said cover. We would suggest installing a cam and lock system, by which a forward linkage or other metal part would engage and push the housing cover open. Then when in the most open position a lock would engage holding the housing cover up and off the reflective cover as it both extends and retracts.

Then when the front most bar approaches the housing the lock is hit in reverse which dislodges the housing cover from its open state and lets it swing down, closing the mechanism.

There is concern about the closing of the housing cover, for there is fear that gravity may not be substantial enough, especially if the car is on a decline, for the cover may swing open and make the occupant uncomfortable. A small spring could readily be attached to the housing cover and housing itself which would help to hold the cover closed when Xtendr is not in use and helps to close the housing cover if dirt or other foreign matter is impeding the motion.

Housing

Just as the linkages were oversized so is the housing material, especially considering it is aluminum. If another prototype were to be built we would highly recommend decreasing the thicknesses of the housing from 0.635cm (0.25") to 0.508cm (0.2") thick (and possibly even more if no noticeable bending is seen from this decrease).

For the consumer ready version we envision the bulk of the housing being made from plastic (ABS/Nylon). Though we still think the slot should have a metal insert if sliding shoulder bolts should be employed.

There is also the question of mounting the housing to the internal seat frame. If the housing is indeed made from plastic then there should also be consideration of creating some kind of snap-fit or clip-on attachment to attach the rear of this housing to the internal seat frame rail, thereby eliminating the need for any fasteners and increasing assembly speed.

Power System

The motor presently used in the prototype is barely able to overcome both friction and nearly non-existent angle the linkages are in when they are in a retracted state. For a new prototype we would immediately upgrade the motor used and the wire appropriately. A higher powered motor coupled with greater tensile strength wire would allow the mechanism to advance/retract more quickly and would allow us to experiment with a cam and lock system, for it would then be able to both open the housing cover via the cam system and be retracting with enough speed to knock the lock out of position.

We would also be interested in creating some sort of wire guide which would prevent the wires from coming off the pulleys when too much slack is in the lines. This would allow for greater repeatability since this failure mode would be eliminated by this improvement.

For a consumer ready system we would still hold to the above mentioned prototype improvements and given a greater amount of time would have tested said improvements for their durability, of which we are confident there would be a great improvement.

System Level

This section will detail any changes affecting the performance of the system as a whole.

Position in the Automobile Seat

If the overall size of the housing could be shrunk (which we believe would be easily doable if such suggestions as optimizing the linkage cross sections and using plastic were employed) then the whole system could be 1) moved further back into the seat thus allowing for more foam to be placed on the front of the housing, thereby vastly improving comfort. 2) Smaller components could also allow for a greater downward extension angle, thus allowing the leading edge of the Xtendr to dip below the steering wheel and come very close to the front edge of the cushion, which would bring the whole reflective cover closer to the seat surface and thereby block even more of the sun's radiation loading.

Deployment & Retraction Algorithm

We have created an initial flow chart level algorithm for the sequences leading up to the extension of the Xtendr. The same is true for the retraction sequence. Any consumer ready system will need to have fully programmed and fully integrated this algorithm into the car system controls for the Xtendr to be a truly automatic system.

CONCLUSION

One of the leading causes of thermal loading on an automotive seat comes directly from the sun. By removing this energy source, it is reasonable to believe that the consumer would feel comfortable and therefore find additional value by this improvement. Johnson Controls is interested in developing a system which prevents an automobile seat from increasing in temperature due to direct thermal loading.

The ideal system would be one that achieves the following specifications:

1) Power draw from the battery limited to 500 J while vehicle is off
2) Final design for manufacturing must weigh less than 1 kg
3) System must be able to retract and store into its off position in under 8 seconds
   * see the specification section for more specifications and details

Moving forward from the specifications, we then worked to develop a functional decomposition and generated over 30 concepts based on the functions we needed to address. These concepts were evaluated using a Go/No-Go process leaving us with only the ideas that could feasibly be implemented in this project and meet the specifications we developed with our sponsors. Each member then evaluated these concepts with the guidance of a Pugh chart before creating their own comprehensive concept. Using a Pugh chart as a team we then gave a ranking to the top sets of designs resulting in a motor driven design being chosen.

Although not under consideration initially, we developed a scissor mechanism we believed would be more consistent than our previous ideas. This scissor linkage, termed the ‘Xtendr’, is motor driven by a string wrapping around a spindle that pulls the base linkage arms together. Solar radiation blockage would be facilitated by a reflective cover that wraps around a torsional spring loaded spindle which has enough force to retract the linkage without external assistance. The ‘Xtendr’ is located in the upper shoulder area of the backrest where there is minimal back pressure exerted by the passenger.

This design has been manufactured and has undergone validation testing for each of the specifications laid out at the beginning of the project. The Xtendr excelled in most of the performance categories, including retraction time, power draw, and manufacturing cost. However, two specifications were not met: comfort impact and durability. Despite these two failures, as a proof of concept, the Xtendr demonstrates the successful potential of this design.

Future recommendations include using thinner walls and linkages that are made out of nylon to allow the device to sit further back in the seat which would increase passenger comfort. Also, by installing a cam and lock system as well as wire guides, durability will dramatically increase by protecting the reflective cover and remove the most common critical error respectively. These minor changes will result in a product that will bring additional satisfaction to customers who are unsatisfied with the current solutions to prevent them from sitting on hot car seats.

ACKNOWLEDGEMENTS

We would like to acknowledge everyone who supported us, directed us, and challenged us to come up with an original solution to an interesting problem. First off, we would like to thank Johnson Controls for sponsoring our project. Thank you to everyone who took time out of their days to attend our meetings and provide valuable insight into our design. Jennifer Carlson in particular, took time out of her day to come to Ann Arbor on a monthly basis on top of being our daily point of contact. Also, thanks to Eric Michalak and Brennon White for being around from the beginning and helping us with our initial design ideas as well as our technical needs.

We appreciated all of the feedback we received from the other teams in our sections. It was exciting to see all of the daunting projects at the beginning of the semester develop into incredible solutions by the end.

Bob Coury and Mark Stock, thank you for opening up your Machine Shop to us over the last several years. You taught us skills that will be valuable in our future as engineers. Namely how to go about physically machining a part we designed.

Thank you Toby Donajkowski for all of the help in the Mechatronics lab over the last few weeks.

We would also like to thank Mike Umbriac for his interest in our projects as well as some of the last minute help in getting our project to expo on time.

Finally, thank you Professor Gordon Krauss for challenging us to make our design as thorough as possible. You could have made it easy on us, but instead you sought the best effort from everyone in your section, and it shows in the quality of projects that were produced. The hard work paid off and will likely pay dividends in our future careers.

Without this guidance and support this project would never have come to completion, so thank you everyone who contributed into making this a phenomenal senior design experience.

INFORMATION SOURCES AND REFERENCE LIST

Before developing potential concepts it was important for us to understand the current designs and the corresponding companies behind these designs. Doing this has provided us with an idea of which designs work, and which won't. These serve as a benchmark for the specifications that we will be expected to meet and exceed in our own design.

Although there are few counterparts in the market, we have found there to be many patents which conduct a similar function of protecting the car seat against exposure to the sun.

One of the earliest can be traced back to 1978 when the Hex Fastener Corporation developed an apparatus and method for shading at least one seat of a vehicle from direct sun rays (Rickle, 1978). The apparatus consists of a spring-wound roller shade which is mounted, for example, to a portion of a seat, such as the bottom edge of the front of the front seat. The end of the shade, when unwound from the spring-wound roller, is attached to the top or beyond the top of the back of the seat, thus entirely covering the seat and protecting it from solar radiation, albeit manually.

ITT Corporation established an automobile seat which had a retractable protective covering (Busso, 1988). The seat includes a retractable extendable rolled covering mounted at the front of the seat below the seat bottom and behind a seat trim piece. The covering includes a combination retention member and grasp engaged to the trim piece to hold the shade in its stored position and providing for finger engagement to extend the covering over the seat.

A more indirect industry product is the all too familiar car windshield sun shade. This design is placed on the dashboard in front of the windshield and is commonly made of reflective material. A more advanced sunshade cover is the eclipse sun shade (Eclipsesunshades.net). It is a more permanent solution because it can be attached to the sides of the windshield and then when it is to be used the two sides are pulled from either side of the car to meet in the middle, thereby covering the entire windshield. It uses an opaque and semi-reflective material to slow/limit the high temperature in the car.

We also found an 'over the car' instead of 'inside the car' approach to keeping the initial car temperature low. Called the 'Cool Cap Reflective Car Cover' (Cool Cap Reflective Car Cover).This was an interesting design where the user would actually pull this cover over the car and the highly reflective cover rejects a high percentage of the solar radiation hitting it from the sun.

Over the course of the semester we have leaned on the expertise of a group of the employees at Johnson Controls Inc. For validation in particular, our group has been required to turn to JCI for testing equipment as well as knowledge of automotive manufacturing. On November 29th, we traveled to Plymouth to use their infrared camera as well as to verify the manufacturability of our design concept (Carlson, Mangus, White, Hebda, & McClelland, 2012). Manufacturing cost was later determined via e-mail communication with Kalrav Buch, a specialist at JCI in design for cost (Buch, 2012).

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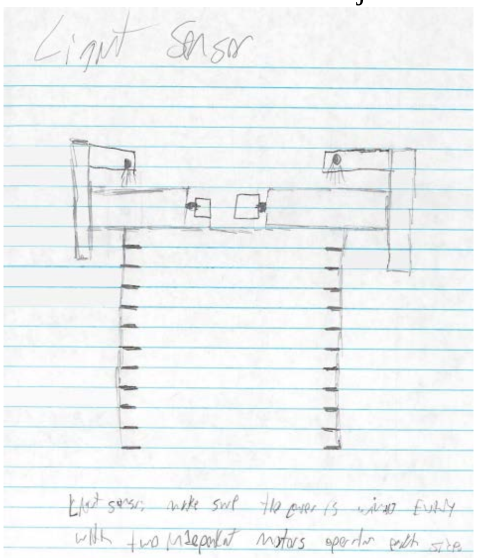
APPENDIX A: CONCEPT DESIGNS

Details all designs and concepts generated in conjunction with final design development.

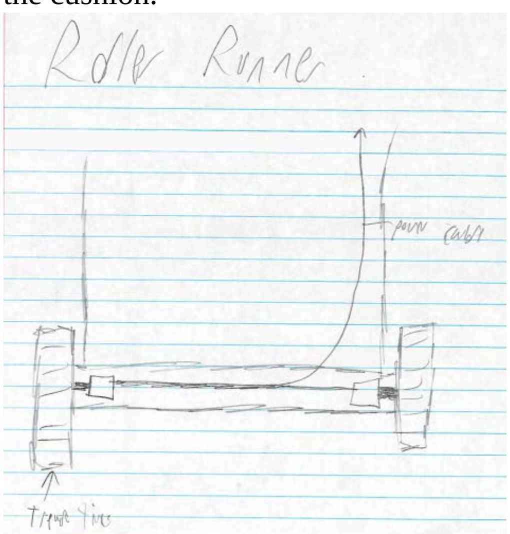
APPENDIX A-1: INITIAL CONCEPTS

Details the designs and concepts generated before any selection or critiquing was employed.

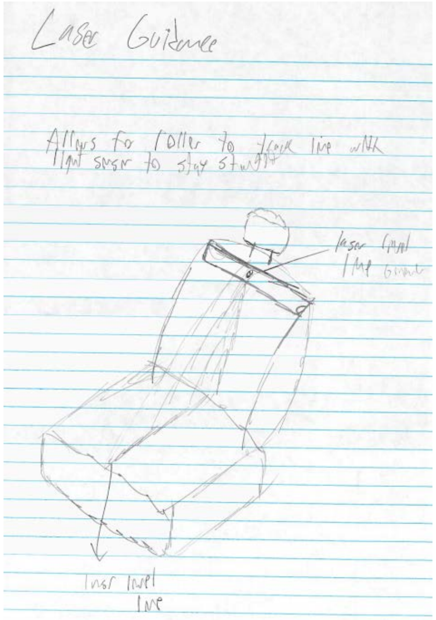
<u>Light Sensor</u>: Light sensor combined with grids on the edge of the cover modulates the motion of the cover so that it could adjust itself when two sides don't move with same speed.



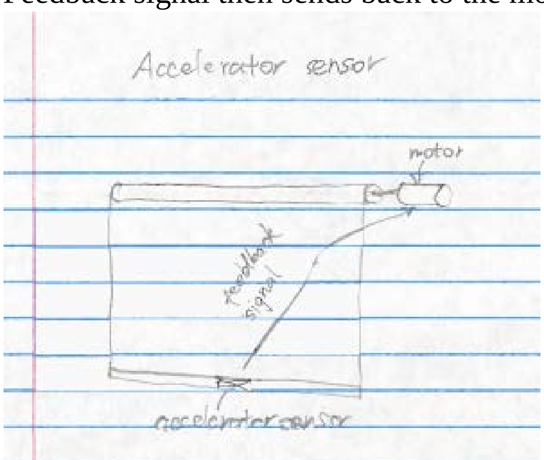
<u>Roller runner:</u> Two wheels are installed on the front of the cover, making it easy to climb over the cushion.



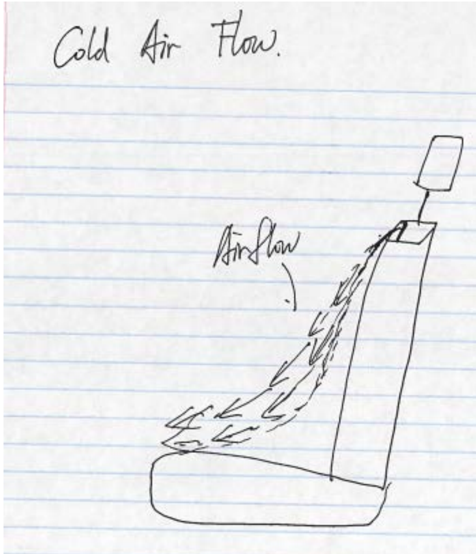
Laser guidance: A laser receiver is placed at the end of cover to trace straight laser line. Consequently, the cover will move straight.



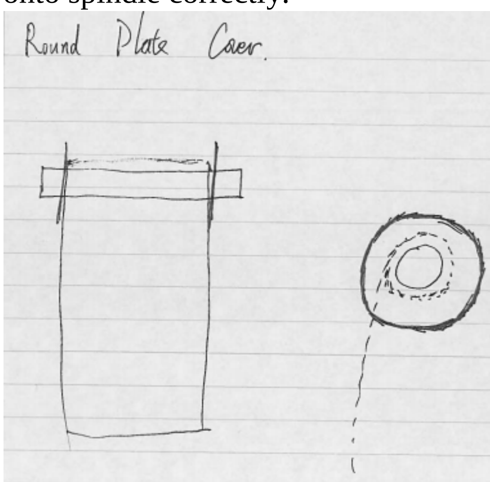
Accelerator sensor: An accelerator sensor is put at the end of the cover to detect any tilt. Feedback signal then sends back to the motor to adjust its speed.



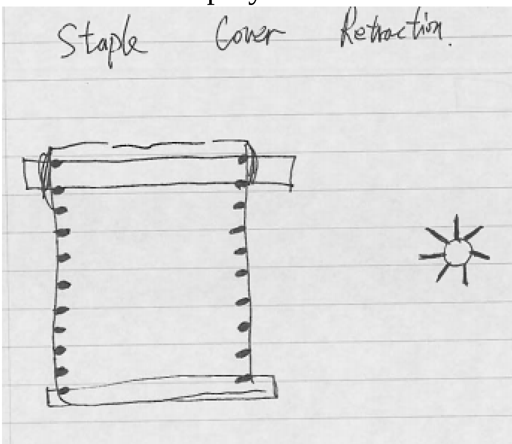
Cold air flow: Strong air is blown onto the seat to cool it down quickly just before occupant gets in.



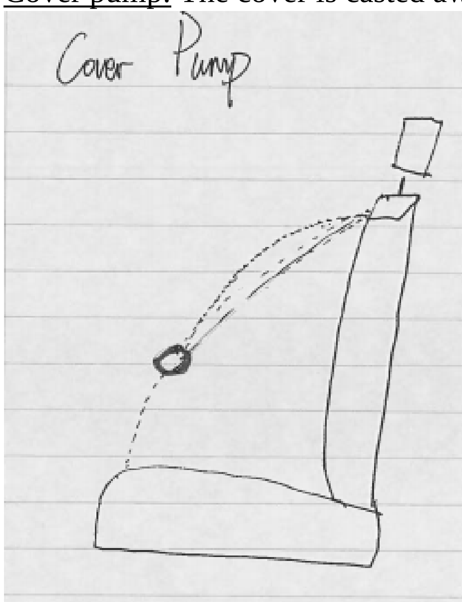
Round plate cover: The two plates on the spindle confine cover in a limit space so cover wind onto spindle correctly.



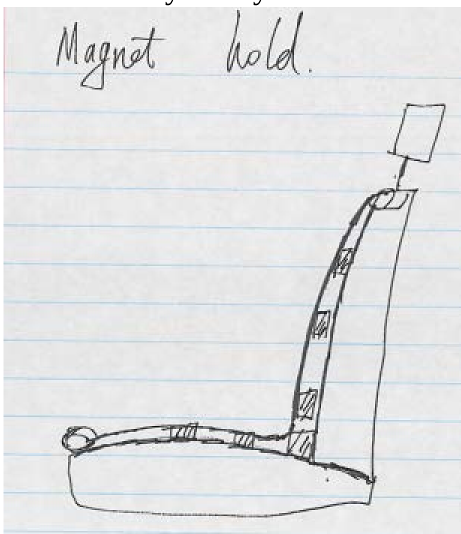
Staple cover retraction: Holes on the cover will meet the spoke. This mechanism makes sure that the two sides deploy and retract with the same progress.



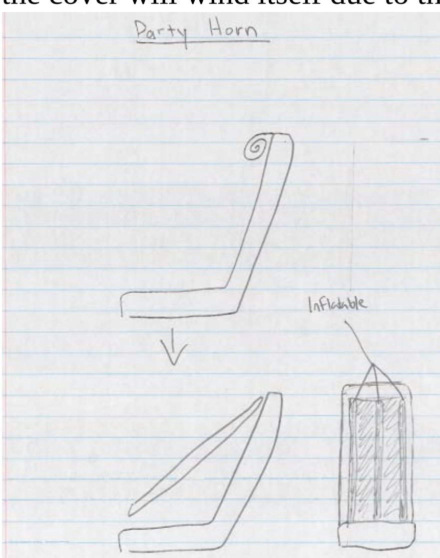
Cover pump: The cover is casted away by a projector and it retracts driven by a motor.



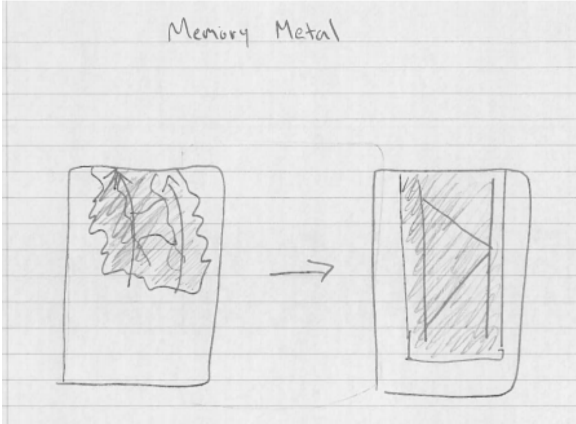
Magnet hold: Electrical magnet is installed under the seat and there is small iron plate inside the cover. When current is put through, the electrical magnet will attract the iron plate, which helps the cover stay firmly on the seat.



Party horn: This cover has three inflatable bars stretching out the cover. When air is drain out, the cover will wind itself due to the length difference of the two sides.

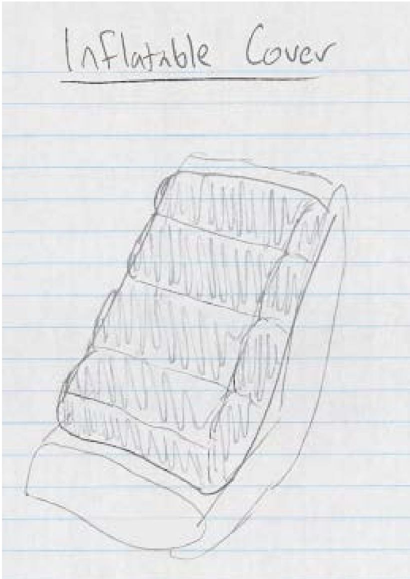


Memory metal: Cover is attached to memory metal that shall extend upon stimulation like heat or current. When stimulation is stopped, the metal should shrink to a compact structure.

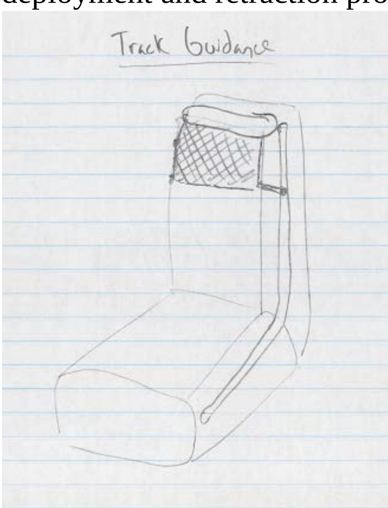


Spring roll retraction: Customer has to pull out the cover manually. For retraction, the spring on the top will draw the cover back.

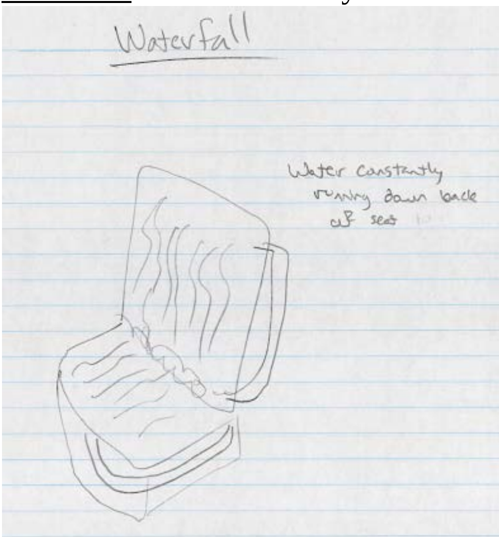
Inflatable cover: Cover will inflate like an air mattress or air bag when deploying. Air will be drain out during retraction process.



Track guidance: Tracks on the side of the seat help the cover stays on the right way for deployment and retraction process.

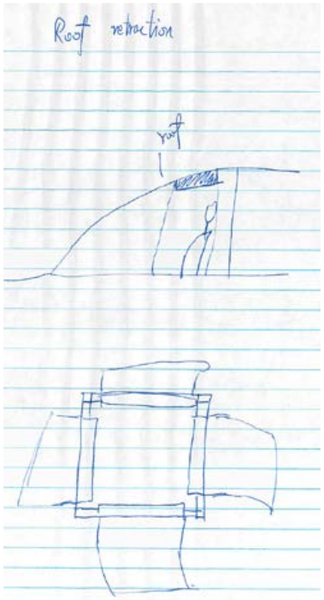


Waterfall: Water constantly runs down back of seat. A pump is needed to complete the cycle.

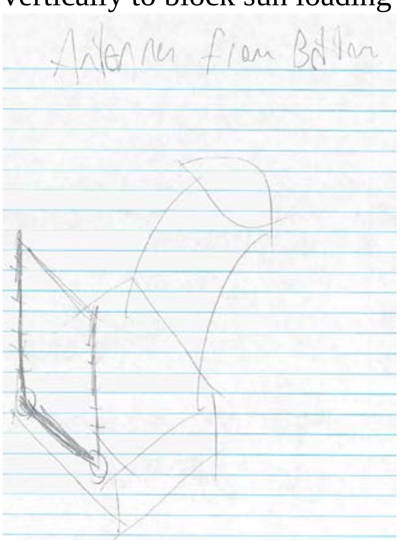


Antenna: Cover will attach to the retractable telescope by small hook. When telescope extend, it will draw the cover.

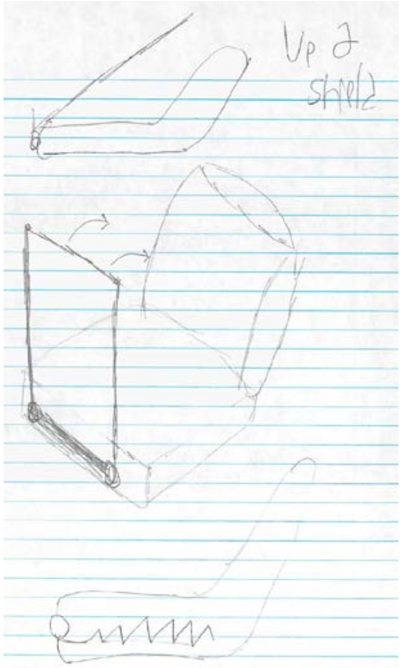
Roof retraction: Cover of high reflective material coming down from the roof will encircle the whole seat.



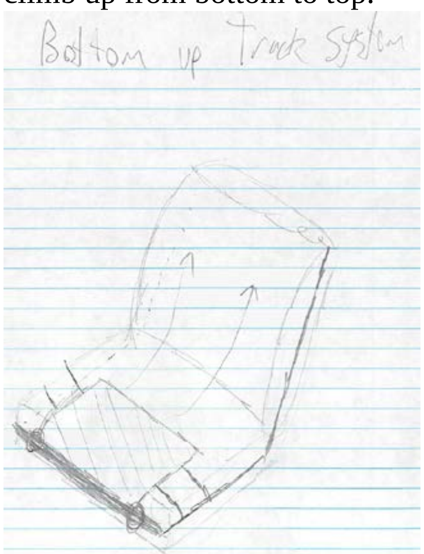
Antenna from bottom: This concept uses the space under seat since we have very limited volume in backrest. Linkage will bring the antenna from bottom to the end of the seat and it shall grow vertically to block sun loading from front side window.



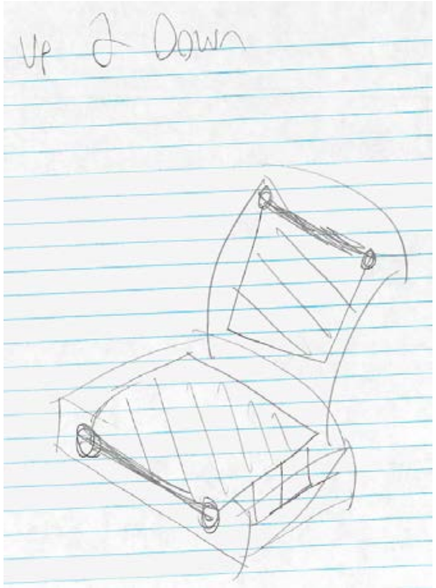
Up & shield: This mechanism grows vertically and then leans back onto the seat. Its tracks are retractable and will come back to the bottom of the seat.



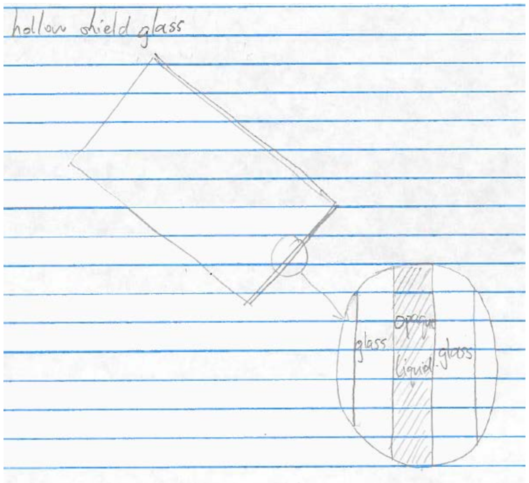
Bottom up track system: With guide on the side, a cover driven by a motor should be able to climb up from bottom to top.



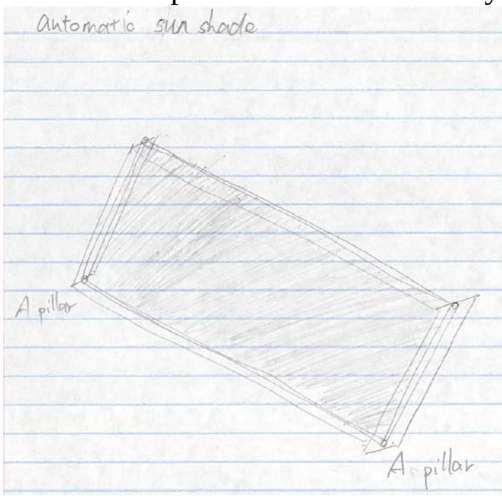
Up & down: Seeing that the cushion incline backwards, we design separate cover that avoids climbing up the inclination of the cushion.



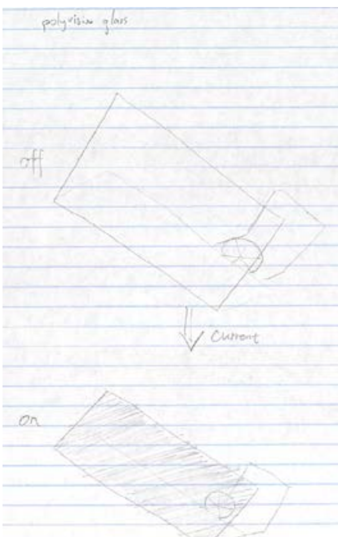
Hollow shield glass: Opaque liquid will inject into the space in between and prevent the interior of the car from sun loading. The liquid will be drained out and recycled when customer get back to car.



Automatic sun shade: This sun shade is installed between the two A pillars and will deployment itself from top to bottom automatically.



Polyvision glass: When current id put through polyvision glass, it will turns to opaque. This characteristic is utilized to make the front window a shield from sun



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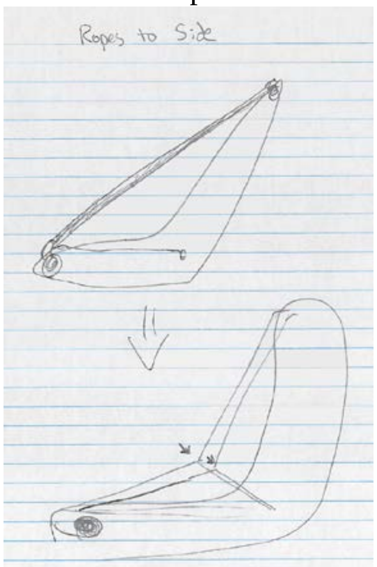
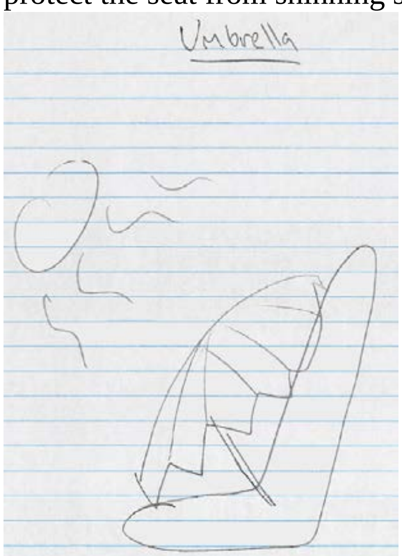
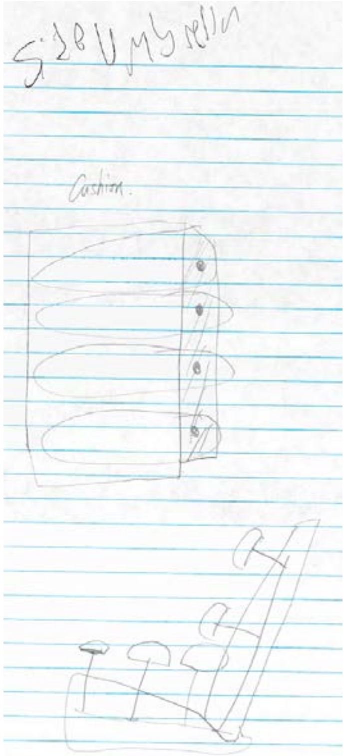
Ropes to side: Two ropes winding at the very end of the seat will pull out the cover directly to the terminal. Once the cover is retracted, these two ropes will go to the side of the seat driven by another two ropes attached.



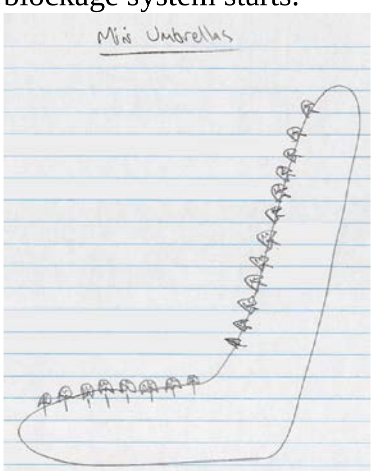
Umbrella: An umbrella is stored in the gap between cushion and backrest. It will open up to protect the seat from shinning sun.



Side umbrella: Considering the difficulty of shrinking the umbrella in between cushion and backrest, we make the umbrella shrinking to the side of the seat.



Mini umbrella: Tiny umbrella is stored below the trim. They are going to open up once our blockage system starts.

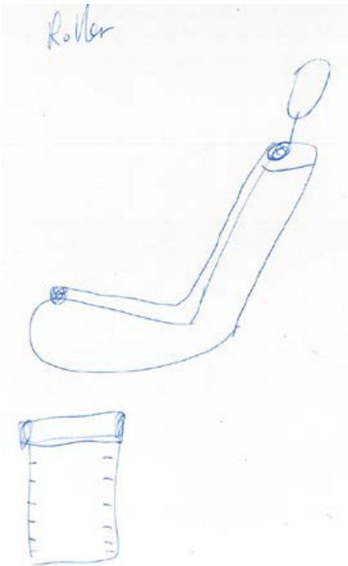


APPENDIX A-2: FINAL DESIGN CONCEPTS

Details the comprehensive designs and concepts generated be each team member.

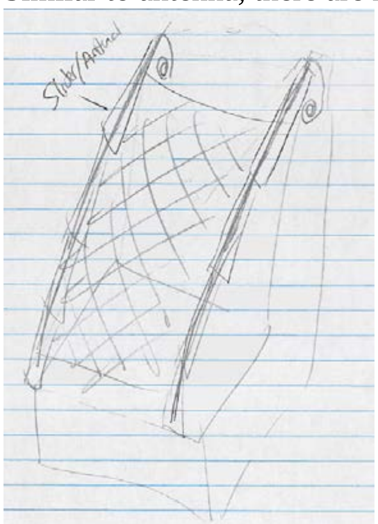
Design 1: Roller runner and staple

Shrinkable antenna shall guide the cover. A round plate combined with a spoke is used to make sure that cover will wind straight onto the spindle.



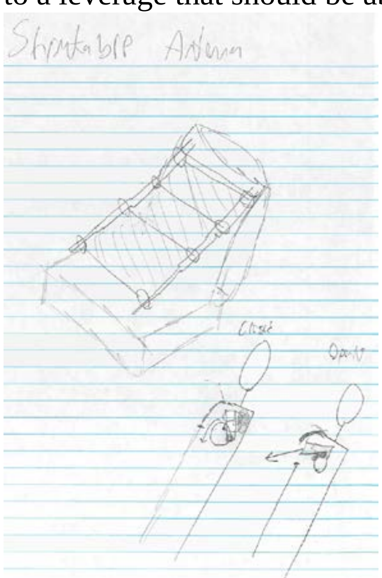
Design 2: Drawer Slide

Similar to antenna, there are rigid slider similar to those in drawers that extend the cover

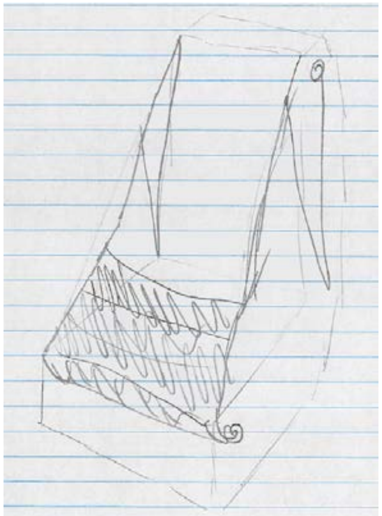


Design 3: Antenna guide and motor
Use antenna as a guide that directly send the cover to the end of the seat. Deployment and retraction of the cover will be implemented by the motor on the top of the seat.

Design 4: Shrinkable antenna
Use antenna as guide. Rings on the side of cover help the cover stay on track. Antenna will link to a leverage that should be able to retract the antenna all the way back into the seat.



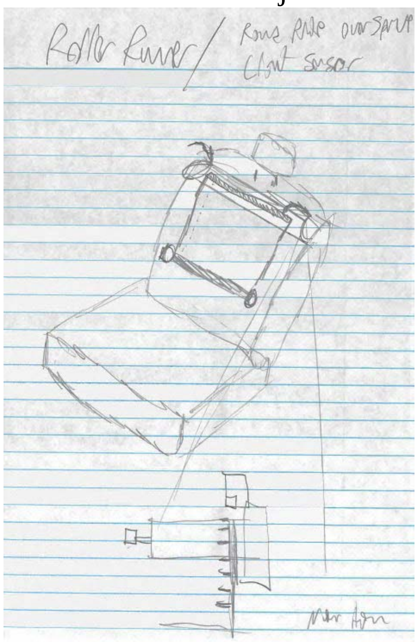
Design 5: Concealed rope guide
Two ropes at the very end of the seat will pull out the cover directly to the terminal. Once the cover is retracted, these two ropes will go to the side of the seat driven by another two ropes attached.



Design 6: Light cover with air flow
Use super light reflective material for cover that can be blew out using a powerful fan. A motor is also needed to retract the cover.

<u>Design 7:</u> Roller runner with light sensor

- Roller runners are used to climb over the cushion.
- Motor on the top helps with deployment and retraction.
- Light sensor combined with grids on the edge of the cover modulates the motion of the cover so that it could adjust itself when two sides don't move with same speed.



APPENDIX B: BILL OF MATERIALS
This appendix gives the detailed list of every part used in our design and the proper sourcing information.

Table 15: Full Bill of Materials for Xtendr Prototype

Material	Supplier	Part number	Price	Qty	Cost	Comments
Reflective Cover	Innovative Insulation Inc	N/A	47.96	1	$47.96	Includes Shipping
Reflective Cover Spindle	Lowes	393923	10.57	1	10.57	
1/4" Aluminum Plate (18"X18")	McMaster	89155K27	86.57	1	$96.58	Includes Shipping
0.04" Aluminum Plate (12" X 24")	McMaster	89015K22	23.55	1	$23.55	
4-40 1/4" Machine Screws; Stainless Steel	McMaster	91735A102	4.33	1	$4.33	Pack of 50
1/4" Dia. 3/4" Lg. 10-24 Thread	McMaster	97345A540	3.48	1	$3.48	
1/4" Dia. 1" Lg. 10-24 Thread	McMaster	97345A542	3.67	1	$3.67	
Nylon Thrust Washer 1/4" Dia	McMaster	2797T1	1.2	11	$13.20	
Nylon-Insert Thin Hex Locknut	McMaster	90633A411	3.18	1	$3.18	Pack of 100
Shoulder Bolts: 1/8" Dia, 1/2" Lg. 4-40 Thread	McMaster	97345A428	3.57	3	$10.71	
Shoulder Bolts: 3/16" Dia, 1/2" Lg. 8-32 Thread	McMaster	97345A489	4.38	2	$8.76	
Shoulder Bolts: 1/4" Dia, 1/2" Lg. 10-24 Thread	McMaster	97345A537	3.22	2	$6.44	
Nylon-Insert Hew Locknut 4-40	McMaster	91831A005	3.93	1	$3.93	Pack of 100
Nylon-Insert Hex Locknut 8-32	McMaster	91831A009	6.06	1	$6.06	Pack of 100
Nylon-Insert Hex Locknut 10-24	McMaster	91831A011	7.04	1	$7.04	Pack of 100
4-40 1/2" Machine Screws; Stainless Steel	McMaster	91735A106	5.52	1	$5.52	Pack of 50
Motor: 499:1 Metal Gearmotor 25Dx58L mm	Pololu	1591	19.95	2	$39.90	
25D mm Metal Gearmotor Bracket	Pololu	1569	7.45	2	$14.90	
Universal Aluminum Moutning Hub for 4mm Shaft 4-40 Holes	Pololu	1081	6.95	1	$6.95	
7/8" Delrin Acetal Rod, 1ft lg	McMaster	8572K59	3.88	1	$3.88	

Captive Pin 1/8" Dia, 1/2lg SS	McMaster	95648A410	11.99	1	$11.99	Pack of 50
Strong Pulley Steel, 3/64" Rope, 1/8" Shaft, 1/2" OD	McMaster	3434T21	3.82	2	$7.64	
Pulley 1/32" Rope, 1/8" Shaft	McMaster	3434T31	1.23	6	$7.38	
Fishing Line 50lb	Amazon	B001AXF3 1M	5.99	1	$5.99	
Thrust Nylon, 0.13" ID, 0.29" OD, .06" Thick	McMaster	90295A370	4.61	1	$4.61	Pack of 100
Thurst Nylon, 0.2" ID, 0.45" OD, 0.03" Thick	McMaster	90295A422	5.25	1	$5.25	Pack of 100
Arduino Board	Trossen Robotics	MG-A000079	27.34	1	$35.33	including shipping
4-40 Nuts	McMaster	90480A005	$0.81	1	$0.81	Pack of 100
Shoulder Bolts: 1/4" Dia, 3/4" Lg. 10-32 Thread	McMaster	91054A140	$8.99	1	$8.99	
Nylon Insert Thin Hex Lock nut	McMaster	90101A004	$4.42	1	$4.42	Pack of 100
Shoulder Bolts: 1/4" Dia, 1" Lg. 10-32 Thread	McMaster	91054A160	$9.27	1	$9.27	
Strong Pulley Steel, 3/64" Rope, 1/8" Shaft, 1/2" OD	McMaster	3434T21	3.82	6	$22.92	
Steel Spring Plunger with Plastic Nose 8-32 Thread	McMaster	8499A11	4.41	1	$4.41	
250W Heat Lamp Bulb	Lowes	76573	5.98	1	$5.98	
McMaster Shipping					$18.51	
Polulu Shipping					$11.90	
				Total	$494.23	

APPENDIX C: ENGINEERING CHANGES SINCE DESIGN REVIEW #3

This section will detail the major changes to our design since Design Review 3.

Considering the issue of durability and cost, we decided to alter the design of the mechanism that deploys a thermally reflective cover across the seat. The design featured in Design Review 3, the Roller Runner, was a system which deployed two motorized wheels capable of driving a cover across the seat. This concept fell out of favor with the group in response to the development of a new design being deemed the Xtendr. It is a design which utilizes a scissor mechanism to extend and retract in a more repeatable manner without additional wear to the sea surface. The following paragraphs detail the two designs, the reasons for changing, and other minor changes to the Xtendr since its late conception.

Roller Runner

As shown in Figure 60, the Roller Runner system uses two motor-driven wheels mounted at the forward end of the cover to pull the cover out as it runs down and across the seat. Up in the shoulder area of the seat where the Roller Runner initially came out of, the cover remains attached to a motorized spindle. To retract, the spindle begins to turn, wrapping the cover around itself and dragging the wheels back up into the seat. On the contrary, the Xtendr (Figure 61 below) uses a scissor linkage mechanism which mechanically moves the front of the cover out over the seat on a downward angle. This scissor mechanism is preferable, because it only uses one motor for cover deployment and retraction (Figure 63), compared to the three motors needed for the Roller Runner design.

Figure 60: Extension is by Means of Two Front Driving Wheels

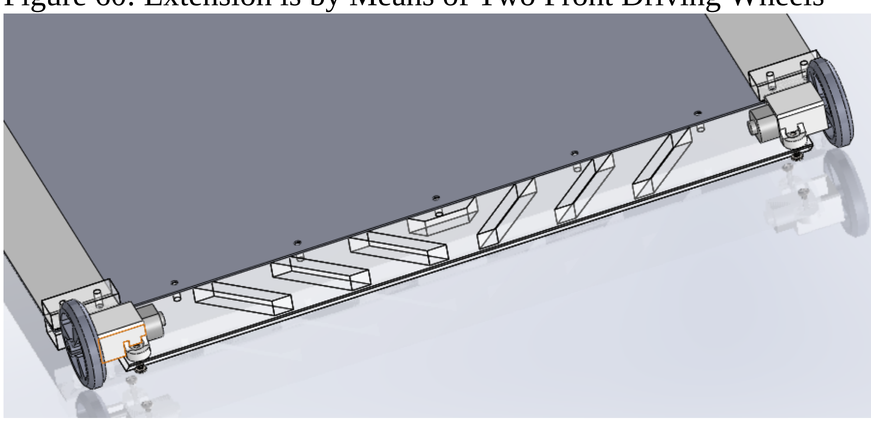


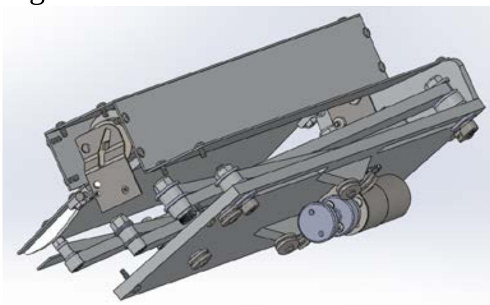
Figure 61: Extension by Means of a Scissor Mechanism

We decided to made this change because our original roller runner design suffers from poor repeatability and a high cost. The Roller Runner could easily go astray due to various uncertainties such as varying angles between the backrest and the cushion, different motor speeds between the two motor-driven-wheels, by simply getting bumped by an occupant in the vehicle. This could result in the cover not winding tightly around the spindle which would cause more issues the next deployment. The unknown repeatability and functionality of the entire system is what caused us to reconsider this concept. Therefore we performed preliminary tests prior to beginning manufacturing to verify that our concerns were well founded. Sure enough, Figure 62 shows that the cover loosely winds around the spindle if it is not centered. The offset between the edge of spindle and the edge of cover could be as large as one inch. This might result in other issues such as an inability to retract the Roller Runner back into position or a failure to fit the spindle within the volume limit.

Figure 62: Preliminary Test Result Regarding Cover Offset Distance

To avoid this, we considered using sensors to modulate the deployment and retraction process. Other ideas included using a laser emitter and receiver to guide the roller runner on top of using an encoder to accurately control the motor rotation speed. However, the vulnerability of the sensor system would also hurt the repeatability and durability of the entire system, not to mention the additional costs when we were already struggling to meet both the budget and the manufacture cost specification (the price for an encoder is 15 dollar). As shown in Appendix C Table 17 the cost for the roller runner design means that we will probably go over our budget. Despite other costs dropping for mass manufacturing, three motors, a laser and a sensor will most likely push our manufacturing cost over the $35 threshold.

Figure 63: Xtendr Uses One Motor



Xtendr

Therefore, we decided to move on to the Xtendr. One of the many advantages is that it only uses one motor to deploy and retract the cover. This alone brings down our budget and manufacturing cost significantly. As shown in Figure 64, Xtendr has a scissor mechanism with four levels. By pulling the two end bolts in the slots closer together, it will deploy the mechanism. Releasing them away from each other retracts the mechanism. Two loops of 50lb fishing line are used to move the bolts. The line wraps around a motor driven spindle that will simultaneously wind up and release the fishing line, before traveling around a system of pulleys, which would vary the direction it is pulling the shoulder bolts. Therefore, the direction of motor rotation will determine whether Xtendr deploys or retracts. Higher repeatability is another advantage over roller runner. We do not have to worry about synchronizing the motor rotation speed, because both fishing lines wind around the only motor and consequently the two bolts will be drawn at the same speed simultaneously. Because of this repeatability, it does not require a sensor, further reducing the cost. The estimated cost for Xtendr is also attached in Appendix C Table 18.

Figure 64: Four Level Scissor Mechanism

Prof. Krauss inspired us (Krauss, Professor, 2012) to develop the scissor mechanism idea as a substitute for the telescope design in a meeting on Nov. 1^{st}. At the beginning of Design Review 3, we started with the highest rated design in the Pugh Chart, that is, the telescoping design, as shown in Table 16. However, we were unable to find an appropriate telescope in market that would fit our weight and volume limits. So we move to the second preferred design, the Roller Runner. This became our original ‘alpha’ design for Design Review 3. Through some analysis and further discussion with Prof. Krauss (Krauss, Professor, 2012) we continued to see problems in further developing the Roller Runner design. After another secondary brainstorming session we came up with and select this scissor mechanism as an alternative solution for the telescopic design. This change was formally authorized by the JCI on a Nov. 8th meeting.

Table 16: Team Comprehensive Pugh Chart; Both Design #2 and Design #4 Use Telescoping Concept

Thermal Blockage		Reference													
Selection Criteria	**Weight**	**1**		**2**		**3**		**4**		**5**		**6**		**7**	
		Rating	Weighted	Rating	Weighted	Rating	Weighted	Rating	Weighted	Rating	Weighted	Rating	Weighted	Rating	Weighted
Keep Seat Cool	14	3	42	3	42	3	42	3	42	3	42	3	42	3	42
No Negative Comfort Impact	7	3	21	3	21	3	21	3	21	3	21	3	21	3	21
Max Area Cooled	5	3	15	3	15	3	15	3	15	3	15	3	15	3	15
Uniform Surface Cooling	2	3	6	3	6	3	6	3	6	3	6	3	6	3	6
Durability	7	3	21	4	28	3	21	4	28	2	14	3	21	3	21
Repeatibility	7	3	21	4	28	2	14	4	28	4	28	1	7	4	28
Automatic Deployment	14	3	42	3	42	3	42	3	42	3	42	3	42	3	42
Low Power Draw	5	3	15	3	15	4	20	4	20	4	20	2	10	2	10
Within the seat volume	5	3	15	3	15	3	15	3	15	1	5	3	15	3	15
No Damage to the seat after Insta	7	3	21	4	28	4	28	4	28	4	28	4	28	3	21
Self Adjustment	5	3	15	3	15	3	15	3	15	3	15	3	15	4	20
Manufacturability	7	3	21	2	14	3	21	3	21	2	14	3	21	3	21
Cost	5	3	15	3	15	3	15	3	15	3	15	3	15	1	5
Retraction Time	10	3	30	4	40	3	30	4	40	3	30	3	30	3	30
Total	100														
Total Score	500		300		324		305		336		295		288		297
Rank															

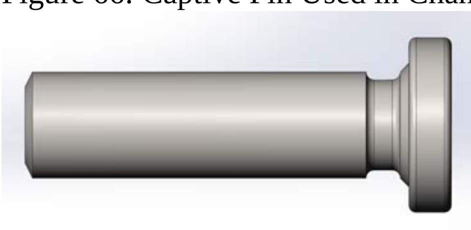
Detail budget estimations are shown in the Appendix C Table 17 and Table 18.

Other Minor Changes

Apart from the main design change from Roller Runner to scissor mechanism, we made several minor changes. Although the scissor mechanism improves the repeatability, it has an issue involving a change point at the first level linkages, which we did not expect when we initially made the design. To minimize the storage volume, the angle between the front most level linkages is designed to be as flat as possible. However, with the cover pulling back on the leading edge, the front linkage arms actually bend inward, preventing the linkage from extending fully out. To overcome this change point, a huge torque is needed to force the front most linkage back into the correct position. As a result of this force, the fishing lines used to pull the linkage broke numerous times during testing.

Our first idea for addressing the change point was to avoid the change point altogether by modifying the mechanical structure. To do this, we press fit a pin into one of the second level linkages that would act as a hard stop, preventing the front linkage arms from moving past the change point (Figure 65). Thus, the beginning angle of the front most level linkages increases and the force needed to go through the change point consequently decreases. But this modification did not solve the problem completely. We observed a phenomenon where the entire linkage system lifted up a little at the beginning of each deployment. This lift caused the first level linkage to be caught by the rim of the pin as shown in Figure 66. This sequentially generates considerable friction and further works against the already strained fishing lines. This lead us to wind tape around the pin to make the diameter of the pin uniform along its entire length. After all of these changes in an attempt to remove the change point, we still couldn’t get the scissor linkages to move smoothly at that point.

Figure 65: Pin on Second Level Linkage Constraining the Initial Position of the Front Most Linkage


Figure 66: Captive Pin Used in Change Point Press Fit Elimination


Another solution that came to mind was to remove one set of linkage bars. This would allow for a larger starting angle, meaning less strain on the fishing lines, as well as a smaller chance of experiencing the change point. To make this change, we removed the second level from the base of linkages because it uses a similar size of shoulder bolts on both ends allowing for a connection between the base links and the links second from the front. After this removal (shown in Figure 67 and Figure 68), the change point and initial sticking issues dropped significantly and the entire linkage mechanism moved much more smoothly. During mechanism extension, the motor drives it readily and we have not seen near as many fishing wire failures. With regards to retraction, the cover is able to come back all the way into the housing cover without ever stopping/sticking. One of our main hesitations concerning removing an 'X' from the overall linkage was that this would increase the retraction time, since the overall linkage must move through a greater angle to reach the same extension length of the four 'X' mechanism. There was ample fear that we would not meet the 8 second specification. When we saw that this three 'X' mechanism could still retract in the allotted time we decided to make the change permanent.

Figure 67: New Design with Three ‘X’s (Levels of Linkages)

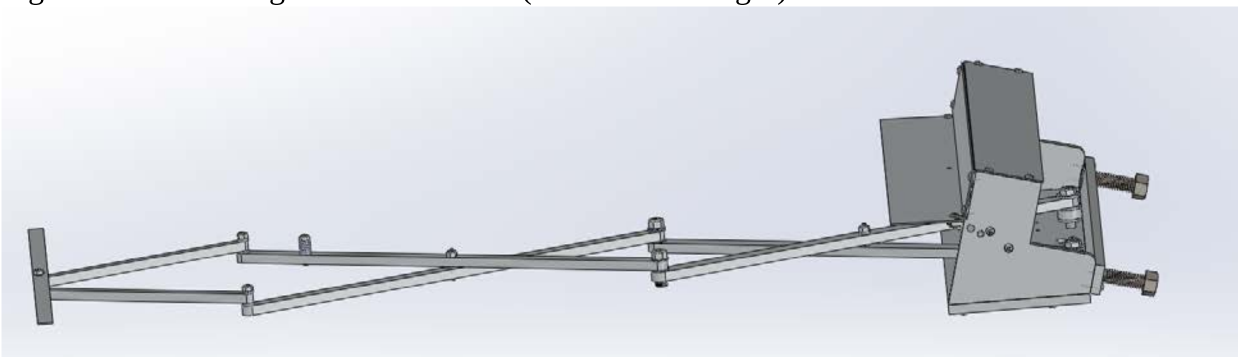
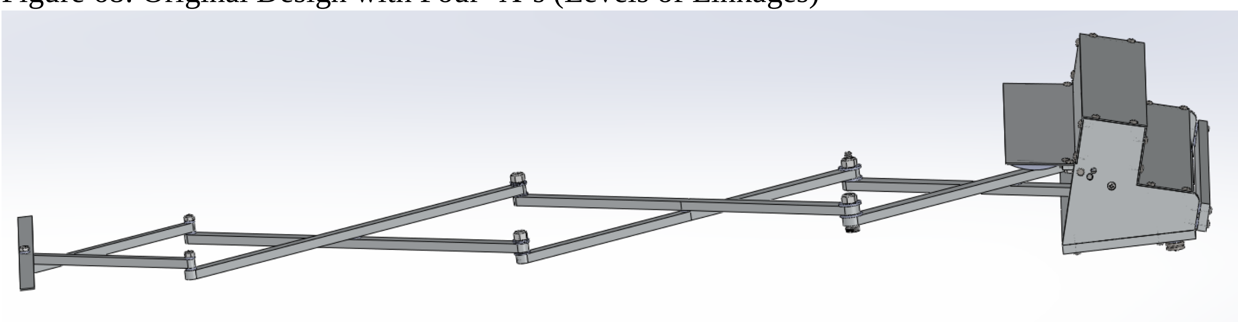


Figure 68: Original Design with Four ‘X’s (Levels of Linkages)



Cost analysis of roller runner and Xtendr

Table 17: Roller Runner Cost Index

Location	Supplier	Part number	Price	Quantity	Cost
Cover	non-woven perforated fabric		47.96	1	$47.96
Motor	Pololu	Pololu item #: 1093	15.95	2	$31.90
Motor Housing	Pololu	Pololu item #: 1089	4.99	2	$9.98
Wheels	Pololu	Pololu item #: 1088	6.98	1	$6.98
Motor: 499:1 Metal Gearmotor 25Dx58L mm	Pololu	1591	19.95	1	$19.95
25D mm Metal Gearmotor Bracket	Pololu	1569	7.45	1	$7.45
Universal Aluminum Moutning Hub for 4mm Shaft 4-40 Holes	Pololu	1081	6.95	1	$6.95
Spindle to gear and bearing transition	McMaster	P/N: 8576K14	1.41	1	$1.41
Spindle Gear	SDP/SI	P/N: A 1T 2-Y32048	6.67	1	$6.67
Spindle Bearing	McMaster	P/N: 60355K506	5.7	2	$11.40
Bottom Board		0.236 in to analysis	7.13	1	$7.13
1/4" Aluminum Plate (18"X18")	McMaster	89155K27	86.57	1	$86.57
0.04" Aluminum Plate (12" X 24")	McMaster	89015K22	23.55	1	$23.55
4-40 1/4" Machine Screws; Stainless Steel	McMaster	91735A102	4.33	1	$4.33
1/4" Dia. 3/4" Lg. 10-24 Thread	McMaster	97345A540	3.48	1	$3.48
1/4" Dia. 1" Lg. 10-24 Thread	McMaster	97345A542	3.67	1	$3.67
Nylon Thrust Washer 1/4" Dia	McMaster	2797T1	1.2	11	$13.20
Nylon-Insert Thin Hex Locknut	McMaster	90633A411	3.18	1	$3.18
Shoulder Bolts: 1/8" Dia, 1/2" Lg. 4-40 Thread	McMaster	97345A428	3.57	3	$10.71
Shoulder Bolts: 3/16" Dia, 1/2" Lg. 8-32 Thread	McMaster	97345A489	4.38	2	$8.76
Shoulder Bolts: 1/4" Dia, 1/2" Lg. 10-24 Thread	McMaster	97345A537	3.22	2	$6.44
Nylon-Insert Hew Locknut 4-40	McMaster	91831A005	3.93	1	$3.93
Nylon-Insert Hex Locknut 8-32	McMaster	91831A009	6.06	1	$6.06

Nylon-Insert Hex Locknut 10-24	McMaster	91831A011	7.04	1	$7.04
4-40 1/2" Machine Screws; Stainless Steel	McMaster	91735A106	5.52	1	$5.52
7/8" Delrin Acetal Rod, 1ft lg	McMaster	8572K59	3.88	1	$3.88
Captive Pin 1/8" Dia, 1/2lg SS	McMaster	95648A410	11.99	1	$11.99
Strong Pulley Steel, 3/64" Rope, 1/8" Shaft, 1/2" OD	McMaster	3434T21	3.82	2	$7.64
Pulley 1/32" Rope, 1/8" Shaft	McMaster	3434T31	1.23	6	$7.38
Fishing Line 60lb	Amazon		5.99	1	$5.99
Thrust Nylon, 0.13" ID, 0.29" OD, .06" Thick	McMaster	90295A370	4.61	1	$4.61
Thurst Nylon, 0.2" ID, 0.45" OD, 0.03" Thick	McMaster	90295A422	5.25	1	$5.25
Arduino Board	Shopping website		27.34	1	$27.34
				Sum total	$418.30

Table 18: Xtendr Cost Index

Material	Supplier	Part number	Price	Quantity	Cost
1/4" Aluminum Plate (18"X18")	McMaster	89155K27	86.57	1	$86.57
0.04" Aluminum Plate (12" X 24")	McMaster	89015K22	23.55	1	$23.55
4-40 1/4" Machine Screws; Stainless Steel	McMaster	91735A102	4.33	1	$4.33
1/4" Dia. 3/4" Lg. 10-24 Thread	McMaster	97345A540	3.48	1	$3.48
1/4" Dia. 1" Lg. 10-24 Thread	McMaster	97345A542	3.67	1	$3.67
Nylon Thrust Washer 1/4" Dia	McMaster	2797T1	1.2	11	$13.20
Nylon-Insert Thin Hex Locknut	McMaster	90633A411	3.18	1	$3.18
Shoulder Bolts: 1/8" Dia, 1/2" Lg. 4-40 Thread	McMaster	97345A428	3.57	3	$10.71
Shoulder Bolts: 3/16" Dia, 1/2" Lg. 8-32 Thread	McMaster	97345A489	4.38	2	$8.76
Shoulder Bolts: 1/4" Dia, 1/2" Lg. 10-24 Thread	McMaster	97345A537	3.22	2	$6.44
Nylon-Insert Hew Locknut 4-40	McMaster	91831A005	3.93	1	$3.93
Nylon-Insert Hex Locknut 8-32	McMaster	91831A009	6.06	1	$6.06
Nylon-Insert Hex Locknut 10-24	McMaster	91831A011	7.04	1	$7.04
4-40 1/2" Machine Screws; Stainless Steel	McMaster	91735A106	5.52	1	$5.52
25D mm Metal Gearmotor Bracket	Pololu	1569	7.45	1	$7.45

Universal Aluminum Moutning Hub for 4mm Shaft 4-40 Holes	Pololu	1081	6.95	1	$6.95
7/8" Delrin Acetal Rod, 1ft lg	McMaster	8572K59	3.88	1	$3.88
Captive Pin 1/8" Dia, 1/2lg SS	McMaster	95648A410	11.99	1	$11.99
Strong Pulley Steel, 3/64" Rope, 1/8" Shaft, 1/2" OD	McMaster	3434T21	3.82	2	$7.64
Pulley 1/32" Rope, 1/8" Shaft	McMaster	3434T31	1.23	6	$7.38
Fishing Line 60lb	Amazon		5.99	1	$5.99
Thrust Nylon, 0.13" ID, 0.29" OD, .06" Thick	McMaster	90295A370	4.61	1	$4.61
Thurst Nylon, 0.2" ID, 0.45" OD, 0.03" Thick	McMaster	90295A422	5.25	1	$5.25
Arduino Board	Shopping website		27.34	1	$27.34
Motor: 499:1 Metal Gearmotor 25Dx58L mm	Pololu	1591	19.95	1	$19.95
			Sum total		$294.87

APPENDIX D: DESIGN ANALYSIS ASSIGNMENT FROM LECTURE

APPENDIX D-1: MATERIAL SELECTION ASSIGNMENT (FUNCTION PERFORMANCE)

The two major components of our final design are the housing cover and the linkages. The housing cover is designed to store the linkages so that the entire device may be easily inserted into the foam opening of the seat. The linkage arms are designed to extend outward, working against the torsional spring in the cover. They must be able to withstand this spring force throughout the entire cycle without major deflection.

Both the linkage and housing cover have to be light and cheap, so that our final design can meet the weight and cost specifications. We estimated the manufacture cost for the motor, the spindle and the cover to be $12 for one product. We also estimated the labor and energy costs to assemble one product to be $6 (Wallick, 2011).If we can make housing cover under $2.5 and linkage under $1.5, the sum of manufacture cost will be about $22 which is far less than our specification of $35. These estimations are shown in Table 19.

The weight of our motor is 100g and the combined weight of the spindle, the mount, and the cover is 100g, which is already fixed for our final design. If we can make the housing cover less than 300g and the linkage less than 150g, the entire system weight will be about 650g which is far less than our specification of 1000g. Taking the manufacture costs into consideration, the target price (upper limit) for the linkage material is $10/kg and it is $5/kg for the housing cover material. The volume of the housing cover for our prototype 340cm^3 and we expect the volume for the final design is 260cm^3, which can be done by reducing the thickness of the housing cover. Therefore, the target density (upper limit) for the linkage material is 1500kg/m^3 and it is 1200 kg/m^3 for the housing cover material. The estimations for weight are shown in Table 20.

Table 19: Manufacture Cost Constrains the Cost for the Housing Cover and the Linkages

Items	Manufacture cost per product (USD)
Motor, spindle and cover	12
Labor cost and energy cost	6
Housing cover	2.5
Linkage	1.5
Sum	22

Table 20: System Weight Limits the Weight for the Housing Cover and the Linkages

Items	Weight (g)
Motor	100
Spindle, mount and cover	100
Housing	300
Linkage	150
Sum	650

Using the Finite Element Analysis shown in Figure 69, the maximum stress throughout the linkage is about 2.7MPa and the maximum stress on the housing cover is about 2MPa. Considering a Safety factor of 10, we determined the desired minimum yield strength to be 30MPa for the linkage materials and 20MPa for the housing cover material. Since we want the deflection at the far end of linkages to be minimized, the Young's modulus of the linkage material should be greater than 2GPa, giving a deflection of 5mm as shown in Figure 70.

Figure 69: Finite Element Analysis Showing the Maximum Stress on the Linkages and the Housing Cover

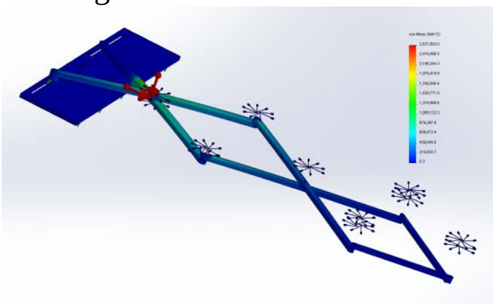
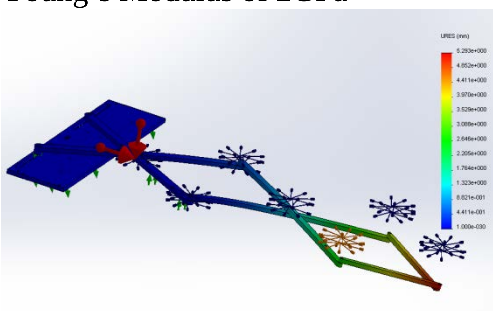


Figure 70: Finite Element Analysis Showing the 5mm of Deflection if the Material has a Young's Modulus of 2GPa



Other elements to be considered for both the linkages and the housing cover were the flammability and UV radiation resistance to be excellent. Moreover, the melting point for both the linkage and the housing cover are 100°C and 80°C respectively. The linkage in particular needs to be capable of handling such temperatures as these because car seats have been recorded as high as 80°C (Carlson, Engineer, 2012). The detailed constraints and results for linkage material and housing cover material are shown in Table 21 and Table 22 respectively.

Table 21: Constraints and Target Values for Linkages

Property	Target value
Price	10 USD/kg
Yield strength	30 MPa
Density	1500 kg/m^3
Young's modulus	2GPa
Flammability	Non-flammable / self-extinguishing
Sunlight (UV) radiation resistant	Excellent / good
Melting point	100°C

Table 22: Constraints and Target Values for Housing Cover

Property	Target value
Price	8 USD/kg
Yield strength	20 MPa
Density	1200 kg/m^3
Flammability	Non-flammable / self-extinguishing
Melting point	80°C

In an attempt to further reduce the cost of manufacturing, one of the focuses will be on choosing materials that can be injected molded. Of the top five linkage materials, the Young's modulus is 150% higher than our constraints (5GPa), the focus will therefore be shifted on reducing the material density. That is why, of the top 5 material options (shown in Figure 72 below), PCT with 15% glass fiber, was the material chosen for linkages. Since the yield strengths of the top four materials for the housing cover are over 23MPa, indicating a safety factor of 11, we will again be focusing primarily on the density in an attempt to reduce the weight. Therefore, we choose PP as the final choice for housing cover (shown in Figure 71 below).

Figure 71: Top Four Material Choices for Housing Cover

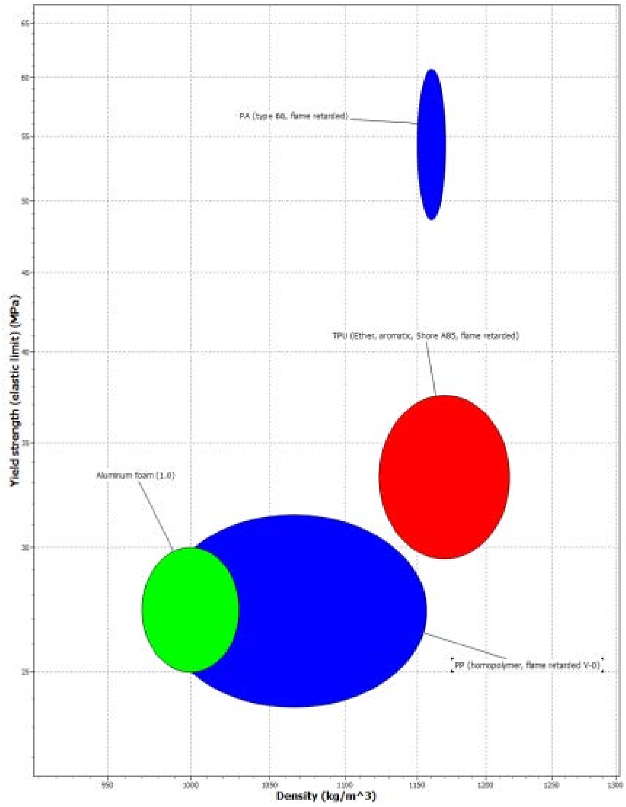
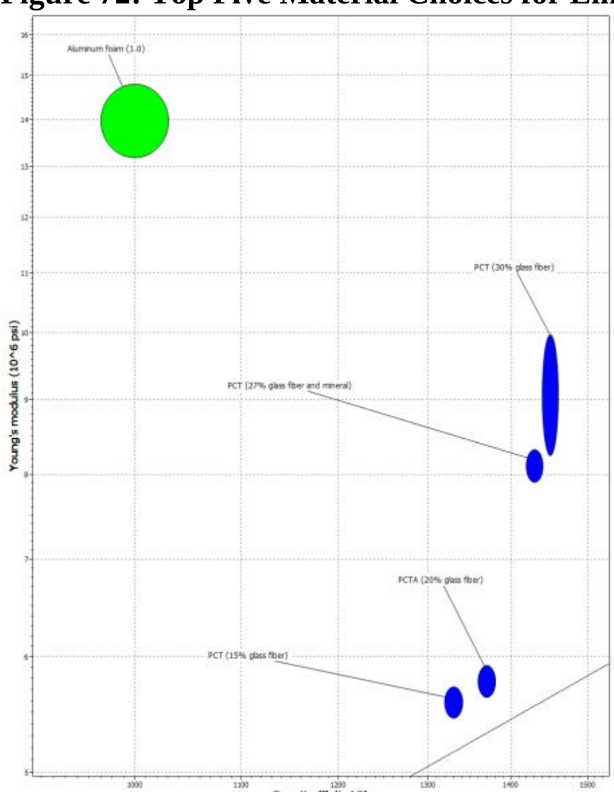


Figure 72: Top Five Material Choices for Linkages

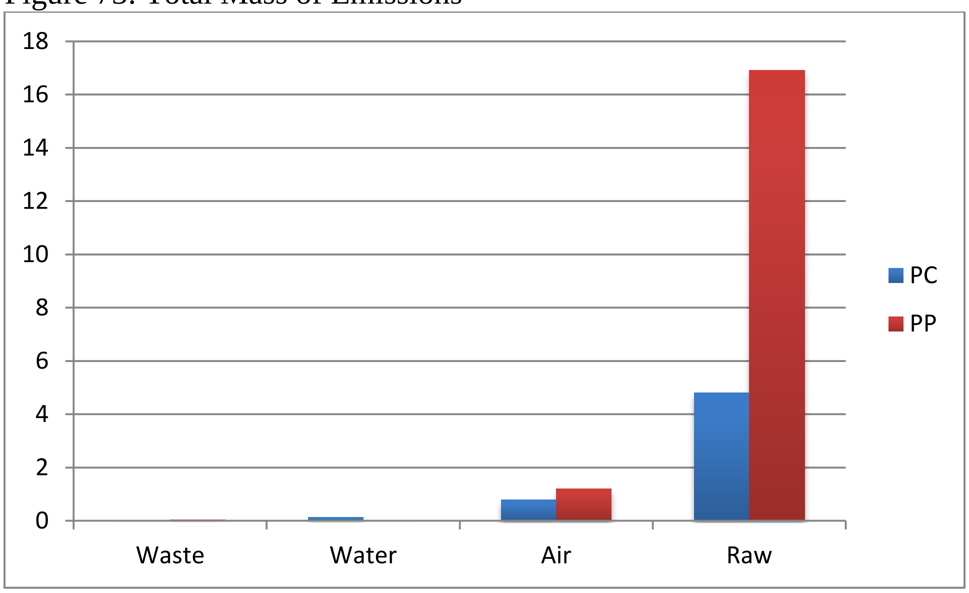


APPENDIX D-2: MATERIAL SELECTION ASSIGNMENT (ENVIRONMENTAL PERFORMANCE)

1. Materials Selected in CES
    a. PCT (Polycyclohexylenedimethylene terephthalate) – Linkages
    b. PP (Polypropylene) – Housing
2. Mass of Materials in Final Design
    a. 128.8 g
    b. 307.3 g
3. Closest Available Materials in SimaPro
    a. Polycarbonate Ganulate (PC)
    b. Polypropylene injection molding
4. Emissions Masses (Figure 73)

    Air: 0.790901 kg
    1.202633 kg
    Water: **0.135824 kg**
    0.000655 kg
    Raw: 4.814616 kg
    16.92276 kg
    Waste: 0.018688 kg
    0.049725 kg

Figure 73: Total Mass of Emissions



5. Which material has a greater emission within each of the categories
    a. PC: Water
    b. PP: Raw, Air, Waste
6. Of the damage meta-categories it would appear that ecotoxicity would most likely be important because when you look at a EI99 Normalized graph (Figure 75) compared to a Characterization graph (Figure 74), the two categories that dominate are both affecting the atmosphere and therefore the ecosystem. These two categories are respiratory inorganics and climate change.

Figure 74: Characterization Graph of Emissions

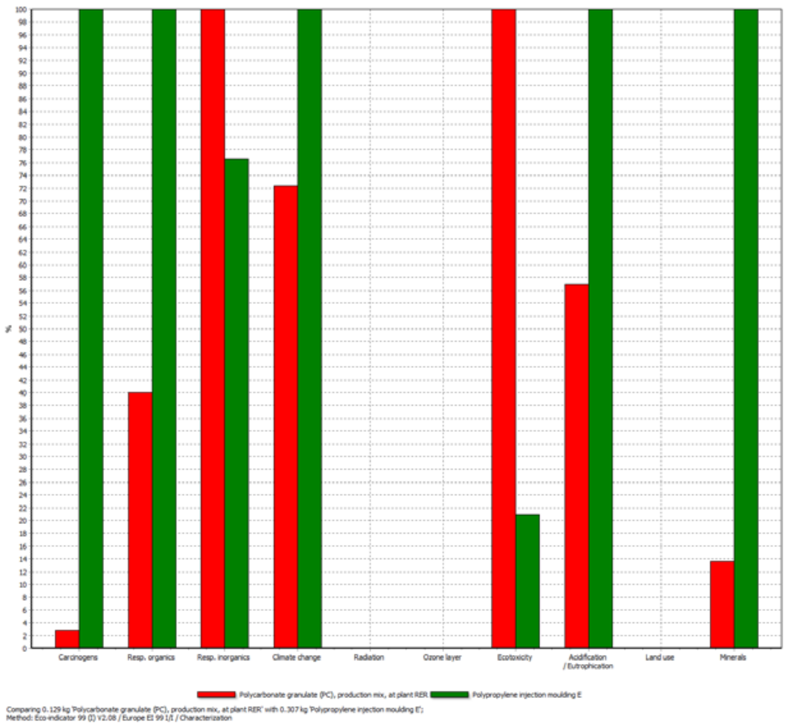
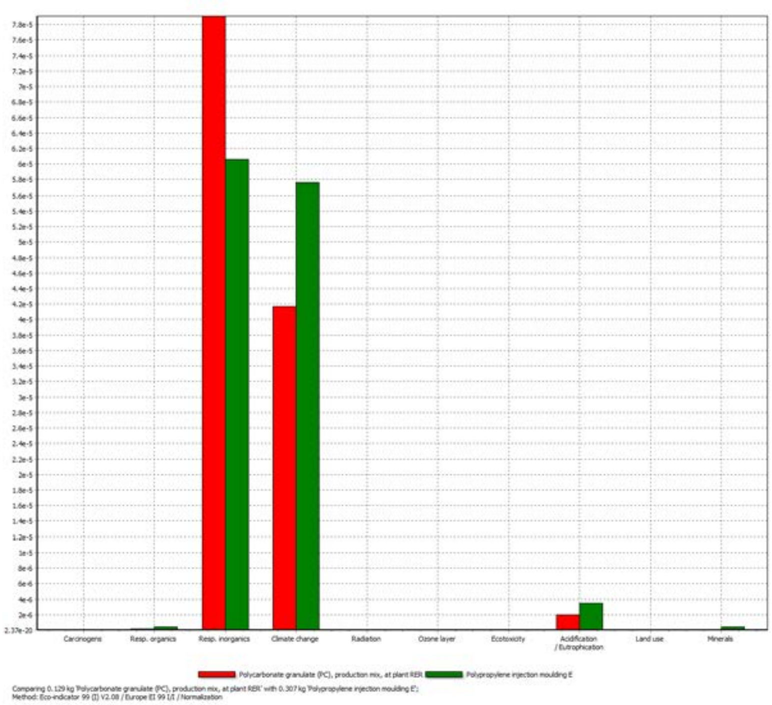


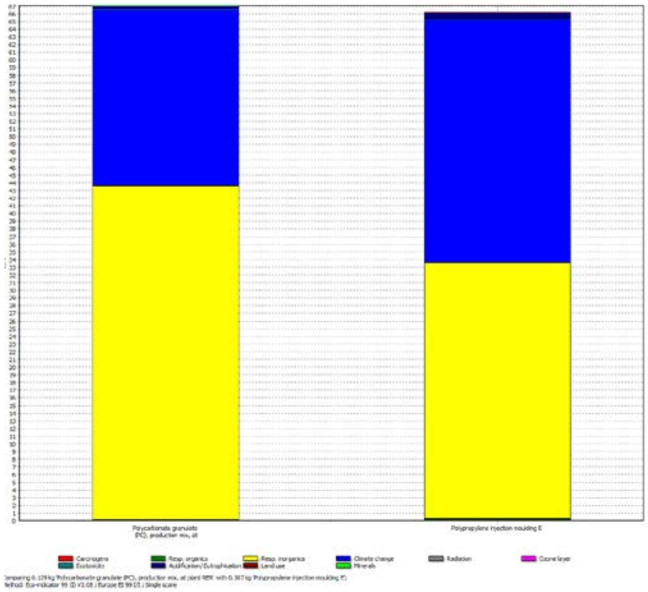
Figure 75: Normalized EI99 Emissions Graph



7. From the point graph (Figure 76), it appears that PC has a slightly higher score than PP with values of 67 and 66 respectively. From these scores the two materials seem to be pretty much equal. Over the long run, if I had to pose a guess, I would say that PP would

have a larger impact on the environment because although it had a slightly lower point value, it had a larger impact on climate change as shown in the single score coupled with the fact that it has much more raw emissions than its PC counterpart.

Figure 76: Single Score Emissions Graph



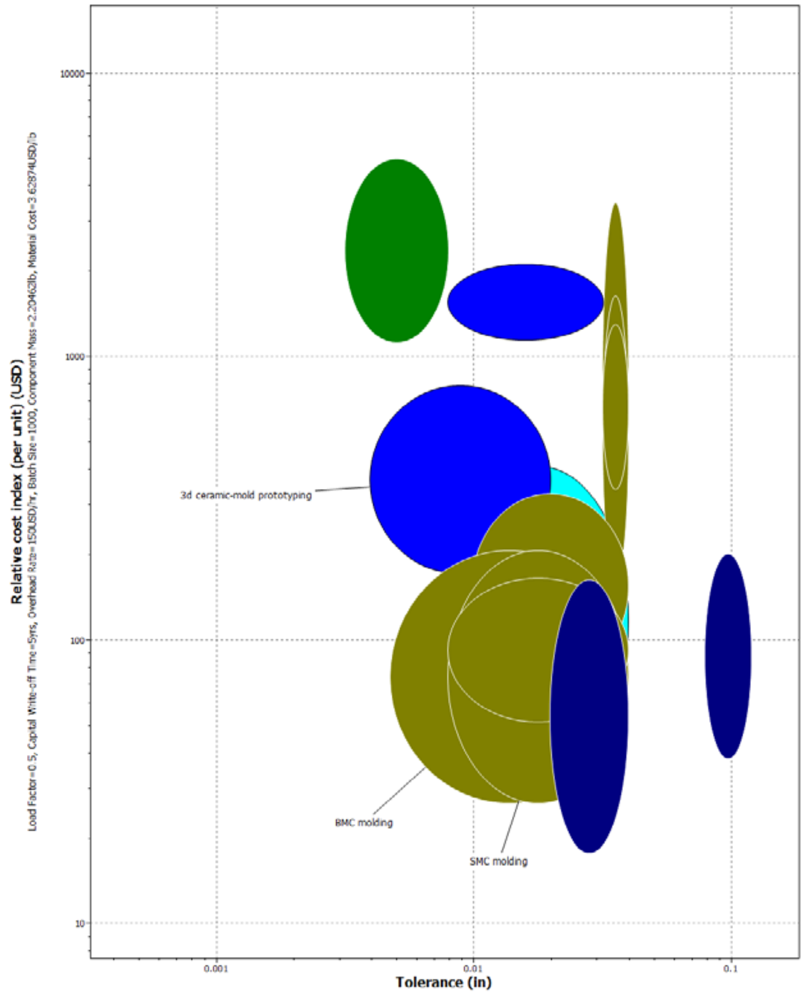
Even after performing this analysis, I would still consider using these two materials. Their overall performance in the previous graphs doesn't appear to be particularly harmful in many of the categories. Because these two different plastics are so similar, I am tempted to believe most injection molded plastics will also have emissions scores in the high sixties making the difference in environmental impact between material minimal.

APPENDIX D-3: MANUFACTURING PROCESS SELECTION ASSIGNMENT

Because our prototype is designed to block the solar radiation and keep the seat surface at a lower comfortable temperature, we believe our design would be most useful for people in warm, sunny climates such as California and Arizona. However, despite cold winters in Michigan, the summers here can also get hot enough to cause an automobile seat to become quite uncomfortable. Going the maximum assumption, every automobile owner in the continental United States would have use for at least 1 product in their vehicle. If we were to continue with this maximum assumption, it could be approximated that every vehicle in the world would have a use for this thermal blockage system. Although there are some cars in very cold climates that may not actually need our device, vehicles in warmer climates may request two and therefore balance the result. According to world vehicle report, the number of vehicles in operation worldwide surpassed the 1 billion mark in 2010. From this, we assumed that our maximum possible production volume could be on the order of 1 billion (Sousanis, 2011).

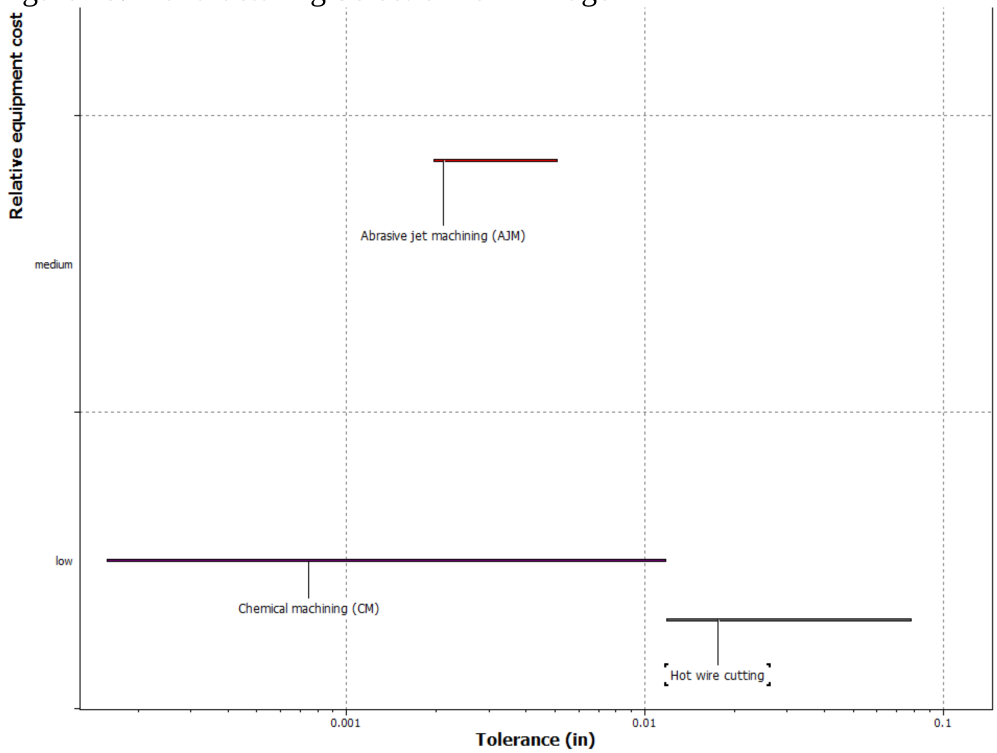
The material used for housing is polypropylene, a thermoplastic polymer. The housing has lower roughness and tolerance requirements than the linkage. We thought molding would be a better way for mass manufacturing. From the CES software Figure 77, we can see that with lowest relative cost per unit, the BMC molding and SME molding would be a good idea. With a similar cost to SME, BMC molding would have a better tolerance and would therefore be better for our application. Also, BMC molding is the most economical processes for high volume production, and with a target of one billion, it doesn’t get much larger than that. CES notes that it is perfect for thermoplastic resins such as PP, the material we used for housing. Therefore we thought it would be the best way for mass manufacturing. Once we had this material manufactured into a flat sheet, we would be able to just cut it as we want and assemble the housing case of our design with screws.

Figure 77: Manufacturing Selection for Housing Material



The material used for linkage is Polycyclohexylenedimethylene Terephthalate (PET), which is thermoplastic polyester. The linkage in our design is bar-size with a maximum thickness of 0.25 inches and a maximum length of 12 inch long. The linkage should have high tolerance and roughness requirements. After the shaping, we will be able to drill precise holes on the bar to meet the linkage requirements. We can use the same method to form PET into a flat sheet, because BMC molding is also a good method to make flat sheet polyester with a good roughness. After we have completed the primary shaping processes, we could cut it using cutting processes. From CES software Figure 78, we can see that we have three manufacturing options, this is because chemical machining doesn't work for polyester and AJM is a little higher cost than hot wire cutting. Since 0.01 inch tolerance is good enough for the linkage bar, we would choose hot wire cutting for the linkage cutting process. Hot wire cutting has a pretty low equipment cost, good tolerance range and similar cutting speeds making it ideal for manufacturing our linkages.

Figure 78: Manufacturing Selection for Linkage



APPENDIX E: PARAMETER CALCULATIONS

Cover Weight Torque

```
g = 9.81 ; % gravity (kg/m2)

tensilestrength = 1.43 ; % tensile strength (MPa) assumed as UTS
coverdensity = 84.5 ; % apparent density (g/m2) 17.3 lb/Msf
thickness = 0.28 * 10^-3; % cover thickness (m) 10.9mil
spindleid = 0.017145; % spindle innder diameter (m)

width = 0.30; % cover width (m)
maxlength = 0.72; % maximum length loaded with weight (m)

% calculate the weight
coverweight = coverdensity * width * maxlength % (kg)

% ans =      18.2520

cushionlength = 0.42; % length of cushion (m)
backlength = 0.53; % length of back (m);


% calculate the rpm of the spindle
roundlength = pi * roller_diameter(0,spindleid,thickness); % perimeter of one
round
rounds = maxlength / roundlength; % how many rounds at most need to be done
time = 6; % requried retraction time (sec)
spindlerpm = rounds / time * 60 % required rpm
% ans =     133.6734
```

Deflection

```
b = [0.3175 0.65 0.65]/100;
h = [0.3175 0.65 0.3175]/100;

L=0.3;
I = b.*h.^3/12;
E =  70e9;
w = 16.3306/1000*9.81/0.03;

level = 3;

del1= level*w * L^4/8/E./I*1000 % total del due to weight (mm)


density = 2.7; % aluminium density (g/cm3)
L= 30; % length (cm)
width = 0.635; % beam width (cm)
thickness = 0.3175; %beam thickness (cm)
g = 9.81; %gravity
onebeam = density*L*width*thickness; % one beam weight (g)
Hz0 = 31; % force from cover retracting (N)
b = 2*onebeam*g/1000*level; % weight of beam for each level (N)


del2 = 0;

l =0.3;
for n = 1:level
    Zi = (Hz0+n*b)/4;
    del2= Zi*l^3/3/E./I + del2  ;%del due to force
end

del2

totaldel = del1+ del2*1000 %(mm)
```

Initial Length

```
beamwidthinch =1/8:1/8:0.5 ; % width of the beam (inch)


L = 30 ; % length of each beam (cm)
intocm = 2.54; % inch to cm

beamwidth= beamwidthinch'* intocm;

i = 3:8;
initiallength = 2* beamwidth*i; % cm


plot(i, initiallength,'o')
ylabel('initial length (cm)')
xlabel('level needed')
xlim([1 9])
x=[1 10]
y=[9 9]
hold on
plot(x,y,'--')
legend '0.3175cm (1/8 in)' '0.635cm (1/4 in)' '0.9525cm (3/8 in)' '1.27cm
(1/2 in)' LOCATION 'NorthWest'
```

Level Angle

```
Maxlength = 32; % maximum housing length (cm)

L = 30 ; % length of each beam (cm)
theta = 20:5:60; % final angle (deg)

% all theta angle is in rad
finallength = sqrt(53^2+32^2) + 10;

i = ceil(finallength./L./sin(theta/180*pi));

plot(i,theta,'o')
ylabel('theta (deg)')
xlabel('level needed')
xlim([1 10])

k = min(i):max(i);
newtheta = asin(finallength./L./k);
figure
plot(k, newtheta/pi*180,'+')
for m= 1:length(k)
    text(k(m),newtheta(m)/pi*180-3,
num2str(newtheta(m)/pi*180),'HorizontalAlignment','center')
end
xlabel('level number')
ylabel('required theta (deg)')
xlim([1 9])
ylim([10 55])
```

Outside and Inside Diameter Spindle

```
L = 850; % length of the total cover (mm)
innerd = 10:30; % inner diameter
thick = 1:0.1:3; % cover thickness

od = zeros(length(innerd),length(thick)); % initialize outer diameter



n = 1; % index of od
x = 1; %index of id
y = 1; % index of t

while(x <= length(innerd))
    while (y <= length(thick))
        od(x,y) = roller_diameter(L,innerd(x),thick(y));
        y = y + 1;
    end
    x = x + 1;
    y = 1;
end


x = [10 30 30 10 10];
y = [1 1 3 3 1];
z = [50 50 50 50 50];
plot3(x,y,z)
hold on

index = find(od<50);
z = 50*ones(length(innerd),length(thick));
z(index) = od(index);


meshz(innerd, thick, od, z)
grid on
xlabel('inner diameter (mm)')
ylabel('cover thickness (mm)')
zlabel('outer diameter (mm)')
title('outer diameter with inner diameter and cover thickness')
hold off
```

Roller Diameter

```
function d = roller_diameter(L,d1,t)
% same unit for L, d1, t, same unit for d
%weight = 183; % (g/m2)
%density = 73; % (kg/m3)

%t = 2; % thickness (mm) generally 3 mm

%d1 = 20; % diameter of center hole (mm)
%d2 = ; % diameter of outside diameter (mm)
%L = 85; % lenghth of material (cm)


% L * t = pi * ((d2/2)^2 - (d1/2)^2) function(regardless of unit here)

%solve('L *10 * t = pi * ((d2/2)^2 - (d1/2)^2)','d2')

d =  (2*((pi*d1^2)/4 + L*t)^(1/2))/pi^(1/2); % meter
```

Spindle Motor

```
Ttop=0.7161 ; %(Nm)
%current vs. torque, take average of 6V and 12V.
%speed vs. current will be the same no matter the voltage.
onintonm=0.00706155183333;
degsectorpm=1/360*60;
rpmtoradsec=2*pi/60;

%Free-run speed @ 6V:
w0=[12 15 25 33 32] ;%rpm
%   first four are 25mmD, last is micromotor

%Stall torque @ 6V:
Ts=[300 250 220 170 125]; %oz-in

%Stall current @ 6 V
Is = [2.2 2.2 2.2 2.2 1.6];

%Free-run current @ 6 V
I0 = [0.08 0.08 0.08 0.08 0.07];

%%target rpm for the bottom wheel
rpm = 0.2653;

%%
%Torque vs. speed
%find curve for different motor
%slope
k1=-(Ts)./(w0);
%curve
for i = 1:5
w=[0:0.01:w0(i)];
T=k1(i)*w+Ts(i);
plot(w,T,'--','color',[i/6,0,0])
hold on
end

xlabel('motor speed output (rpm)')
ylabel('motor torque output(oz-in)')

plot(rpm,Ttop/onintonm,'o')
legend  '499:1 300oz-in' '378:1 250oz-in' '227:1 220oz-in' '172:1 170oz-in'
'1000:1 125oz-in' 'target point'
title('motor comparison without ratio change')

hold off
ylim([0 300])
%%
%power draw
i = 1; % select third motor
Kc = Ts./(Is-I0);
current = I0(i)+Ttop/onintonm/Kc(i)
power = 6*current
energy = power * 8
```

Spindle Stress

```
T = 0.0538; % torque at the spindle(Nm)
L = 0.3; % length of the spindle (m)
od = 0.015875; % outdiameter of the spindle (m)
id = 0.00635; % inner diameter of the spindle(m)
theta = 0.001 / od; % the target theta is having maximum 1 mm difference
throught the spindle

J = pi * ((od)^4-(id)^4)  / 32;

G = T * L / J / theta / 10^6 % modulus of rigidity (Mpa)
% ans = 42.1721 Mpa
% target plastic material has a rigidity (G) larger than 42.1721 Mpa
```

Xtendr

```
% sym H is the force on the tip of extender
% sym theta is the angle of beam with horizontal line
% sym Xi is the horizontal force at each beam bottom joint
% sym Yi is the vertical force at each beam bottom joint
% sym XMi is the force at beam center joint

% level at the tip is 1

% Assumption 1: beams are horizontal and no vertical deflection
% Assumption 2: No friction from joint

%It should  be  noted  that the  reaction  loads  are  completely
%independent  of the  length of the scissor  members and  only  depend  on
%the applied  load (including  the distributed weight  of the lift)  and
%the angle  of the scissor  members from  horizontal.
width = 0.9525; % beam width (cm)
level = 3; % level number
%-----------------------------------------------------------
density = 2.7; % aluminium density (g/cm3)
L= 30; % length (cm)
thickness = 0.635; %beam thickness (cm)
g = 9.81; %gravity
onebeam = density*L*width*thickness; % one beam weight (g)



b = 2*onebeam*g/1000; % weight of beam for each level (N)
H = 31; % center force of tip (N)
theta = 0.9257; % final angle(rad)



H = H*2; % convert to fit the equations.
Xi = (H+level .* b/2).*level./2./tan(theta)
% ans = 71.6
Yi = (H+level.*b)/4
% ans = 16.2
XMi = (2*level-1).*H/2.*tan(theta)+(2.*level.^2-2.*level+1).*b./4./tan(theta)
% ans = 208.3

spoolerdiameter = 0.01; % assumed diameter of the spooler (m)

torque = spoolerdiameter/2 * 2*(Xi)
% ans = 0.7161
displacement = 0.1/2; % displacement of the bar end (m)
rpm = displacement / (spoolerdiameter * pi ) / 6
% ans = 0.2653
```

APPENDIX F: ARDUINO CODE FOR XTENDR

```
// This code is for University of Michigan ME450 F12 Team 11 Project.
// The function is to deploy and retract the cover automatically.
// This code should be combined used with a motor shield for Arduino board.

int pinI1 = 8;//define I1 interface
int pinI2 = 11;//define I2 interface
int speedpinA = 9;//enable motor A
int button = 2; // define Button
int coverfdbutton = 6; // define forward button for adjustment
int coverbdbutton = 7; // define backward button for adjustment
boolean out = false; // the cover status


int coverfdspead = 255;//define the spead of motor
int coverbdspead = 255;//define the spead of motor

int coverfdtime = 13; // forward time in sec
int coverbdtime = 11; // backward time in sec

void setup()
{
  pinMode(pinI1,OUTPUT);
  pinMode(pinI2,OUTPUT);
  pinMode(speedpinA,OUTPUT);
  pinMode(button,INPUT);
  pinMode(coverfdbutton, INPUT);
  pinMode(coverbdbutton, INPUT);

}

void  coverbackward()
{
     analogWrite(speedpinA,coverbdspead);//input a simulation value to set the speed
     digitalWrite(pinI2,LOW);//turn DC Motor A move anticlockwise
     digitalWrite(pinI1,HIGH);
}
void coverforward()
{
     analogWrite(speedpinA,coverfdspead);//input a simulation value to set the speed
     digitalWrite(pinI2,HIGH);//turn DC Motor A move clockwise
     digitalWrite(pinI1,LOW);
}


void coverstop()
{
     digitalWrite(speedpinA,LOW);// Unenble the pin, to stop the motor. this should be
done to avid damaging the motor.
     digitalWrite(pinI2,LOW);//turn DC Motor A move clockwise
     digitalWrite(pinI1,LOW);

}



void loop()
{
```

```
  while (digitalRead(button) == HIGH)
  {
    if (!out)
      {
        coverforward();
        for (int i = 0; i < 10 * coverfdtime; i++)
        {
          if (digitalRead(coverfdbutton) == HIGH || digitalRead(coverbdbutton) == HIGH)
          {
            break;
          }
          else
          { delay(100);}
        }
        coverstop();
        delay(1000);
        out = !out;
      }
    else
      {
        coverbackward();
        for (int k = 0; k < 10 * coverbdtime; k++)
        {
          if (digitalRead(coverfdbutton) == HIGH || digitalRead(coverbdbutton) == HIGH)
          {
            break;
          }
          else
          {delay(100);}
        }
        coverstop();
        delay(1000);
        out = !out;
      }
  }

  while (digitalRead(coverfdbutton) == HIGH)
  {
      coverforward();
      delay(100);
      coverstop();
  }

  while (digitalRead(coverbdbutton) == HIGH)
  {
      coverbackward();
      delay(100);
      coverstop();
  }
}
```

APPENDIX G: XTENDR PART DRAWINGS

This appendix shows all of the part drawings used to manufacture the respective parts for the Xtendr mechanism.

Figure 79: Back Mounting Plate

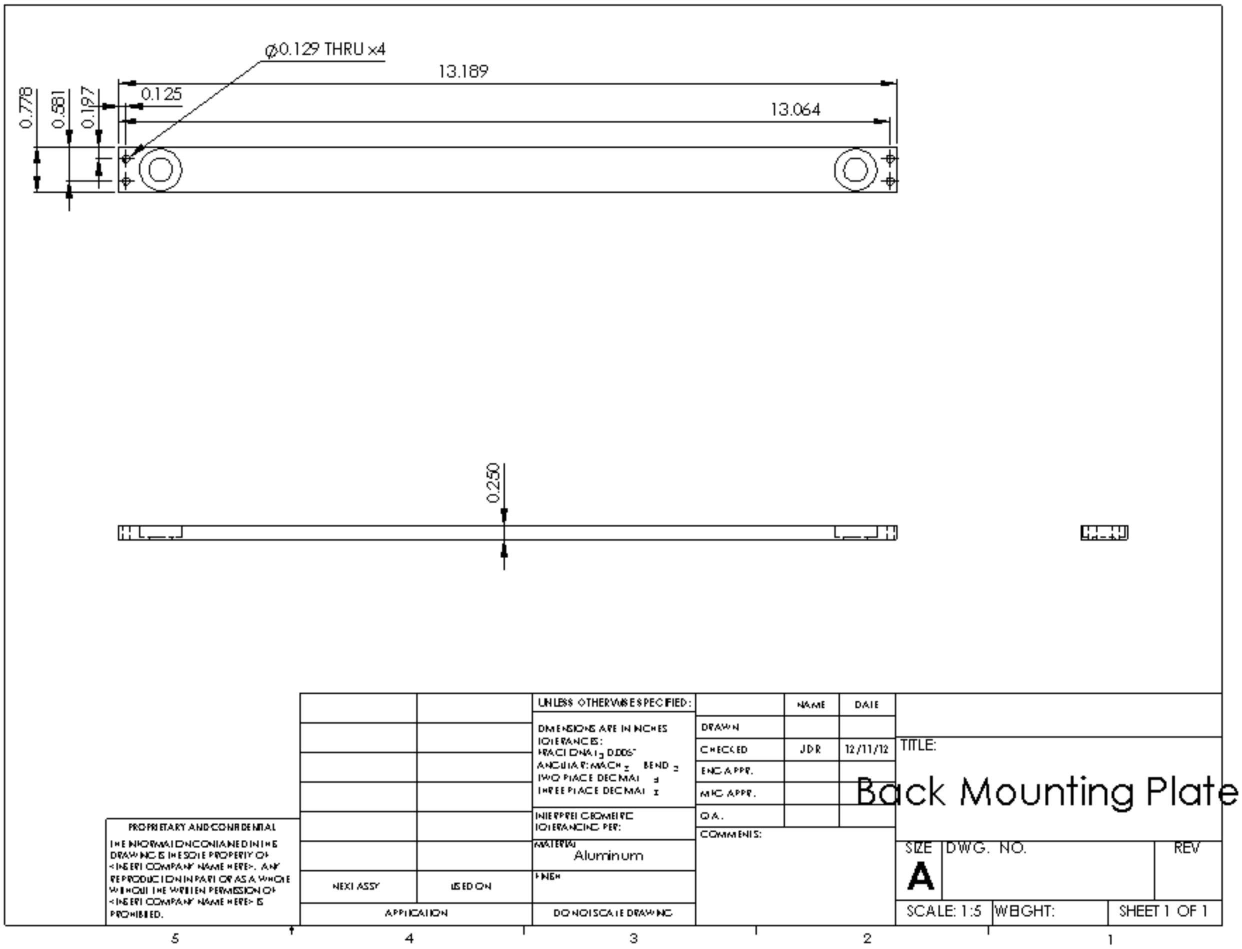


Figure 80: Beam 1 btm

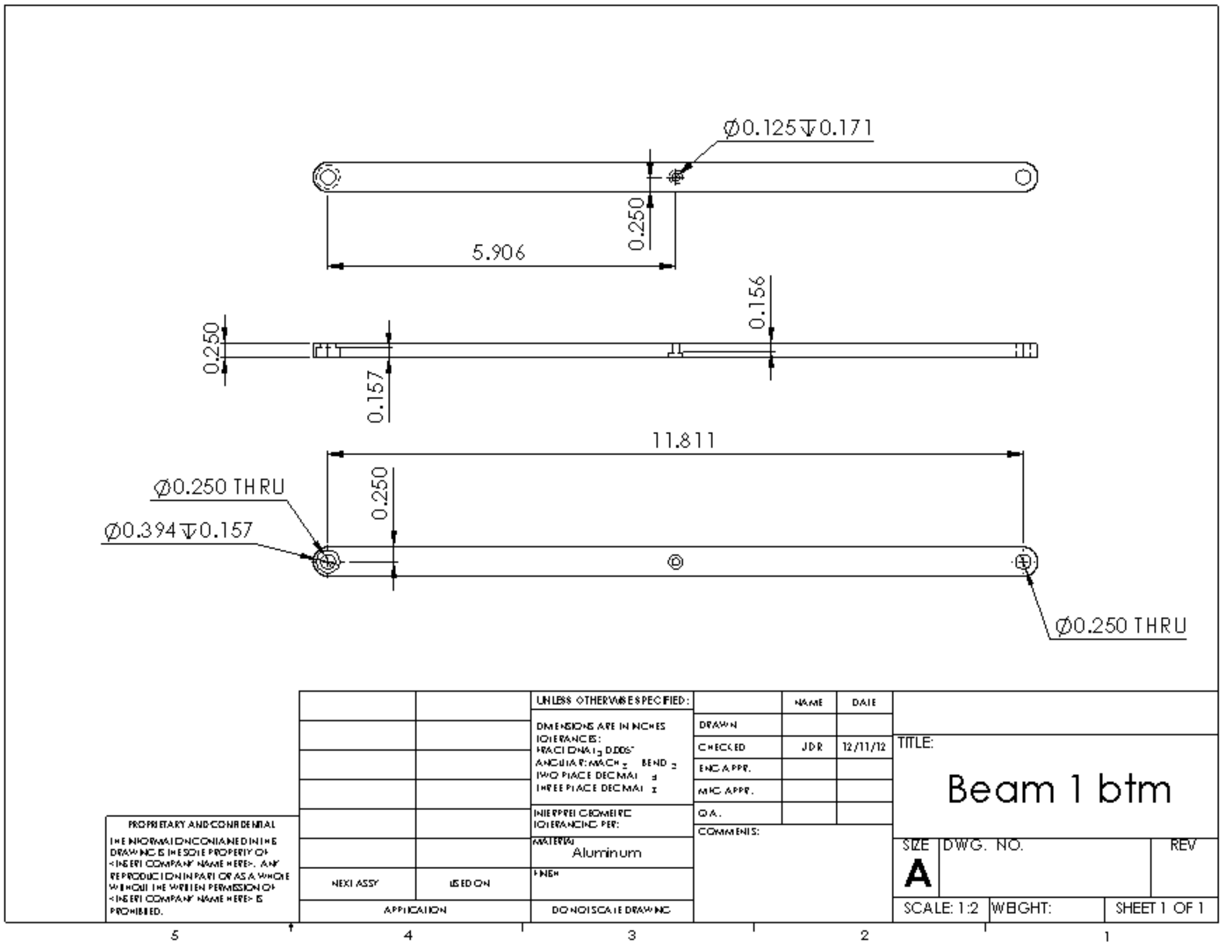


Figure 81: Beam 1

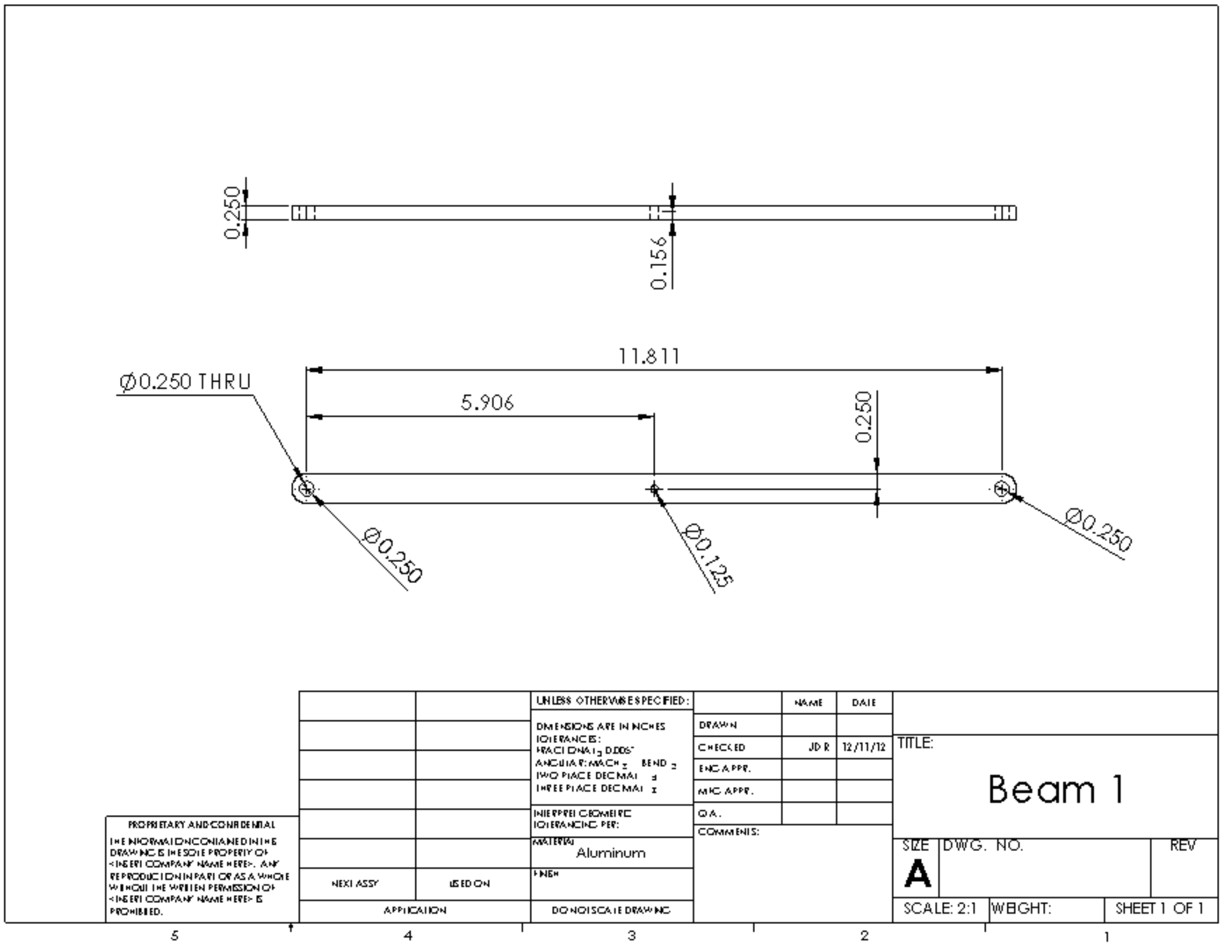


Figure 82: Beam 3 btm

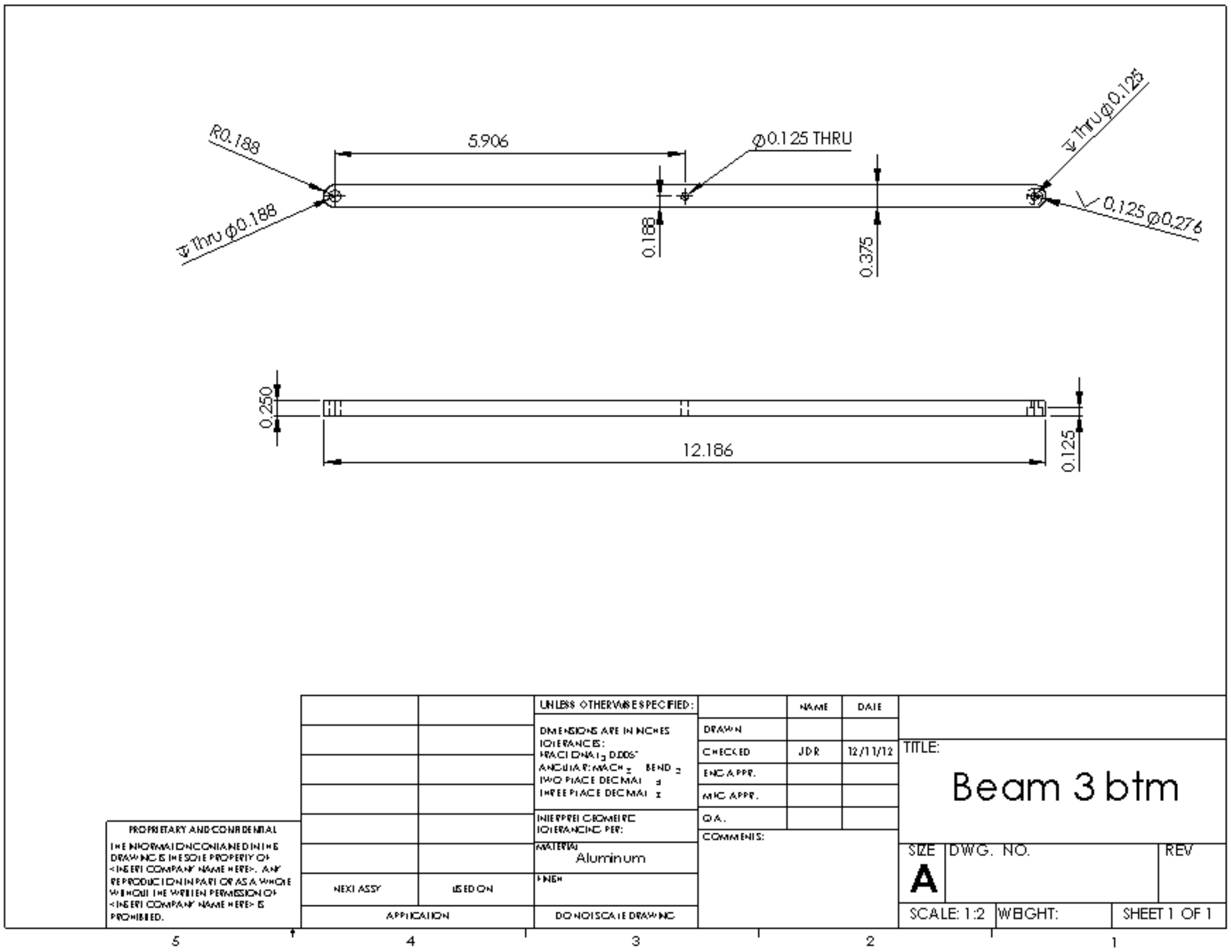


Figure 83: Beam 3 Top

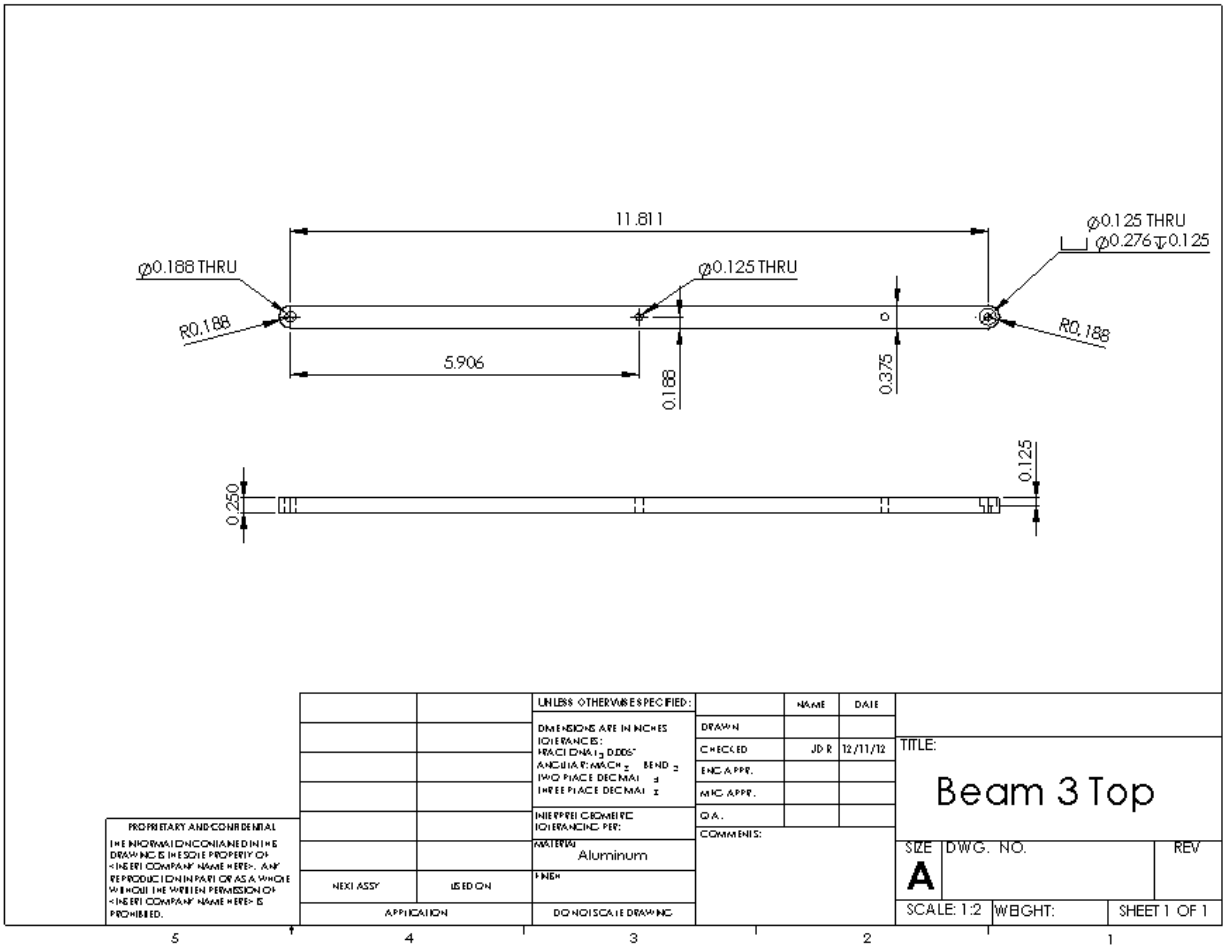


Figure 84: Beam 4 top

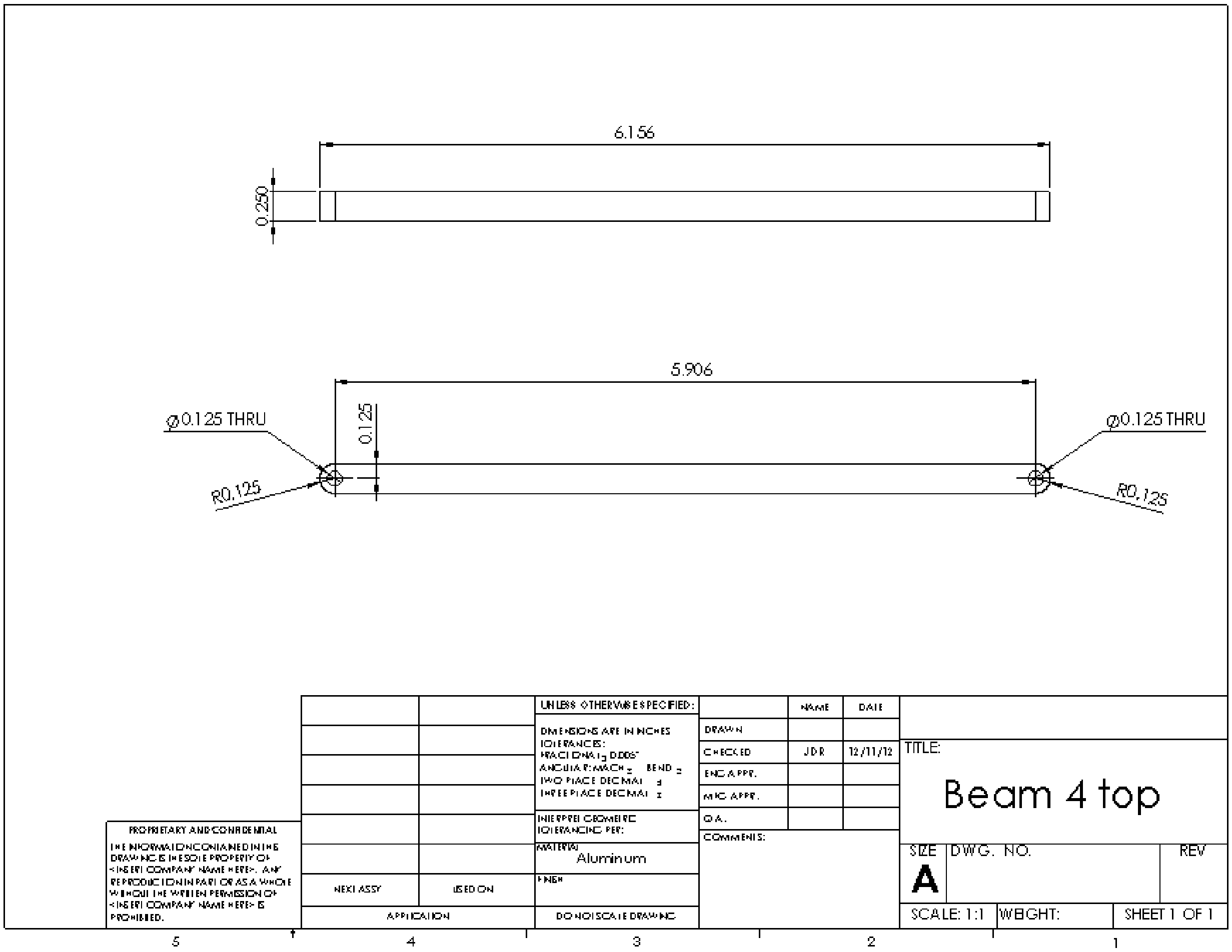


Figure 85: Beam 4

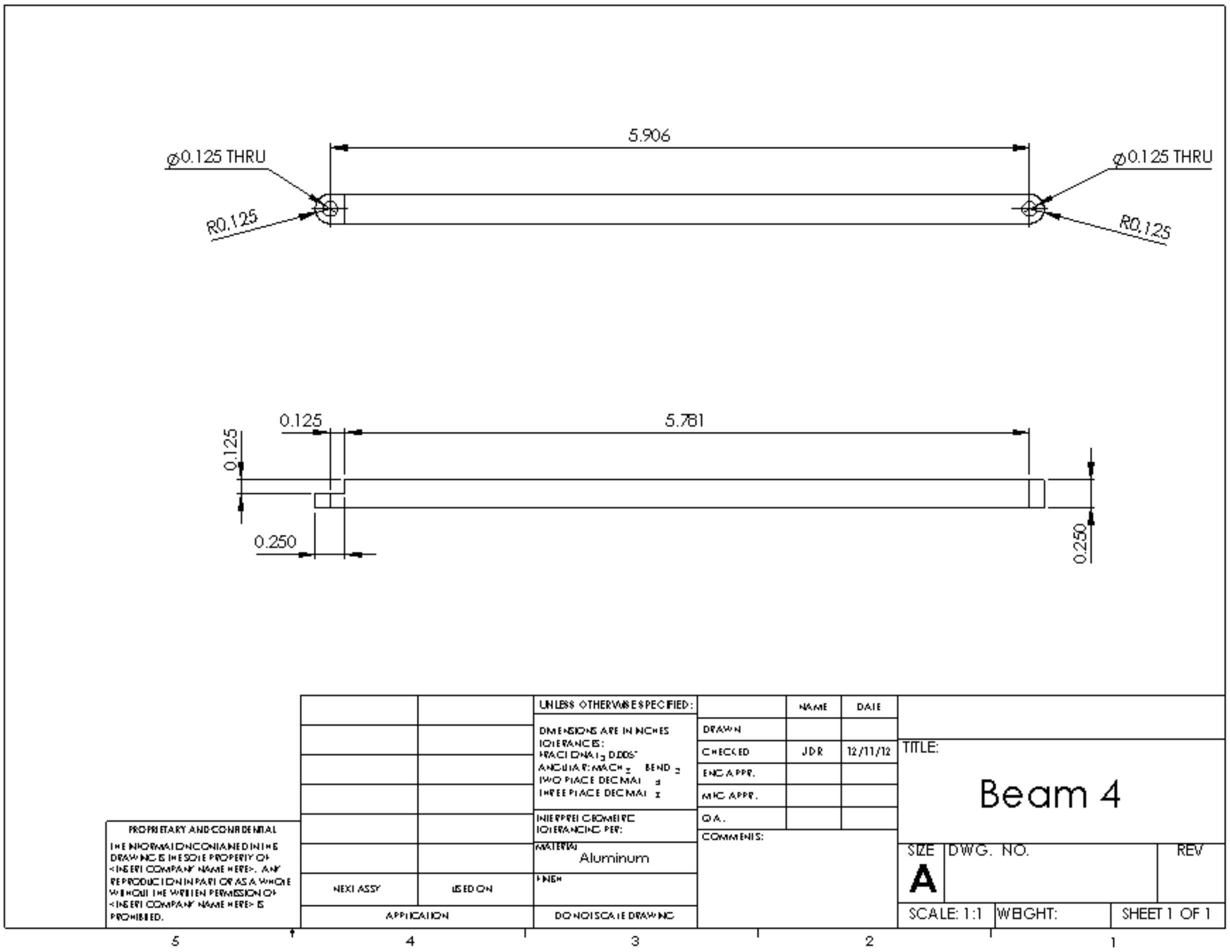


Figure 86: Bottom Base Plate v2.0 Extra Holes

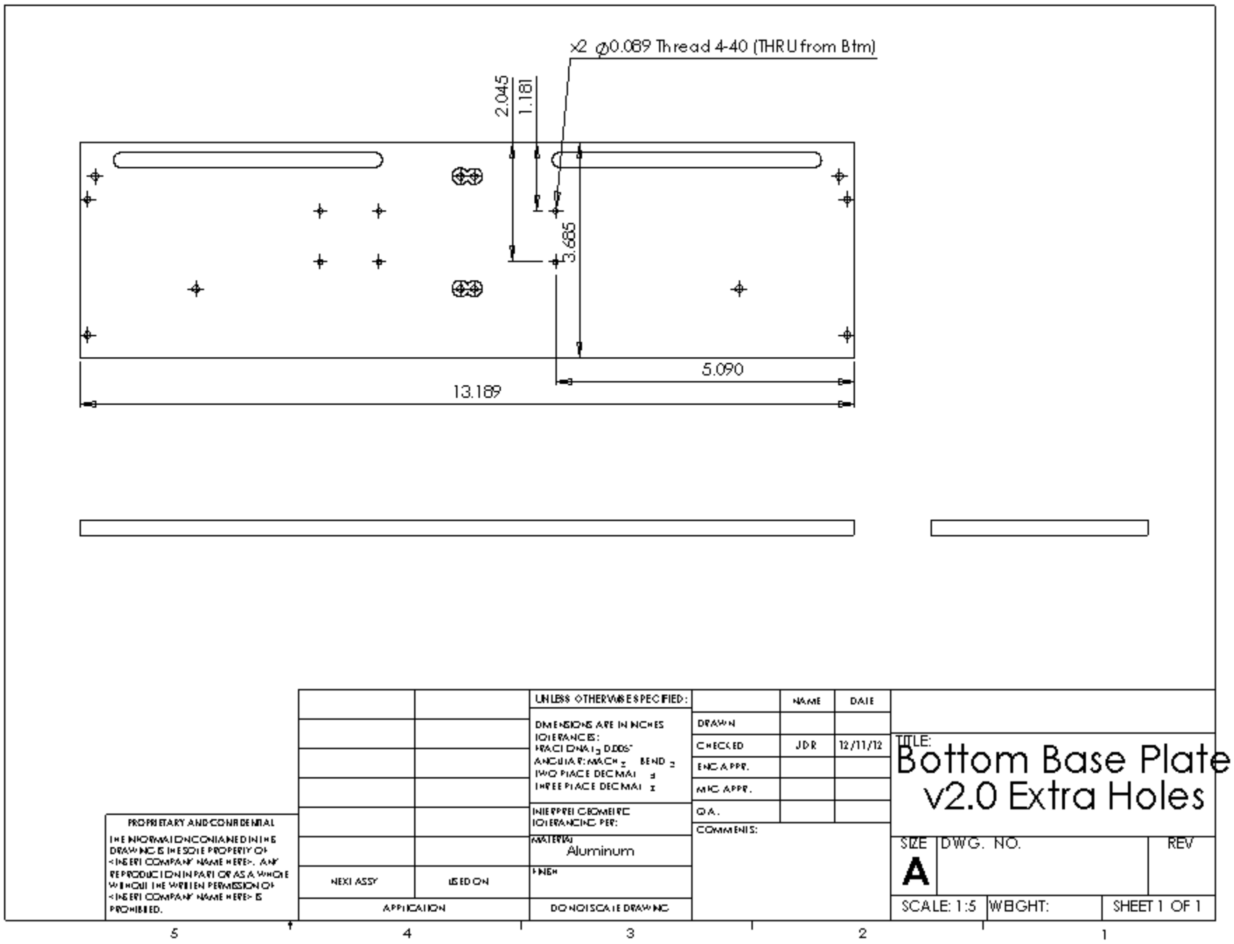


Figure 87: Cover Extension Holder

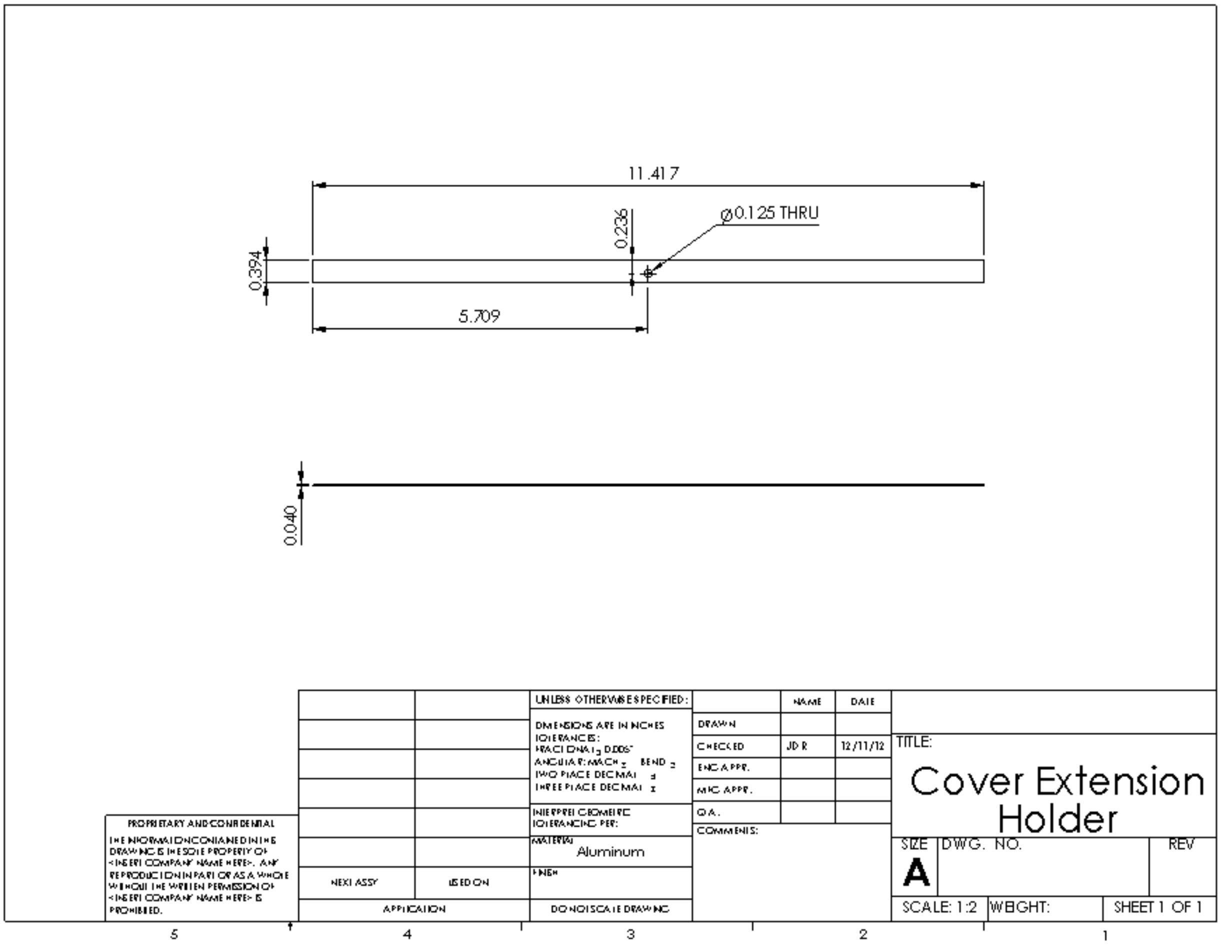


Figure 88: Hinges

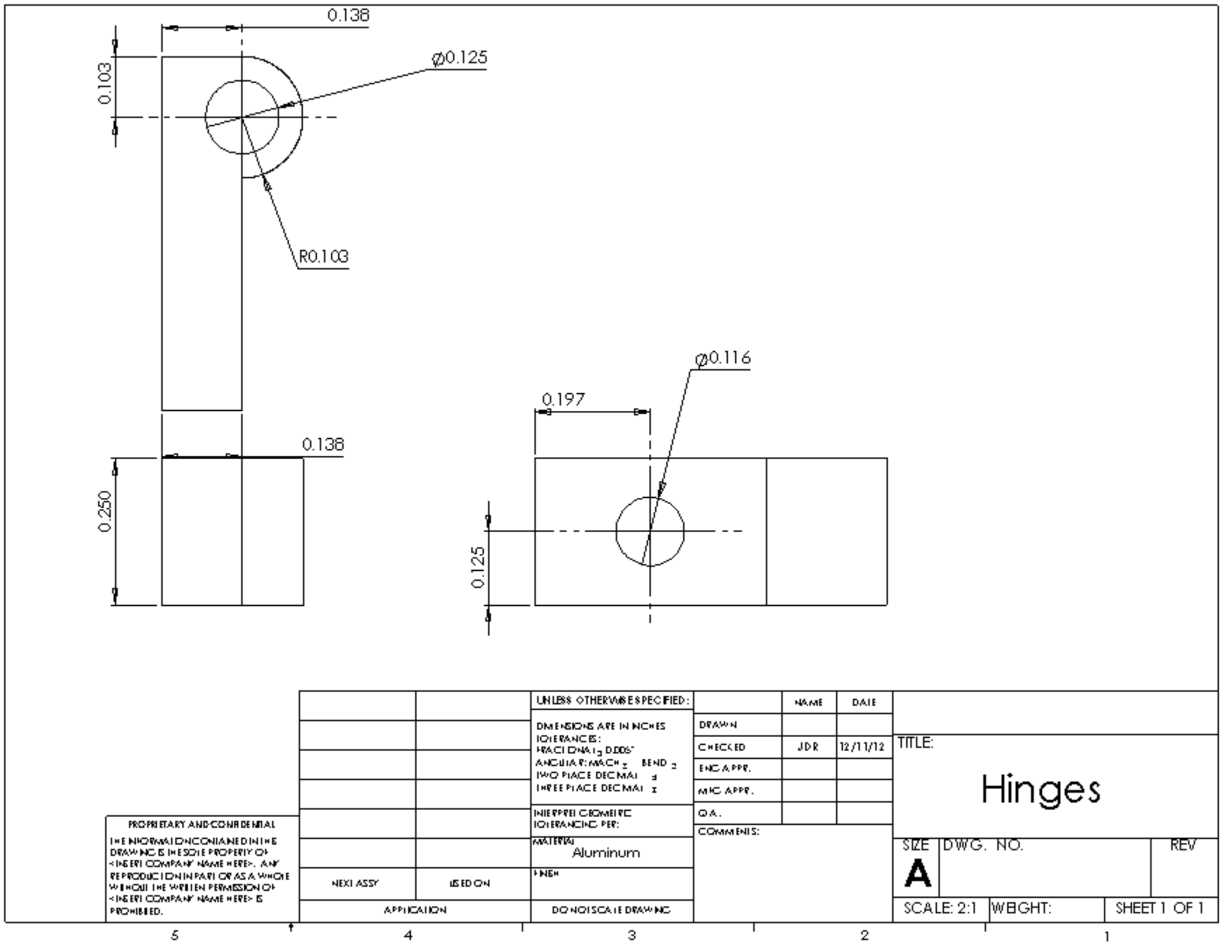


Figure 89: Housing Cover Opening

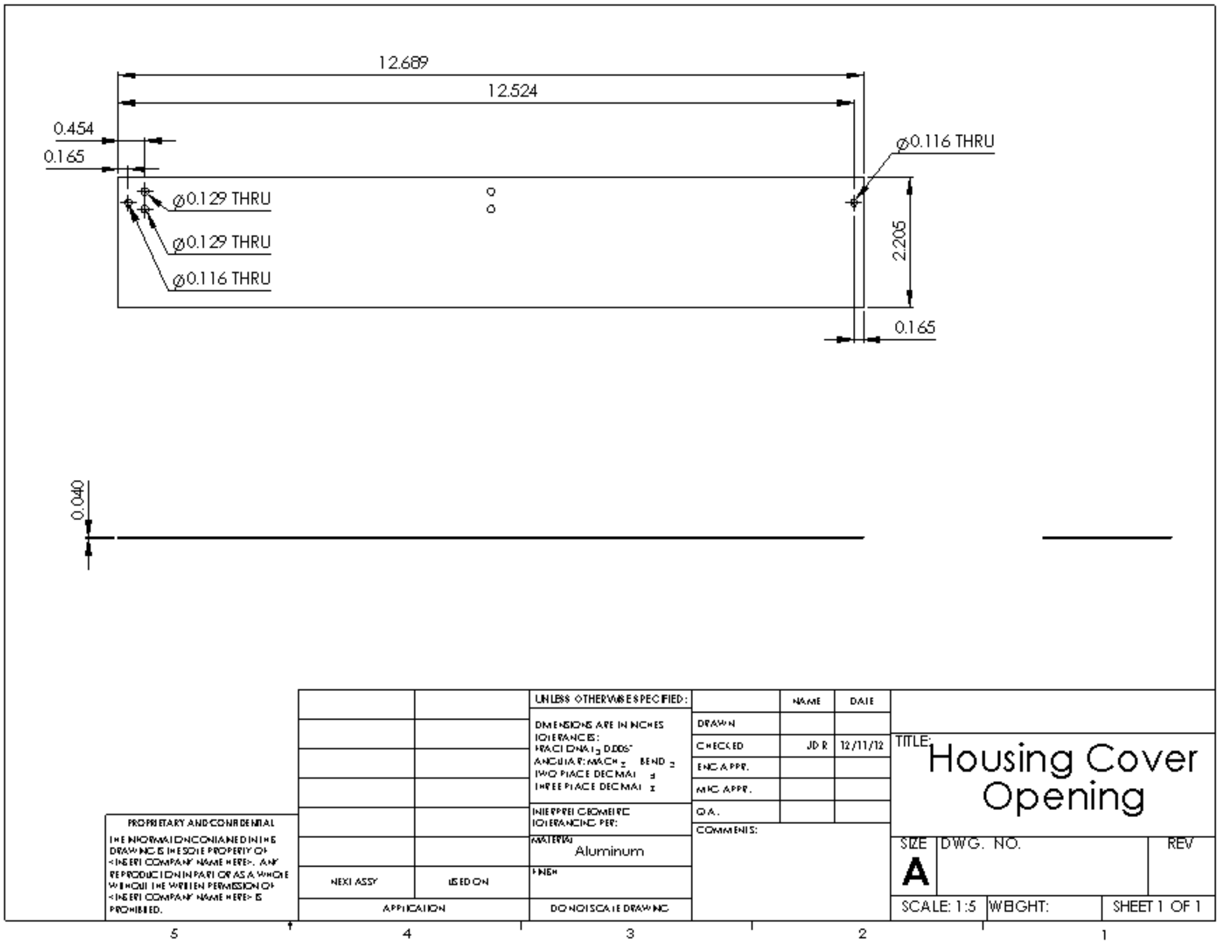


Figure 90: Pully Lower Support v2.0

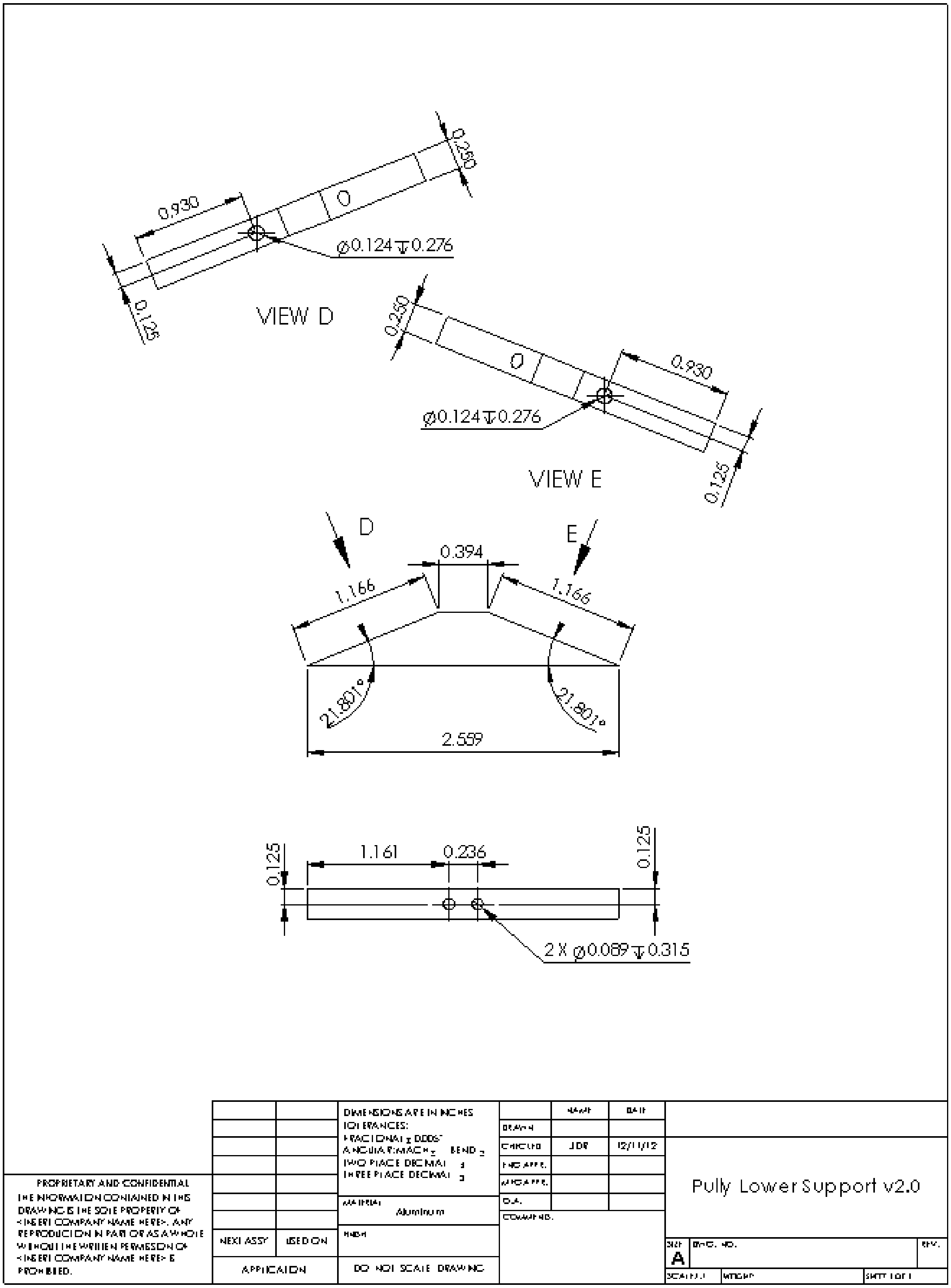


Figure 91: Side Plate L Hinge Holes

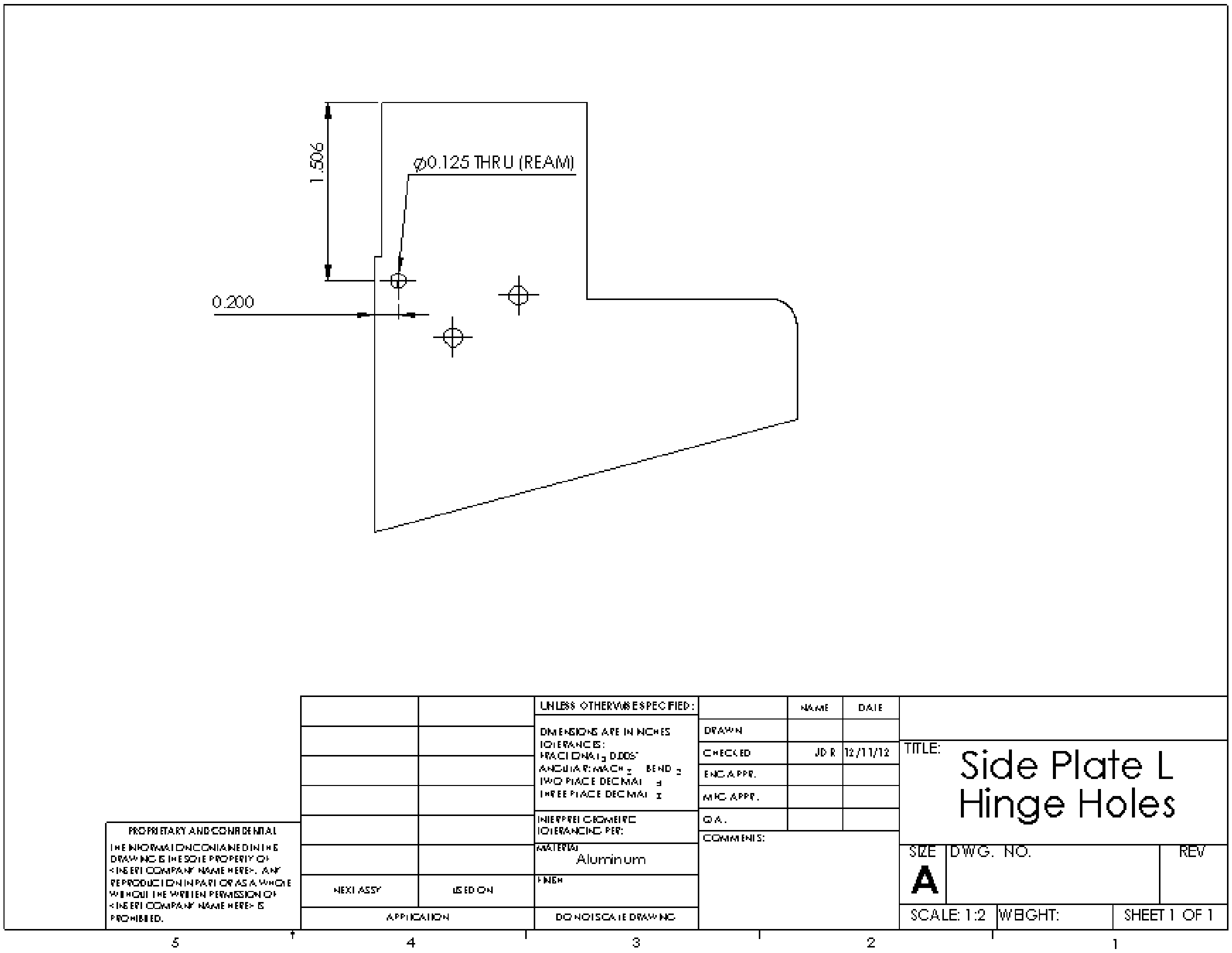


Figure 92: Side Plate L v2.1

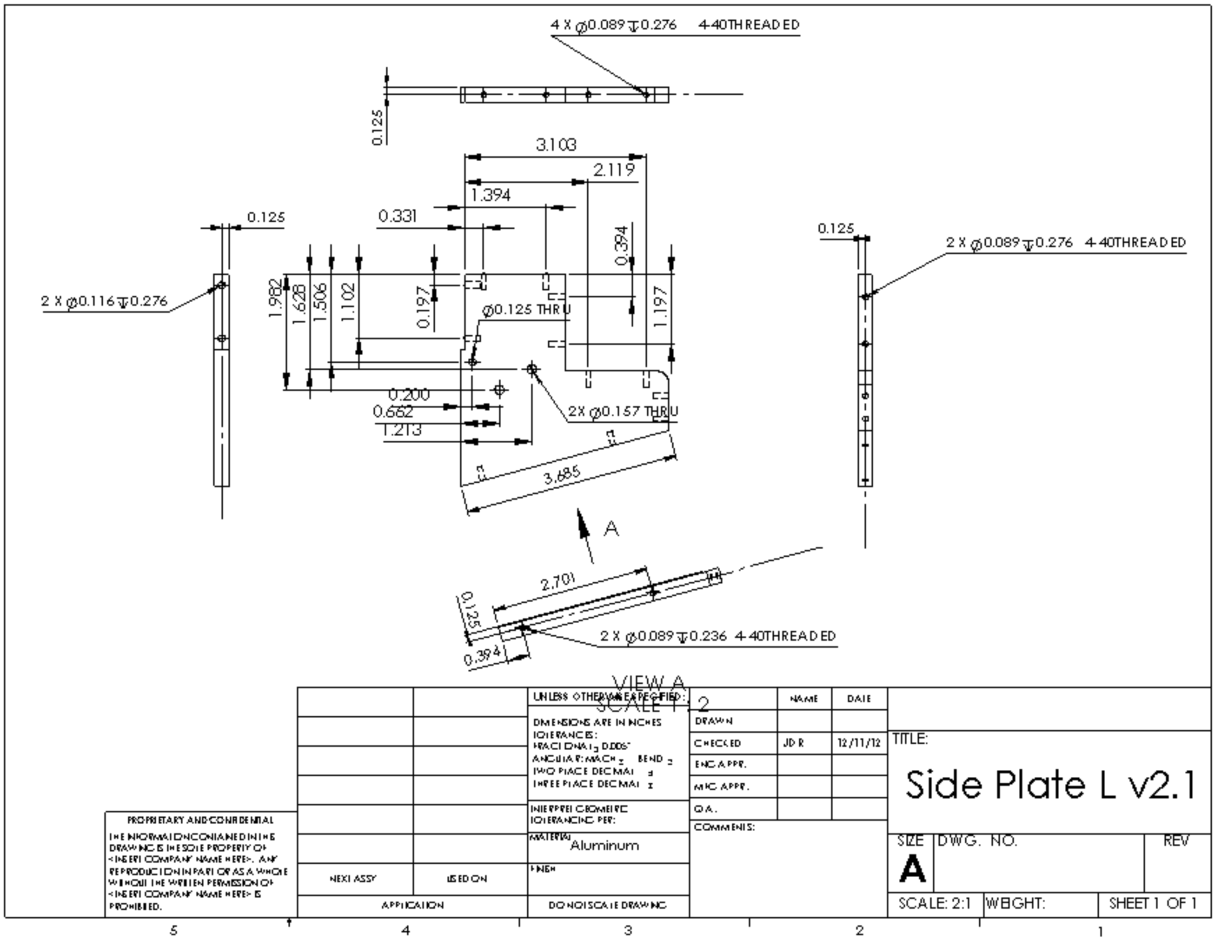


Figure 93: Side Plate R Hinge Holes

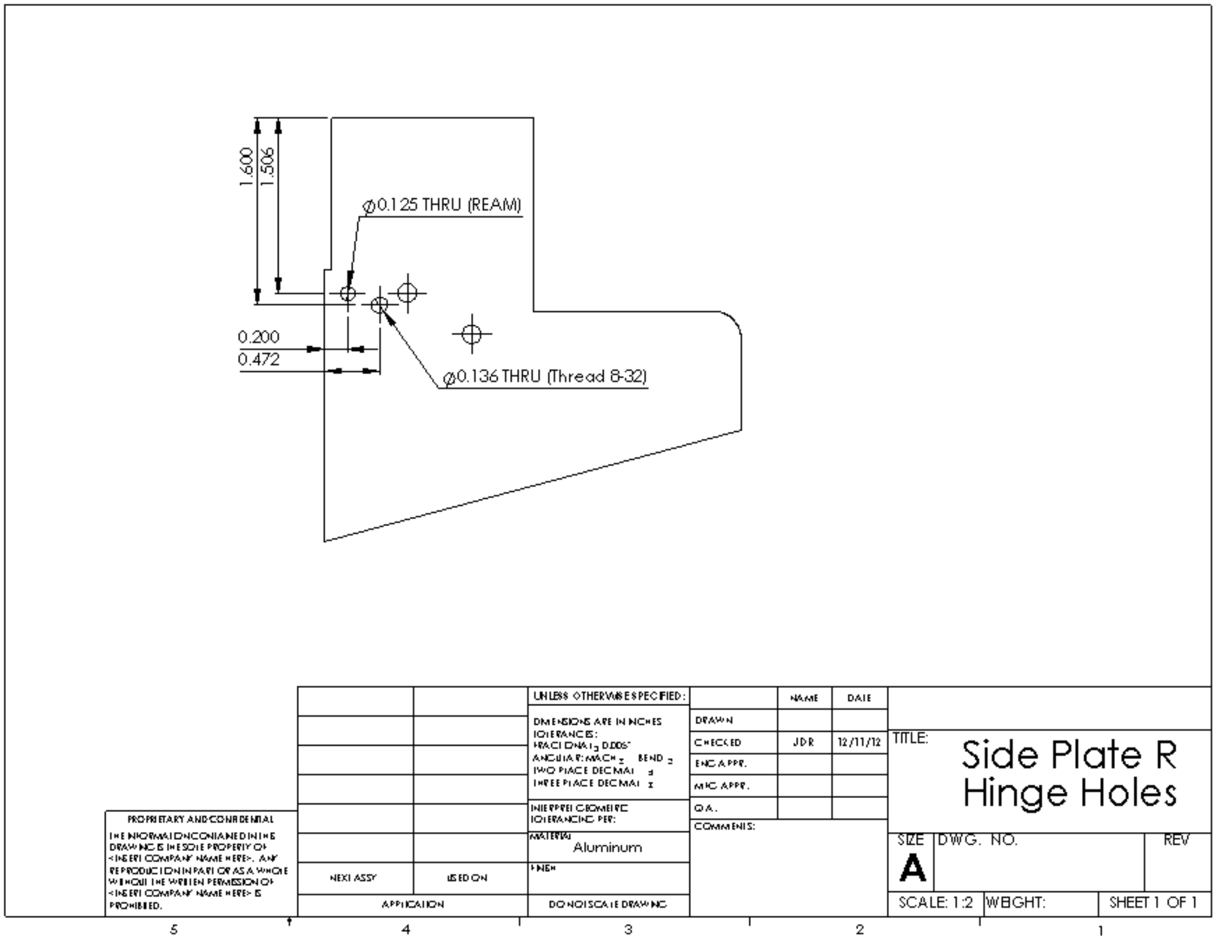


Figure 94: Side Plate R v2.0 Back Support Holes

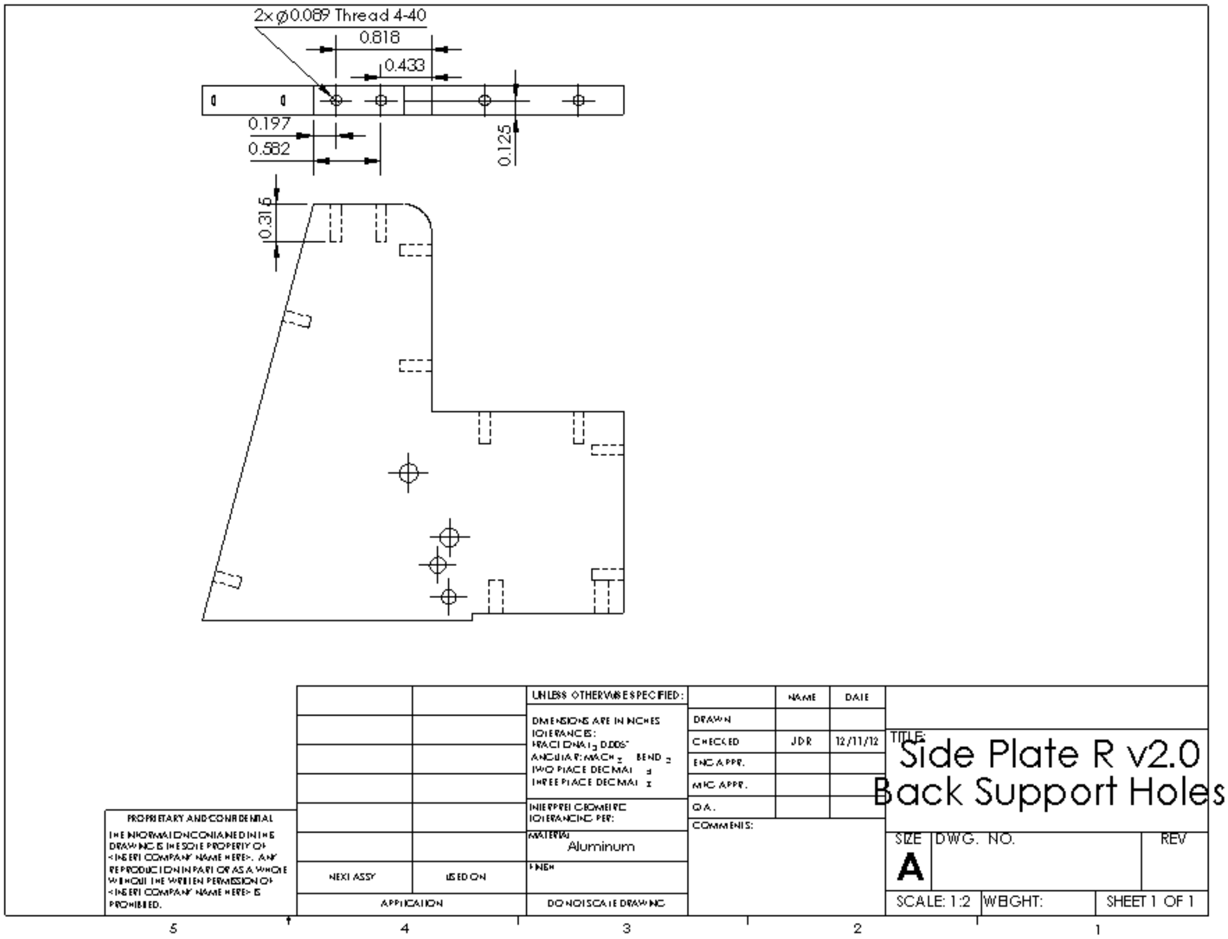


Figure 95: Side Plate R v2.0

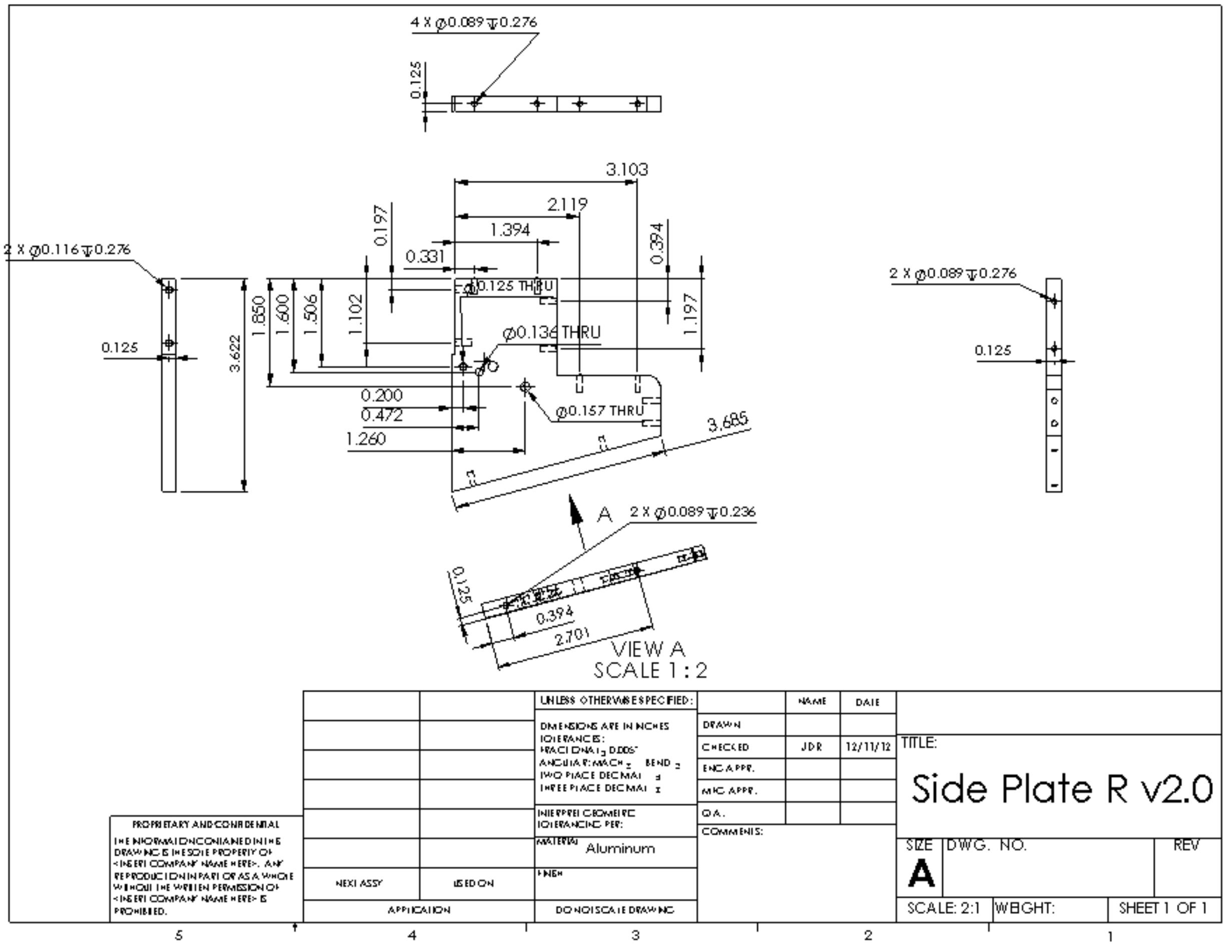


Figure 96: Side Plate L v2.0

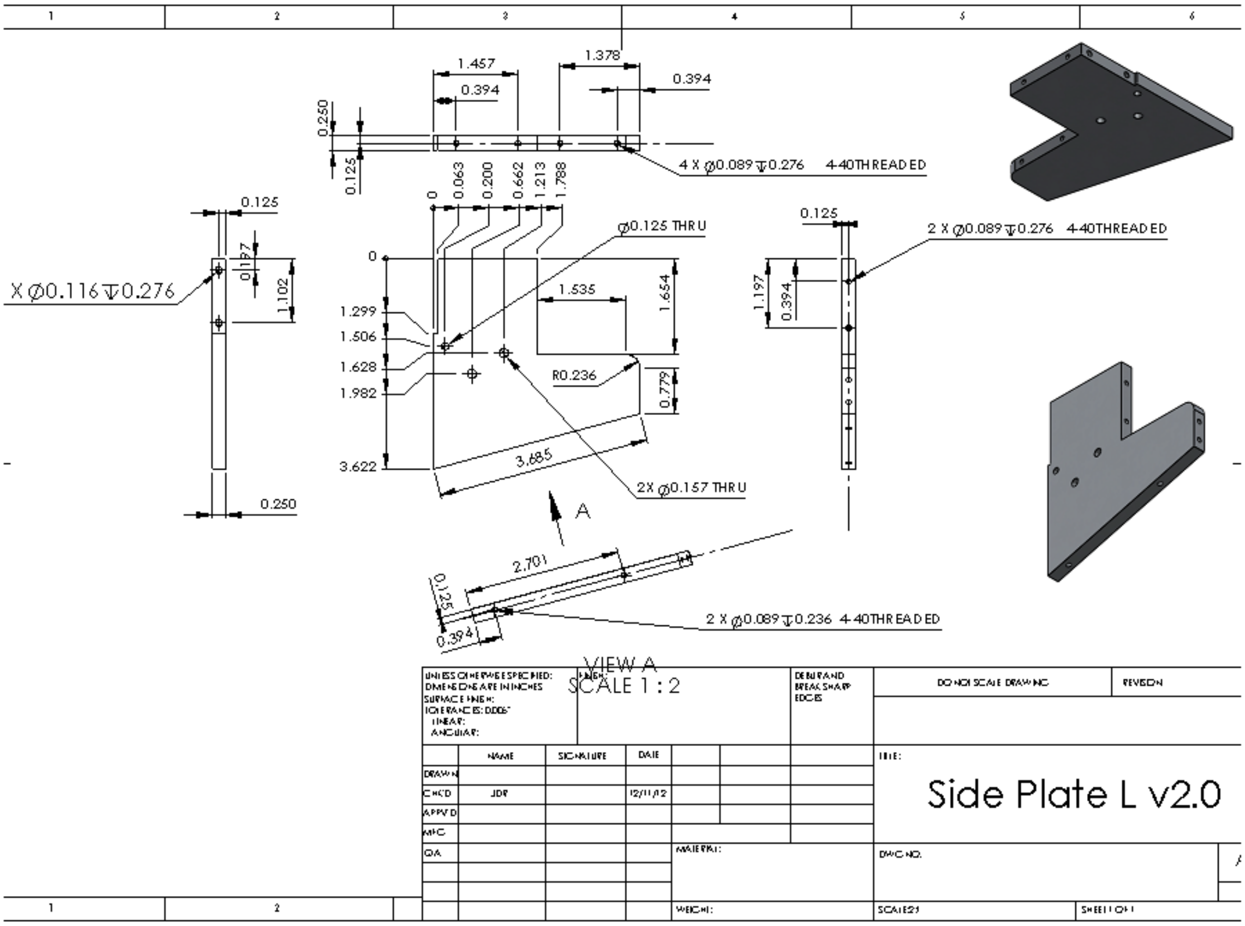


Figure 97: Spacer Aluminum

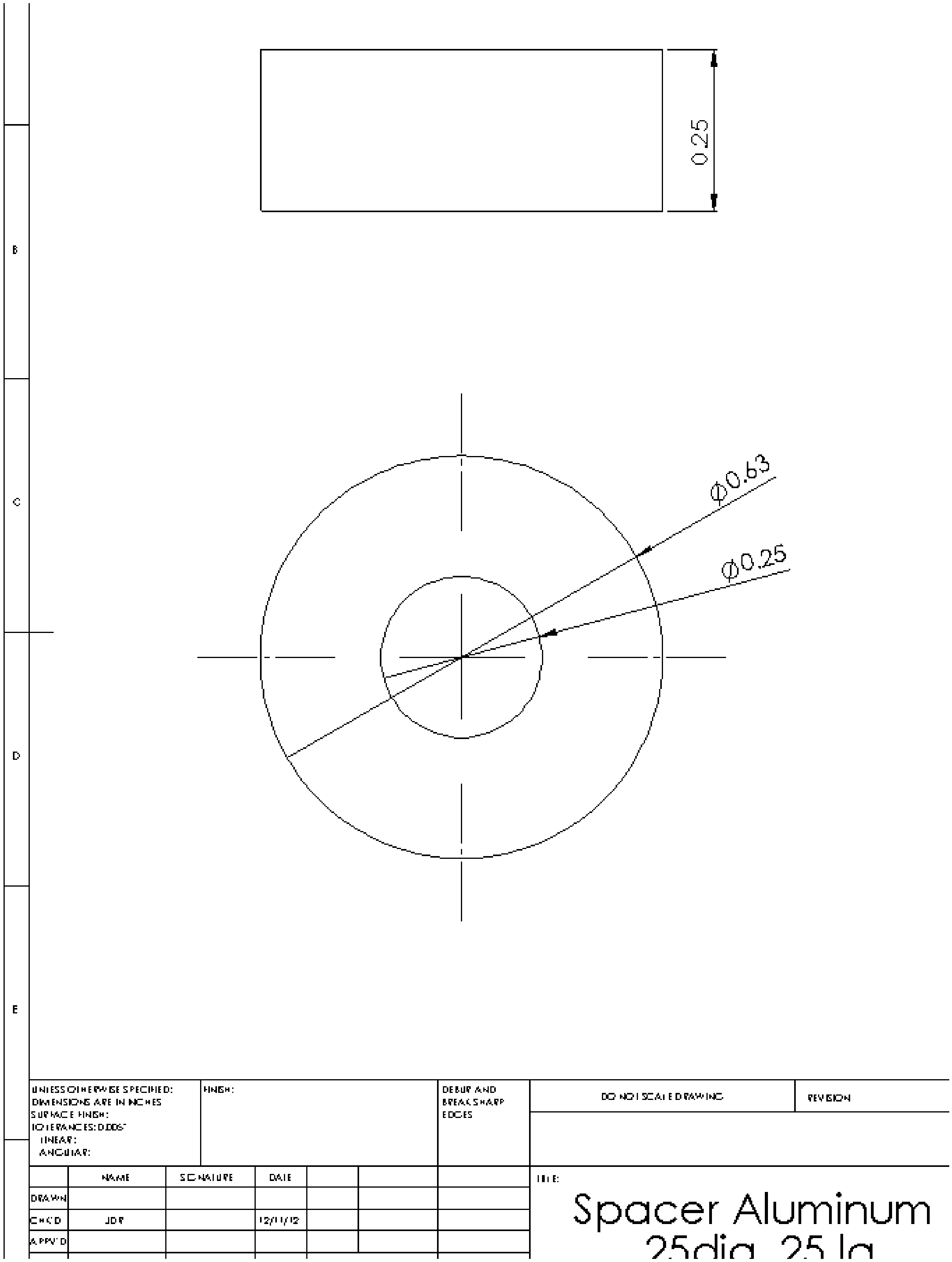


Figure 98: Spindle Mount Bracket L

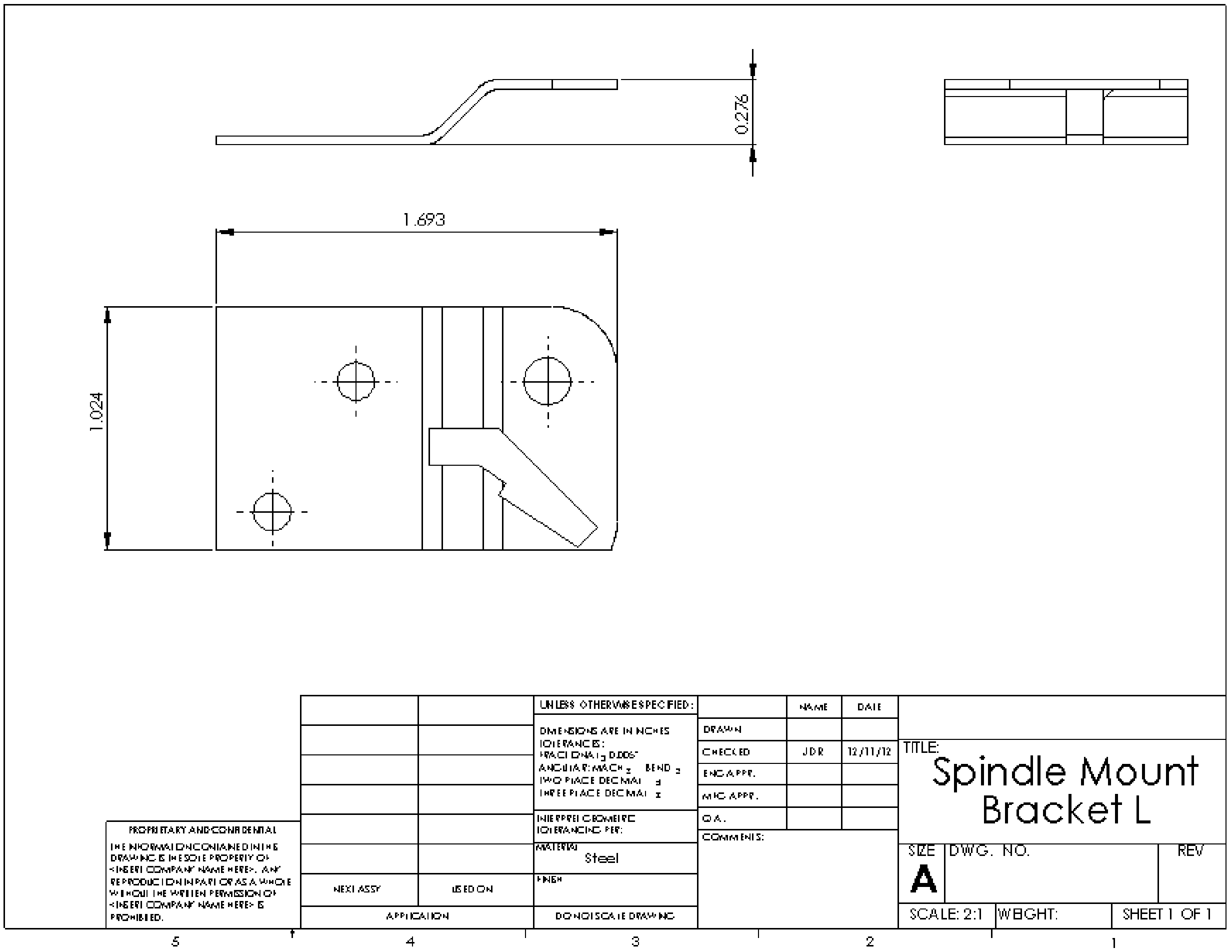


Figure 99: Spindle Mount Bracket R

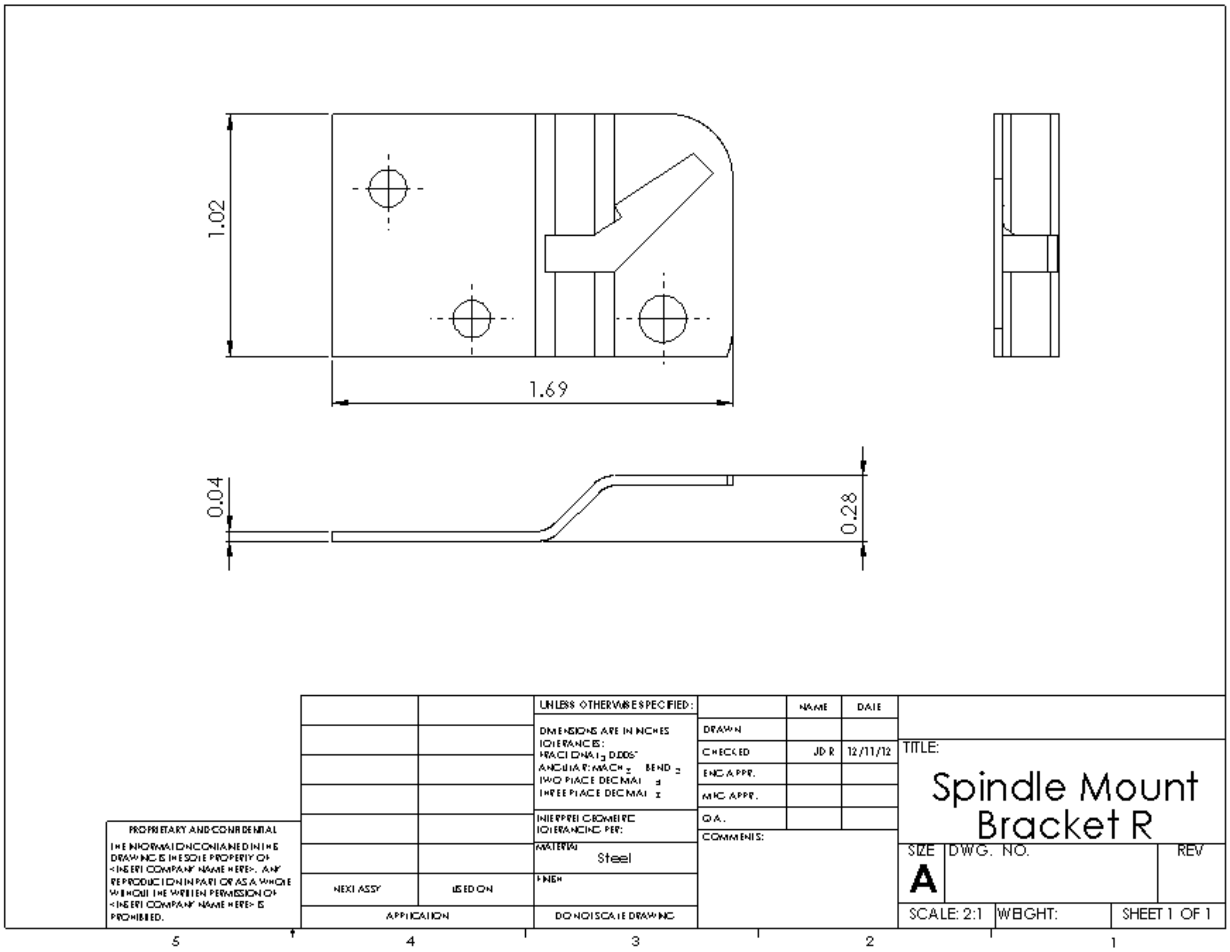
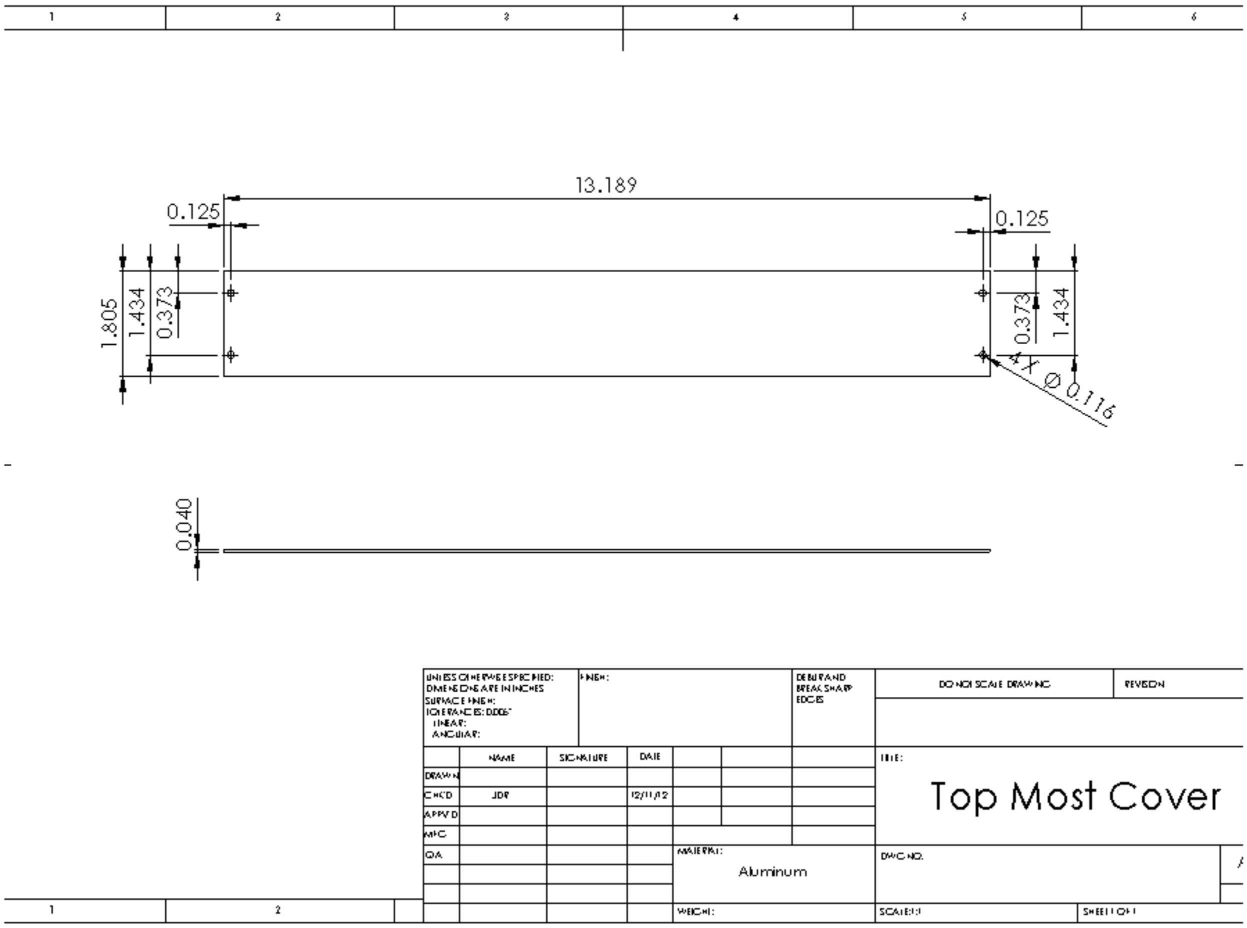


Figure 100: Top Most Cover



APPENDIX H: VALIDATION DATA

Table 23: Power Draw Test

deployment			retraction			*Time is 9 secs retract and 13 sec deploy		
No.	V	mA	V	mA		deploy power(W)	retract power(W)	energy for one cycle (J)
1	6.43	287	6.72	107	9V	1.84541	0.71904	30.46169
2	6.47	262	6.74	103	9V	1.69514	0.69422	28.2848
3	6.45	278	6.75	102	9V	1.7931	0.6885	29.5068
4	6.5	283	6.74	101	9V	1.8395	0.68074	30.04016
5	6.5	300	6.76	96	9V	1.95	0.64896	31.19064
6	6.43	298	6.76	100	9V	1.91614	0.676	30.99382
7	6.5	322	6.78	102	9V	2.093	0.69156	33.43304
8	6.52	301	6.81	98	9V	1.96252	0.66738	31.51918
9	6.6	290	6.78	93	9V	1.914	0.63054	30.55686
10	6.55	280	6.78	92	9V	1.834	0.62376	29.45584
11	6.6	300	6.8	97	9V	1.98	0.6596	31.6764
12	5.96	300	8.24	110	11V	1.788	0.9064	31.4016
13	6.27	291	8.55	110	11V	1.82457	0.9405	32.18391
14	6.4	344	8.44	111	11V	2.2016	0.93684	37.05236
15	6.16	294	8.54	120	11V	1.81104	1.0248	32.76672
16	6.3	289	8.37	110	11V	1.8207	0.9207	31.9554
17	6.32	319	8.29	104	11V	2.01608	0.86216	33.96848
18	6.3	330	8.31	105	11V	2.079	0.87255	34.87995
19	6.32	300	8.3	107	11V	1.896	0.8881	32.6409
20	6.24	370	8.39	105	11V	2.3088	0.88095	37.94295
21	6.35	339	8.47	108	11V	2.15265	0.91476	36.21729
22	6.33	335	9.5	120	12V	2.12055	1.14	37.82715
23	6.3	306	9.2	115	12V	1.9278	1.058	34.5834
24	6.5	345	9.16	114	12V	2.2425	1.04424	38.55066
25	6.46	313	9.37	120	12V	2.02198	1.1244	36.40534
26	6.65	310	9.03	113	12V	2.0615	1.02039	35.98301
27	6.5	299	9.2	120	12V	1.9435	1.104	35.2015
28	6.5	339	9.11	114	12V	2.2035	1.03854	37.99236
29	6.5	316	9.2	118	12V	2.054	1.0856	36.4724
30	6.41	320	9.48	115	12V	2.0512	1.0902	36.4774
31	6.65	333	9.54	126	12V	2.21445	1.20204	39.60621
32	6.54	335	9.45	126	12V	2.1909	1.1907	39.198
					DONE!			
Avg	6.422	310	8.14	108.81		1.992285	0.894567	33.95081
Max	6.65	370	9.54	126		2.3088	1.20204	39.60621

Table 24: Storage/Deploy Time Test

No.	deploy time(sec)	storage time(sec)	Voltage
1	11.8	8.6	9V
2	11.6	9.3	9V
3	11.3	9.6	9V
4	11.6	9.1	9V
5	11	9.4	9V
6	11.1	6.7	12V
7	11.9	8.5	10V
8	11.7	7.5	11V
9	10.8	7.9	11V
10	11.7	7.1	11V
11	11.2	7.7	11V
12	11.7	8.1	11V
13	11.2	failed, housing cover cannot close	11V
14	10.8	7.7	11V
15	11.6	7.8	11V
16	11.5	failed, cover cannot retract.	11V
17	12.3	8.3	11V
18	11.7	9.7	9V
19	12.5	7	12V
20	12.3	8	11V
21	12.1	7.7	11V
22	11.6	9.6	9V
23	11.6	9.5	9V
24	11.2	9.4	9V
25	11.5	9.8	9V
26	11.6	6.2	12V
27	12.2	7.5	12V
28	12.1	6.6	12V
29	12	7.1	12V
30	12.5	7.2	12V
31	12.3	7	12V
32	12.7	7.2	12V
33	12.2	7.4	12V
34	11.9	7.3	12V
			DONE!