

**EZ-Ject** CIRCUIT BOARD  
EJECTOR  
MECHANISM

Sponsored by Schweitzer Engineering Laboratories

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## Executive Summary

A mechanical device was designed to reduce the force required to insert and eject 351S circuit boards. The given circuit boards took approximately 40 lbf to insert and eject. Through surveying random subjects, it was determined that a comfortable push/pull force for a single finger was about 5 lbf. This result was further supported by SEL internal work instruction WI-11751 (Appendix A) which recommended a maximum exertion of 5.3 lbf per thumb and 2.8 lbf per hand to prevent musculoskeletal disorders.

A down selection process of 11 initial designs led to a final design concept that consisted of two simple lever arms and a rail system. Multiple manufacturing methods were considered and two were chosen based on design compatibility and economics. The final design concept was modified for injection molding and sheet metal fabrication and then compared for highest effectiveness and lowest cost.

Both designs were tested for mechanical advantage to prove theoretical calculations. Two fish scales rated for 110 lbf were used to test the lever arms. Each lever arm confirmed to output 20 lbf when 5 lbf was input to the end of the arm. Since two lever arms were used for each tray, the total output force would be 40 lbf successfully meeting the project goal. Prototyping further confirmed strength and durability of the apparatus. Estimated assembly costs for the injection molding design and the sheet metal fabricated design were \$3.50 and \$15.00 respectively based on a batch size of 10,000 assemblies per year.

User surveying brought light to a few potential issues with the design. One issue was alignment upon insertion which could be fixed with the addition of a spring. Another complaint was that it was "scary" to use because of creaking noises. This was not avoidable in the sheet metal iteration, and after a few uses the subjects became comfortable realizing that the noise did not signify precariousness.

## Background

Schweitzer Engineering Laboratories (SEL) produces many digital products and systems that make electrical power safer to utilize. One of these products is the 351S relay. Within each relay, there are multiple electronic elements and circuit boards. These circuit boards are attached to a metal tray that slides in and out of a set of rails within the chassis. Upon assembly of these relays, it was given that approximately 40 lbs was required to fully insert the circuit board tray into the connectors and to eject the circuit board for repairs and replacements. In the current assembly process, the trays are shoved into the connectors by hand in any way the worker can manage to get it in completely. This process is slow and frustrating for assemblers. The circuit boards also include a battery which needs to be replaced every couple of years. This means that the client will eventually have to eject the circuit board tray even if there is never any repair work needed.



Figure 1: SEL-351S

Musculoskeletal disorders (MSD) are common in the workplace and caused by overuse, repetitive stress, and repetitive motion. By emphasizing ergonomics in their products, SEL can reduce these risk factors and save money on workers compensation. It is also beneficial for the buyer to know that they are investing in a safe and easy-to-use product. A simpler, more ergonomic product also entails faster assembly and therefore allowing more units to be assembled in a given amount of time. In the end, it is in the best interest of both SEL and SEL's clients that this issue is addressed.

## Problem Definition

Through the scope of this project, a mechanical device was needed to reduce the necessary user input force and improve ergonomics while adhering to SEL's design requirements and constraints. As per SEL internal work instruction WI-11751, Version 5 which can be found in Appendix A, it was recommended that the user should not exert more than 5.3 lbr per thumb or 2.8 lbr per hand. Through user testing (Appendix A), the team found that about 5 lbr was comfortable for someone to push or pull with one finger. This result led the team to set 5 lbr as the goal for the mechanical device that was to be designed. To accomplish this goal, a few requirements were considered.

The first major requirement was containment. The designed mechanism needed to be an integral part of the existing assembly and needed to completely fit inside the chassis when closed. The mechanism was to be permanently attached with rivets, spot welds, threaded nuts, and/or screws flush with the outside faces and no elements of the design were to interfere with existing components within the chassis.



*Figure 2: Available Space within the Relay*

The second design requirement was reducing the necessary user input force. The design had to be capable of overcoming the high friction areas. The connection tabs located at the back of each tray produced the majority of the 40 lbr of friction, but the rails located on the sides of the trays were found to produce some sliding friction as well. Although the rails only produced a small amount of friction, they could cause jamming from misalignment upon insertion.



*Figure 3: View of Circuit Board Tray Inserted into Connectors*

The third requirement was ergonomic quality. The goal of implementing this mechanism was to make the insertion and ejection of the circuit board ergonomic. This means the user should not have to use any uncomfortable positions or movements and the mechanism should be easily accessible and not include sharp edges.

The last major requirement was minimizing cost. To maximize SEL's return on investment, each mechanism needed to be optimized to be as low cost as was reasonable while considering all other requirements listed above. The general target value for this design is to be below \$2.00 per unit. This should be reflected in both the design specifications and manufacturing methods. After completion of the final design, it will need to fulfill SEL's vibration and temperature testing standards before implementation.

## Project Plan

### Team Roles:

All team members took an active role in design development, revision, and general research.

Jaime Ayala:	Directs instructor/client meetings Creates meeting agendas
Emily Chambers:	Manages budget Creates meeting minutes
Davis Hill:	Primary client contact Moderates Wiki Page
Nikki Imanaka:	Team leader Facilitates team meetings Manages schedule

### Schedule:

Preliminary scheduling set a goal of design completion by December 2018. This would have allowed for more developed model creation and refinement during the spring semester. The goal was to have the selected design ready to tool at the beginning of the spring semester to accommodate for a 10-12-week lead time on professional part manufacturing. This would allow a finished product to be displayed at the University of Idaho Engineering Exposition (EXPO). Realizing this was an ambitious goal, the first semester ended with a down selection process of 12 ideas to 4 ideas. A lot of the first semester was spent on design development and refining design constraints.

Manufacturing method research became a larger part of the project than anticipated. After doing a simple fabrication and cost analysis the team was able to narrow down the four ideas to one design concept to move forward with. The fabrication selection came later in the second semester and had huge effects on the cost analysis and final designs. Prototypes were followed by final designs for the chosen manufacturing methods which pushed back some testing. Within the last month of the project timeline, final prototypes were put together, user testing was done, and quotes were acquired from NIC Global Manufacturing and Protolabs for sheet metal fabrication and injection molding respectively.

The final schedule is outlined in Table 1 below.





## Design Development

The project began with idea generation. The team came up with 11 preliminary ideas and created a decision matrix to rate and weed out the ones that were less promising. An online priority tool was used in collaboration with client input to create the weightings on each category (Appendix C). An overview of each initial design is described below.

### 1. Cleat and Claw

The following idea is a simple lever mechanism that uses a claw placed on both sides of the front of the chassis box and a modified lip on the front of the circuit board tray as a cleat to grab onto. Figure 4 on the right shows the mechanism on the right-side looking in.

The space between the trays constrained the length of the claw which restrained the mechanical advantage it could produce. The mechanism also had difficulty catching the cleat on the circuit board tray for insertion purposes.



Figure 4: Wood Iteration of Right Claw

### 2. Gears

This idea in its simplest form is a rack and pinion. The gear is rotated with an extended lever arm. **Error! Reference source not found.** on the right shows the left corner of the front of the chassis looking in.

The main problem with this design was the alignment upon insertion that could cause the lever arm to rotate into the chassis making it impossible to insert the tray further or not enough making it impossible to close. There is also the possibility that the gear teeth could slip under high loads.

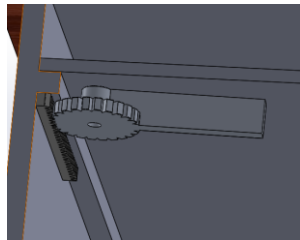


Figure 5: SolidWorks Model of Gear Lever

### 3. Rubber

This idea uses a rubber aluminum interface to create a surface that can grip the outer wall of the chassis to eject the circuit board trays. Figure 6 on the right shows the left front corner of the chassis looking in.

The rubber idea lacked feasibility. Most rubber materials have a really poor resistance to hydrocarbons that soften, harden, and in extreme conditions causing the rubber to dissolve. The rubber idea had the same alignment issues as the rack and pinion.

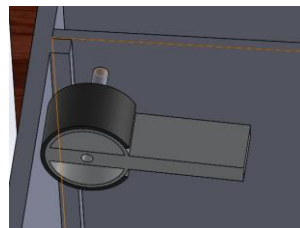


Figure 6: SolidWorks Model of Rubber Lever

#### 4. Rails

The basic concept of this idea is that of a lever arm. Like a crow bar, there is a long lever that produces a large amount of mechanical advantage depending on how far away the hinge is from the end of the bar. The first iteration of this design consists of two lever arms, one on each side of the front of the chassis. Each arm has a peg sticking up from the top surface. This peg slides in and out of a set of rails located on the underside of the circuit board tray. Figure 7 above shows the top view of this basic assembly excluding the tray.

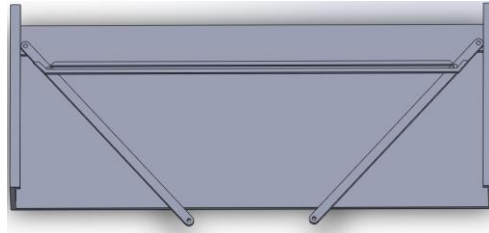


Figure 7: SolidWorks Model of Initial Rails Design

One drawback is that the tray would need special modification to include the rails. The opening on each side of the rails may also cause some alignment issues if the arms are not positioned correctly before the insertion of the tray.

#### 5. Over-Center

This system utilizes mechanical advantage generated by an over-center mechanism similar to latches used in tool boxes or sealing jars. The design went through several iterations, the first of which is shown in Figure 8. The user would move the lever arm forwards and backwards to insert and eject the tray. The side location caused several issues with tray canting, so over time the design evolved to be centrally located and reflected across the central axis, so forces were evenly distributed. This design can be seen in Figure 9.

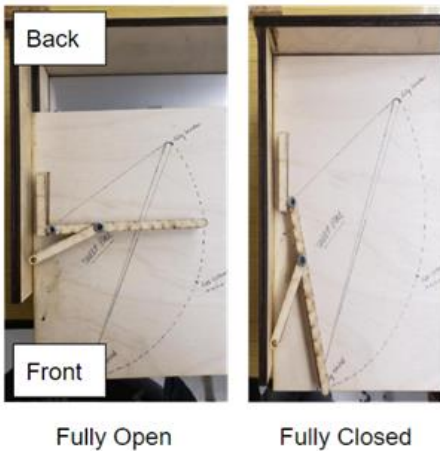


Figure 8: Open and Closed Over-Center Mechanism



Figure 9: SolidWorks Model of Over-Center Mechanism

## 6. Slotted Arm

This system uses a single lever connected to the back of the chassis to push on a pin attached to the bottom surface of the tray. The lever in its current format uses a slot in the end of the arm to latch onto the pin (Figure 10). The slot design would require spring loaded return for accurate positioning to allow the pin into the slot at the right time. Due to there being only one lever per tray, canting is a large concern as it causes asymmetrical friction on the tray and the length of this arm is too great to avoid component interferences.

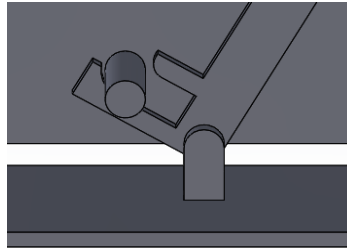


Figure 10: Bottom View of Tray and Slotted Arm

## 7. L-Hole

This system uses a simple “L” shaped lever to push on the edges of a hole made in the tray. The geometry of the lever can be easily adjusted to create the force required for removal of the tray, but the geometry did not allow for full removal of the tray because of physical interferences with the bottom of the chassis, the lower tray, and the hole in the tray being ejected.

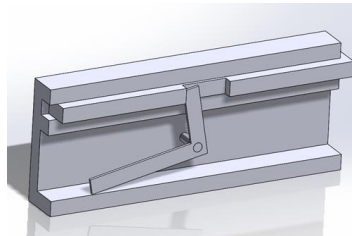


Figure 11: Side Section View of the L-Hole Mechanism

## 8. Threaded Rod

This system uses a rod attached to the bottom of the tray that threads into a nut that is permanently attached to the back of the chassis. The nut would be located in the center of the chassis to attempt to avoid any canting upon insertion. The handle telescopes for easier access and collapses when not in use, shown below in Figure 13 and Figure 12. The pitch of the threads can be adjusted to achieve various mechanical advantages and revolutions needed to insert and eject the tray.

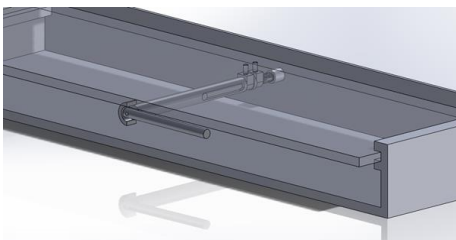


Figure 13: Threaded Rod Collapsed Handle

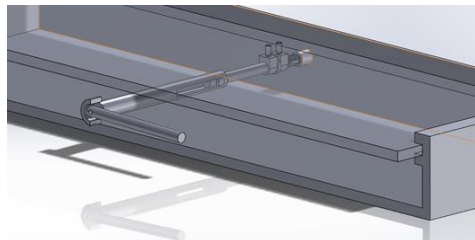


Figure 12: Threaded Rod Extended Handle

## 9. Puzzle Piece

This design consisted of two puzzle-like pieces that would swivel in and out of the sides of the chassis. The puzzle pieces would latch onto a similar cut out made in the tray to pull it out and push it in. The main problem with this design is that it would not allow for the cover plate to be secured.

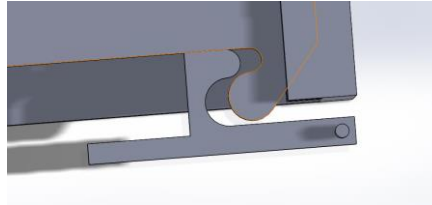


Figure 14: Top View of Right-Side Puzzle Piece

## 10. Peg Slide

This system uses a pin that pushes on an angled channel to insert and eject the tray from the chassis. The ramp angle can be increased or decreased to output the necessary force. The pin is attached to an arm that slides on a track beneath the tray. Placement of the track was an issue as the track interfered with removal of the tray.

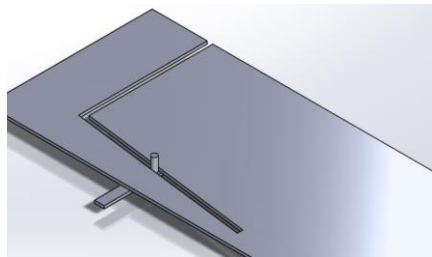


Figure 15: Peg Slide Design

## 11. Y-Rod

Figure 16 shows a schematic of the Y-rod mechanism. This idea uses two “Y” shaped claws that will grab a peg attached to either sidewall of the chassis. The two “Y” claws are attached by a long rod that runs across the front of the tray. It is configured to give the operator a handle that swivels to rotate the claws.

The main issue with this design is the low mechanical advantage it produces and torsional failure in the handle is very likely to occur during operation.

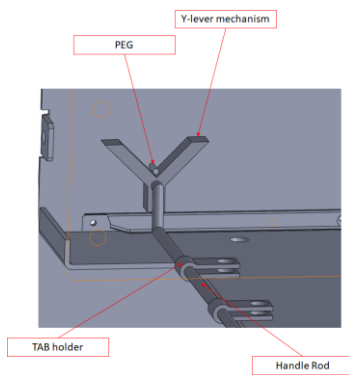


Figure 16: Side View of the Y-Rod Idea

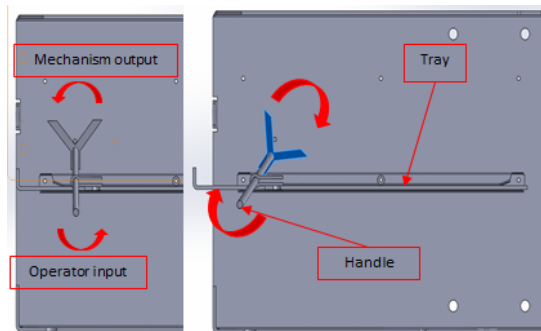


Figure 17: Side View of the Y-Rod Idea in Operation

## Design Selection

### Decision Matrix

Through the use of an online priority tool the team was able to come up with the following weights for each category of the decision matrix shown below in Table 2. The weightings represent percentages and all the category weightings should add up to 100 with higher values signifying greater importance.

Average Order	Category	Weight
1	Ergonomic	26.9
2	Operation Time	14.3
3	Ease of Access	13.83
4	Simplicity	13.68
5	Low Profile	7.63
6	Cost(materials)	7.3
7	Repairability	4.2
8	Complexity of Design	4.15
9	Tooling Cost	4.05
10	Mod. Complexity	4.03

Table 2: Decision Matrix Category Weighting

Using these weightings, each of the 11 designs were ranked on a scale of 1-10 with 10 being the perfect design and 1 being the worst. Descriptions of each category at the high end of the spectrum are as follows:

- Ergonomic – Comfortable, causes no pain, repetition causes no harm
- Operation Time – Minimizes time to complete task, very fast
- Ease of Access – Up front, no reaching or squeezing into small spaces needed
- Simplicity – Easy to understand without prior instruction
- Low Profile – Takes up minimal available space within chassis
- Cost – Relative price of materials needed, higher volume= higher price, metals>plastics
- Repairability – Minimal cost and time to repair parts
- Complexity of Design – No complex parts (gears, threads, high tolerances)
- Tooling Cost –cheaper tooling/fabrication and minimal set up time
- Modification Complexity – Simple, low cost, and minimal modifications needed on existing components

The decision matrix assumed that all designs being considered had met all SEL requirements. Some ideas scored high but through preliminary prototyping failed to meet the main requirements of the project. These ideas are highlighted in red in Table 3 below and were not considered moving forward. From the remaining ideas, the top idea came out to be the Rails design followed closely by the Over-Center Mechanism and the Threaded Rod designs.

Category	Sub-Category	Weight	Cleat & Claw	Gear	Rubber	Rails	Overcenter	Slotted Arm	L-hole	Threaded Rod	Puzzle	Peg slot	Y_Rod
			Idea 1	Idea 2	Idea 3	Idea 4	Idea 5	Idea 6	Idea 7	Idea 8	Idea 9	Idea 10	Idea 11
Cost	Tooling Cost	4.03	8	6	5	7	7	9	8	4	7	4	5
	Cost(materials)	7.3	8	8	8	7	7	9	8	5	8	4	7
Manufacturability	Complexity of Design	4.14	8	7	7	7	4	7	8	1	8	6	5
	Ease of Access	13.82	9	2	2	9	9	2	1	10	9	8	9
User Friendly	Simplicity	13.67	10	3	4	9	9	9	7	9	7	9	10
	Operation Time	14.3	10	8	8	9	8	7	9	7	8	9	10
	Repairability	4.2	8	3	5	8	5	5	4	9	9	4	8
	Ergonomic	26.9	4	7	7	9	9	8	2	9	7	9	7
Current System Modification	Mod. Complexity	4.02	8	8	9	7	8	8	7	4	6	8	8
Space	Low Profile	7.62	6	4	4	8	7	6	7	7	7	3	7
			7.4692	5.5815	5.8021	8.492	8.0628	6.958	5.1405	7.6741	7.5776	7.4637	8.0343

Table 3: Decision Matrix for Preliminary Designs

## Process Selection

Process selection is an integral part of design. The fabrication process can determine how the material is joined, shaped, and finished, therefore influencing the final design itself. There are multiple processes that an engineer can select which is also dependent on the material, function, and the shape of the part. Therefore, a simple process selection was conducted based on shape type and economic batch size to better understand what was available for this project. The following figure shows the processes that work well with each different type of shape in the desired design. From the preliminary designing stage, the team figured that 3D solid shapes would be a good place to start.

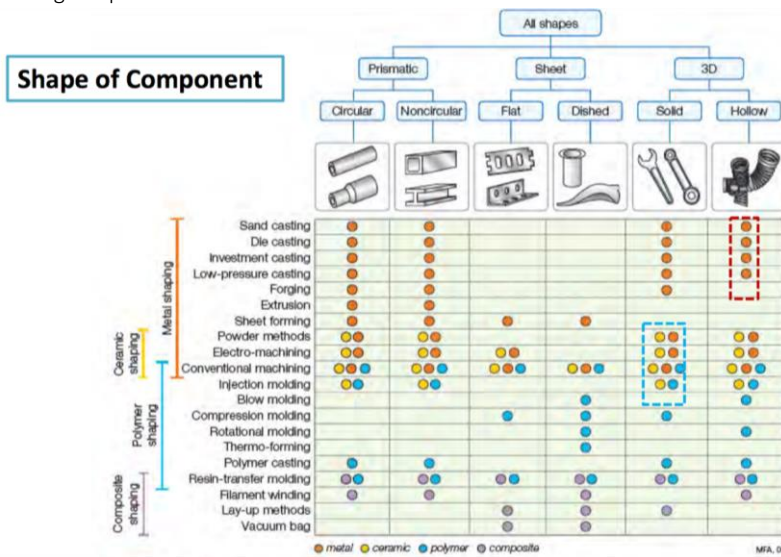
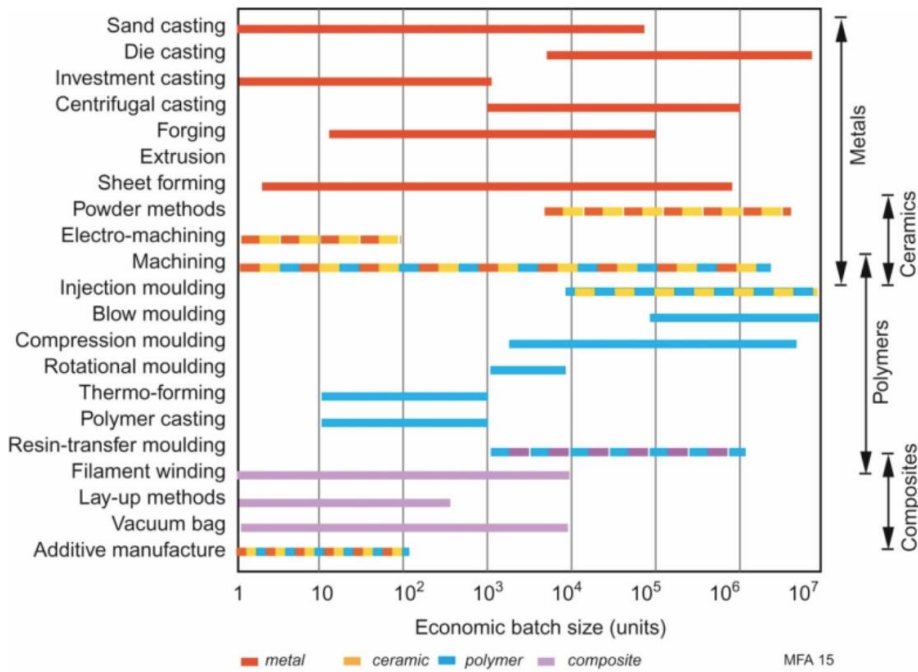


Figure 18: Process Selection Based on Component Shape

Figure 19: Process Selection Chart Based on Economic Batch Size. Figure 19 shows processes that correlate with economic batch sizes. The team was given an estimated batch size of 10,000 units per year. In addition to using these charts, the team researched what processes were common and available for SEL to use and ended up Sheet metal fabrication and injection molding as the



two processes to move forward with.

Figure 19: Process Selection Chart Based on Economic Batch Size



## Sheet Metal Forming

Sheet metal fabrication was especially appealing because SEL already has a close working relationship with NIC Global Manufacturing in Woodinville, WA and a majority of SEL products contain sheet metal components.

Sheet metal fabrication consists of bending, rolling, shearing, stamping, and more. Designers need to keep sequential forming in mind as well as limitations on bend radii. Usually sheet metal machines are able to press multiple features at once depending on the tooling for design.

- Advantages
  - High production rate = low part cost
- Disadvantages
  - Tooling less flexible
  - High up-front cost

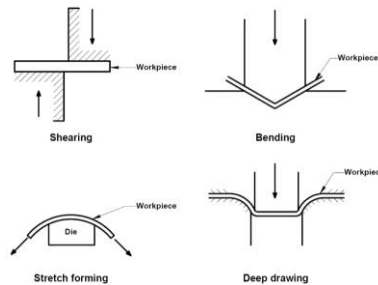


Figure 20: Sheet Metal Forming Techniques

## Injection Molding

Injection molding was considered for many reasons. For one, SEL has an in-house injection molding facility in Lewiston, ID. Plastics are also cheap as a material and reduce the risk of interaction with the electrical components within the relays. The plastic parts are light which makes them cheaper to ship and safer to handle.

Injection Molding starts off with plastic pellets that are melted through a barrel to the point that it can be injected into a cavity or mold. The parts cool in the mold and are then ejected with ejector pins. This process repeats itself until all the parts are created.

- Advantages
  - Low scrap rates
  - Highly reproducible
  - Low part cost
  - In-house facility
- Disadvantages
  - High up-front cost for tooling
    - Wall drafting
    - Uniform wall thickness
    - Strength of plastic

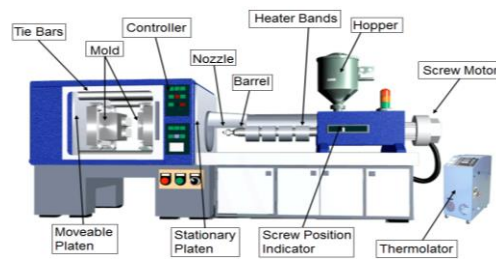


Figure 21: Injection Molding Schematic

## Material Selection

Given the two manufacturing methods selected previously, materials needed to be determined for future stress analysis. By using the material selection charts below, multiple materials can be pooled together to understand what is available for the proposed design.

The final design in its simplest form is a beam. The team algebraically derived the following material indices:

$$M = E * C_{vr} \quad (1)$$

$$M = f * C_{vr} \quad (2)$$

Where  $M$  is the material index,  $E$  is the Elastic Modulus,  $C_{vr}$  is the relative cost per volume of material, and  $f$  is the strength of the material. Equation 1 and 2 are used for a stiff beam and a strong beam respectively to conduct a multistage selection. The elastic modulus and strength were maximized and the relative cost per volume of material were minimized as much as possible. The red lines represent these material indices which intersect materials that will perform similar to each other. The indices were strategically placed to intersect the most metal and polymer materials since those are the materials used in the two manufacturing methods the team decided to use.

After pooling the resulting materials from each chart, the overlapping materials highlighted in Table 4: Multi-stage Material Selection Results were used in cross reference with SEL's common materials.

5052 Aluminum was chosen for sheet metal and Nylon 6 was chosen for injection molding.

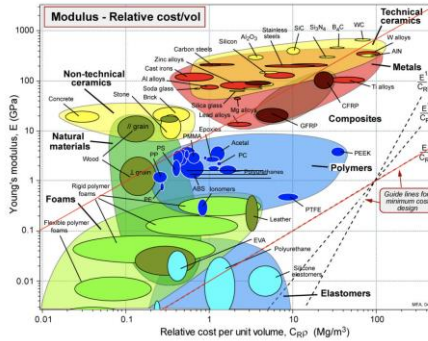


Figure 22: Material Selection for a Stiff Beam

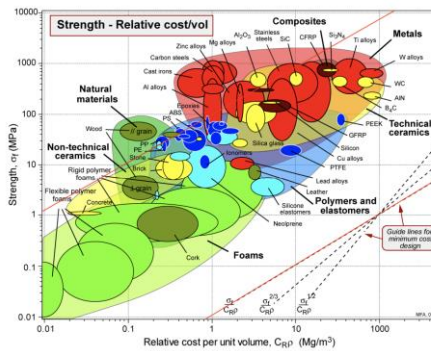


Figure 23: Material Selection for a Strong Beam

	Stage 1-Stiffness			Stage 2-Strength		
	Metals	Polymers	Composites	Metals	Polymers	Composites
M	Carbon Steels	PMMA	CFRP	Carbon Steels	PMMA	CFRP
A	Cast Irons	ABS	SMC	Cast Irons	ABS	
T	Aluminum Alloys	PP		Aluminum Alloys	PP	
E		PA			PA	
R		PE			PE	
I		PS			PS	
A		Nylon			Nylons	
L		PC			PET	
S		PUR				
		POM				
		Epoxy				

Table 4: Multi-stage Material Selection Results

## Final Design

The Rails idea, as stated previously, was selected to be the final design. The preliminary design went through multiple stages of development to improve alignment, minimize part volume, and maximize ergonomics.

The long rails were cut in half and formed into two smaller blocks for added strength and ease of attachment. The opening in the rail block was widened and the walls were smoothed out to allow for a smoother transition.

The final design consists of two lever arms, two rail blocks, and two chassis wall connectors for each arm.

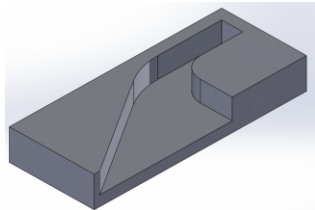


Figure 24: Refined Rail Design

## Sheet Metal Design Specifications

The sheet metal version of the Rails design uses 14-gauge 5052 Aluminum. This thickness allowed for the use of PEM fasteners and is also a common sheet used in the given relay assemblies. The lever arms take on the most stress, so the thin metal would not work as is. Tabs were added to the arm to increase rigidity and prevent torsion. Another tab was folded down and hemmed to provide a comfortable surface for the user to push and pull on. The connector has a tab on top for the arm to connect to and a tab in the front to stop the arm at an angle that would allow for proper insertion. The rail block has the same overall shape as shown in Figure 21, but because it is being stamped out of the thin sheet of metal it requires 4 identical pieces on each side to be stacked together and screwed into the tray.



Figure 25: Sheet Metal Rails Design Right-Side Assembly

There are four different fasteners needed for this design. Two of which are already being used in the current relay assembly. There are two rivets used to connect each connector piece to the chassis side wall. These are the same rivets used all around the outside of the chassis. The rail block will slide over two stand offs that are currently used on the top of the tray for the circuit boards, so just 4 more of the same standoffs will be needed on the underside of the tray. The last two are new fasteners found on the Penn Engineering website. The peg is a self-clinching stud that is pressed into the sheet and the pivoting connection is a spot fast hinging fastener. Figure 26 shows where each of these different fasteners will go in the rails design assembly. Part numbers for all the listed parts can be found in [Table \\_](#).

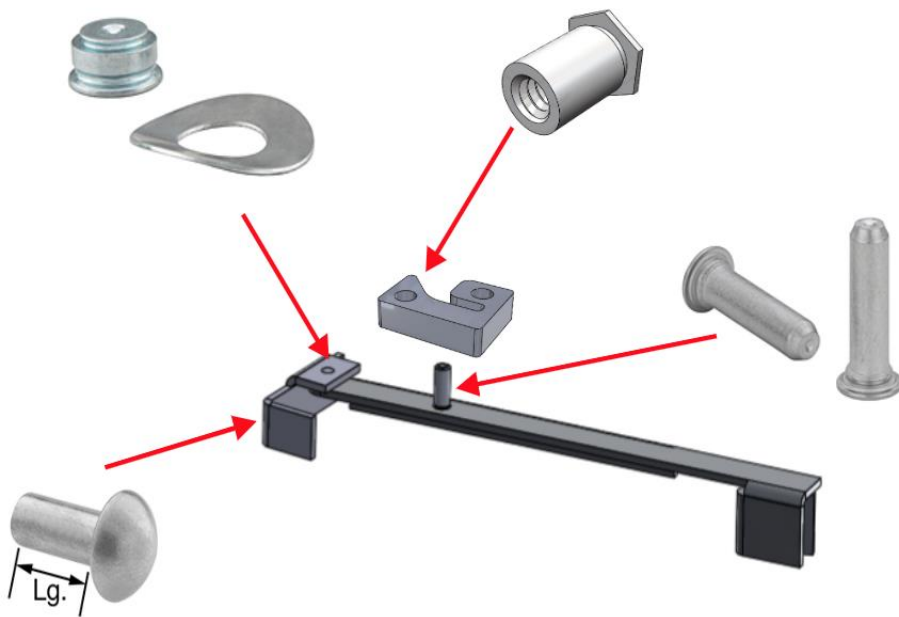


Figure 26: Fastener Placement for Sheet Metal Assembly

## Injection Molding Design Specifications

The injection molding version of the rails design had to be modified a bit more because of the process constraints. To get the best result, the plastic needs to cool at the same rate everywhere within the part. To achieve this, all of the parts need to have even wall thickness between 1mm and 4mm in thickness. With plastics already being weaker than metals a lot of supporting walls needed to be added. The lever arm ended up looking like an I-beam to get that extra rigidity. The rail block had to be hollowed out for the walls to have even wall thickness, so webbing was added for support. The connector was made with enclosed walls for extra strength as well. All parts have a 2-degree wall draft to allow for ejection after cooling.

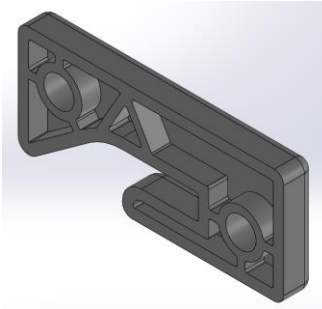


Figure 27: Bottom of Injection Molded Rail Block

The same standoffs can be used for the injection molding rail block. The hinging fastener is a binding barrel screw and the connector to wall fastener is called a tapered thru threaded insert. This insert is heated and pressed into the plastic connector. There were multiple versions of this fastener and we chose to use the press in ones because they were cheaper, and they were available in 6-32 #2 thread, so the assembly would remain consistent in that way. They are not as strong as the ones that are molded into the part, but the connector does not see any major pulling forces, so it was not seen as a critical aspect for this design.

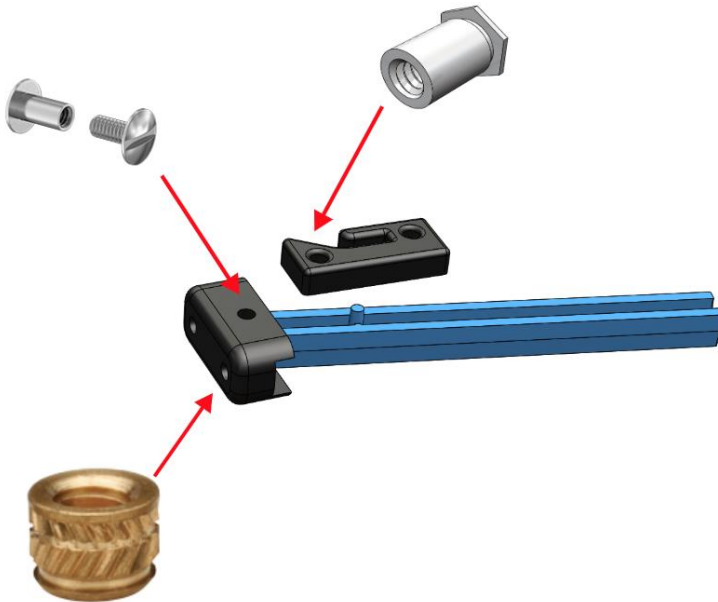
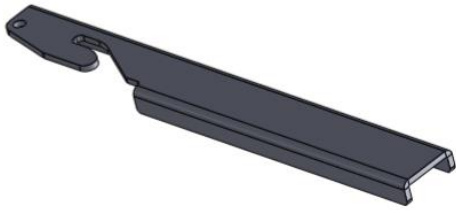


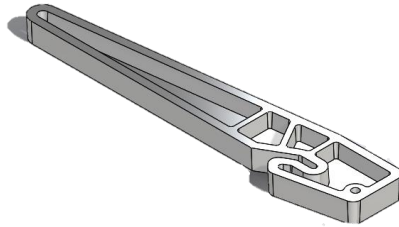
Figure 28: Fastener Placement for Injection Molded Assembly

## Flipped Rails Design

Another version of the Rails design was experimented with towards the end of the semester. This version swapped the location of the peg and the rail block. The slot characteristic was now embedded into the arm and the peg became a stud that protruded downward from the tray. This design eliminates the need for the rail block and therefore requires two less parts in the assembly. A few versions of this idea were prototyped. The first used 1/8" aluminum for the arm, the second used the same 14-gauge sheet as the previous sheet metal design (Figure 29), and the last used the injection molding process (Figure 30). Further refinement on this design may be desired. User surveying, discussed in a later section, concluded that the plastic version of this design was the smoothest and quietest of the designs and with the current dimensions it is very sturdy and does not feel like it is about to break.



*Figure 29: Flipped Rails Sheet Metal Design*



*Figure 30: Flipped Rails Injection Molded Design*

This design allows for a smoother insertion because the peg slides down the whole arm and then into the slot instead of having to be positioned just right to insert into the slot on first contact.

## Design Evaluation

### Stress Analysis – Sheet Metal Rails Design

The selected material for the sheet metal lever arm is a 5052-H32 aluminum whose yield stress is 28kpsi. During ejection of the tray (Figure 28), the max stress determined by a SolidWorks simulation study was 1882 psi and occurs at the folded over tab alongside the main body of the arm. This results in the design having a factor of safety of approximately 15. During insertion, the max stress as determined by the SolidWorks simulation was 1934psi and occurs at the tab foldover. This results in the design having a factor of safety of approximately 14.

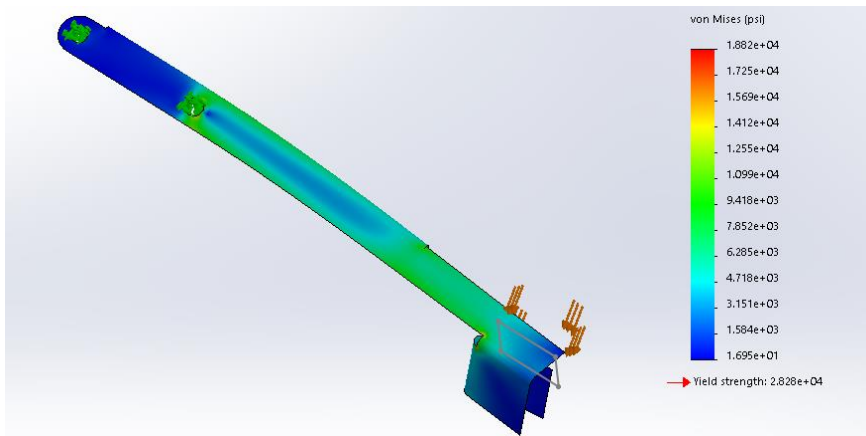


Figure 31: Stress Analysis for Sheet Metal Rails Arm- Pull 5 lbf

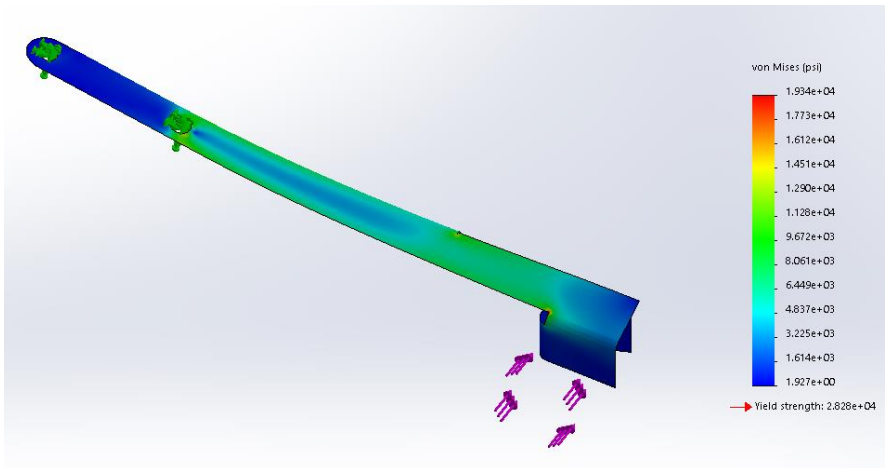


Figure 32: Stress Analysis for Sheet Metal Rails Arm- Push 5 lbf

## Stress Analysis – Flipped Sheet Metal Rails Design

This design uses the same 14-gauge 5052 Aluminum sheet and incorporates the flipped pin and rail locations. The max stress during removal of the tray (figure 30) was 4559 psi and occurs at the tab folded over. This results in the design having a factor of safety of approximately 6. The max stress during insertion was 3344psi. This results in the design having a factor of safety of approximately 8.5.

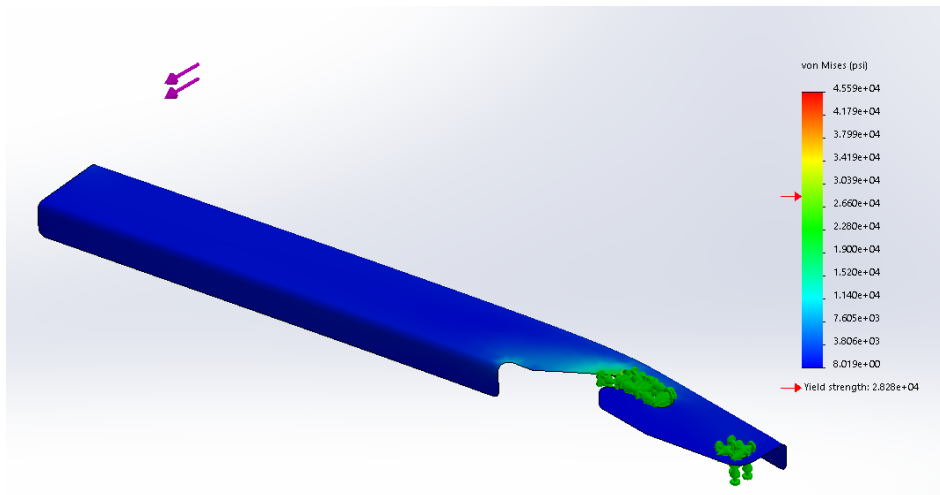


Figure 34: Stress Analysis - Flipped Rails Arm Ejection

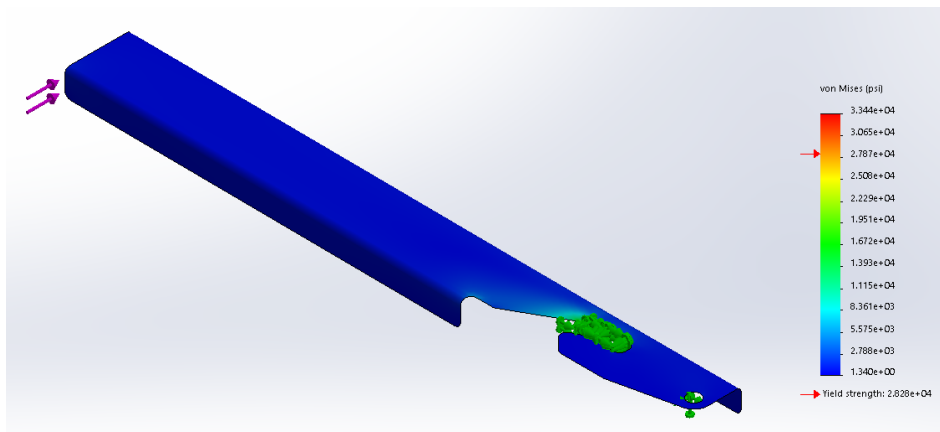


Figure 33: Stress Analysis - Flipped Rails Arm Insertion



## Stress Analysis – Plastic Rails Design

A simulation was completed for the standard plastic injection molded parts. As the arms are symmetrical for both sides, both the pull and push movements can be simulated with one run. 5 lbr is applied to a contact patch 0.25" wide and the full height of the arm, the opposite end is hinged, and the pin is set to be fixed. The max stress as determined by the simulation is 7812 psi and occurs at the base of the pin as shown in Figure 35. When made with the selected PA Type 6 material, which has a yield strength of 12-15 kpsi, a factor of safety of approximately 1.9 is calculated.

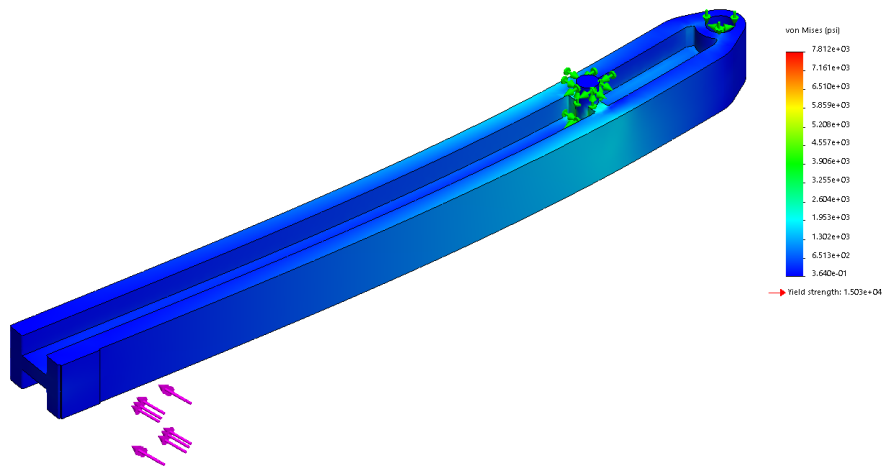


Figure 35: Stress Analysis for Plastic Rails Design

The maximum input force that can be applied before yielding was determined to be 9.5lbs by multiple runs of simulation varying the input force until the factor of safety is less than one.

## Stress Analysis – Flipped Plastic Rails Design

The material selected for this design was PA Type 6. In the first study 5lbf was applied to the far-left end of the lever arm. A fixed hinge feature was added to the pivoting hole and a fixed geometry feature was added to the inside jaw area where the peg would react. The max von Mises stress was found in the red section shown in Figure 36. The stress at this area came out to be  $2.1132 \times 10^7 \text{ N/m}^2$  which is well under the yield strength of the material,  $1.036 \times 10^8 \text{ N/m}^2$ . It was concluded that the part would not break. The maximum displacement of the part was calculated to be 1.454 mm which is less than 0.05 inches. This result further confirmed our conclusion from the stress analysis. For the second study a 5lb input force was applied to the near side of the far-left end. The fixed hinge feature was kept the same and the fixed geometry was applied to the lower jaw section shown below.

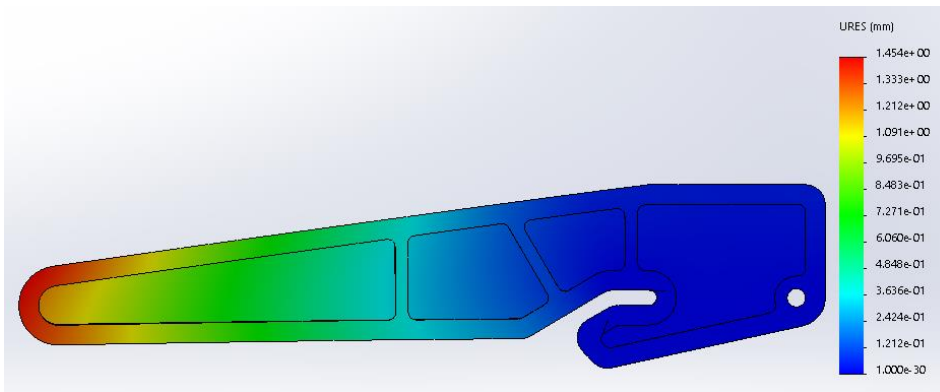


Figure 36: Displacement on Plastic Flipped Rails Design

The majority of the stress in this configuration is in the very back of the slot. The maximum von Mises stress calculated for this configuration of forces came out to be  $2.298 \times 10^7 \text{ N/m}^2$ . This is still below the yield strength value, so it was again concluded that the part would not fail under the given 5lb input load.

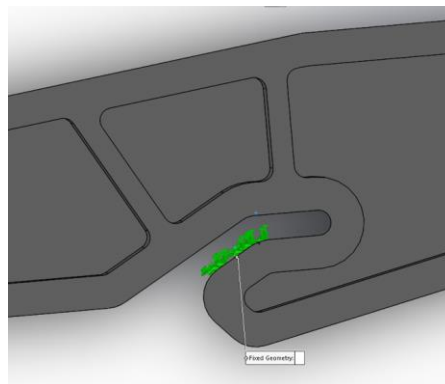


Figure 37: Peg Contact Area on Plastic Flipped Rails Design for Push Study

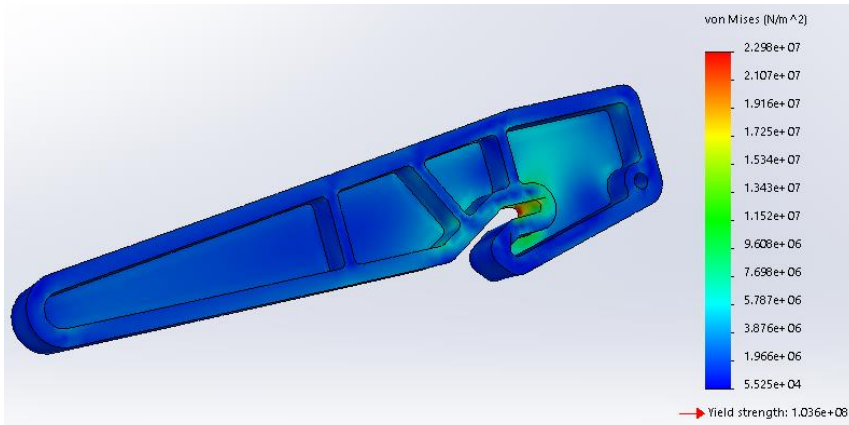


Figure 38: Stress Analysis on Plastic Flipped Rails Design-Input 5 lbf

Another study was completed to calculate the theoretical maximum input force that the single arm could handle. This study was done in the push configuration because it generated more stresses than the pull configuration. The same fixtures were applied, and the input force was varied from 5lbf to 50lbf. 21lbf was the maximum whole number that produced a max stress under the yield strength of the material. This study was done to ensure that the arm would not break under greater loads caused by misuse or misalignment within the mechanism. Another source of increased input force could be a higher required output force. From previous testing, it was found that some new circuit board-connector assemblies produced more friction than others. The 5lbf input used is based on the initial project requirement output force of 40lbf. It is possible that the new assemblies could require a greater output force to eject and insert the trays.

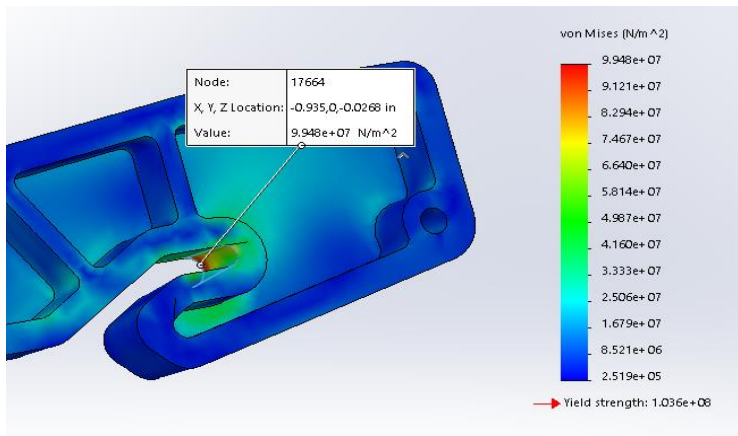


Figure 39: Stress Analysis on Plastic Flipped Rails Design - Theoretical Maximum Input Force

## Test Bed

The team constructed a test bed shown in Figure 41 and Figure 41 to prove the theoretical mechanical advantage previously calculated and to observe any physical issues. Item 1 is a fish scale rated for a max of 110 lbs. The scale will be attached to item 2, the lever arm being studied, and pulled upward until the scale reads 5 lbs. Item 3 is identical to item 1 and will have the handle fixed so it will be constrained in the upward direction. The hook will secure the lever arm's peg, labeled as item 5. Item 4 represents a pin that slides into the pivot hole in the arm. This fixes the pivot location.

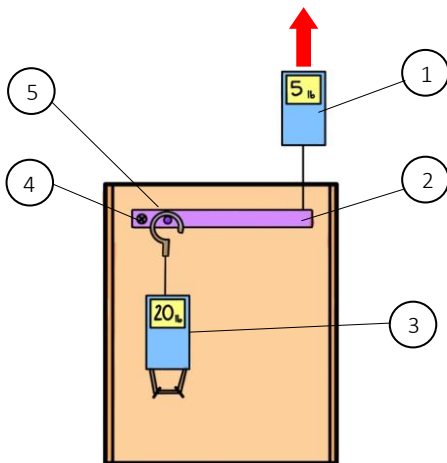


Figure 41: Test Bed Schematic



Figure 41: Test Bed in Use

## Results

In Figure 41, the sheet metal arm is being tested. The fish scales read 5.08 lbs. on the top and 20.45 lbs. on the bottom. This confirms the mechanical advantage previously calculated and there is little to no deflection to be seen in the arm. Although the sheet metal arm did not bend, it did twist a little because of the placement of the forces.

The plastic arm also met the mechanical advantage needs. The plastic arm showed more bending with about a 0.25" displacement of the tip in the z direction. It also twisted a tiny bit, but not enough to cause worry.

## Cost Analysis

For each design the team was able to attain quotes which specified what the cost would be for each individual assembly based on a batch size of 10,000 units. For the injection molding design, a quote was obtained from Protolabs which resulted in a part cost of roughly \$3.00. It is important to note that this cost will likely decrease because of SEL's in-house injection molding facility. For the sheet metal design, quotes were obtained from NIC global manufacturing solutions and the assembly cost was roughly \$15.00. It is apparent from these quotes, that an injection molded solution would be much cheaper than a sheet metal fabricated solution. The original quotes can be found in Appendix D.

Hardware costs were estimated from McMaster-Carr to create the following tables. Cost of hardware parts already existing in the original relay assembly were ignored. The binding barrel screws were thought to be the best way to attach the arm to the connector, but it may be too costly to implement.

Sheet Metal Rails Design				
Part No.	Part Cost	Quantity	Total Part Cost	NOTES
NPN-RIVET_CHICAGO_RIVET_R3553	0.00822	4	0.03288	Connector to chassis connection (in original chassis)
SFW-3-1.6-LZ	0.25	2	0.5	Single point hinging fastener for arm to connector piece (new)
TPS-125-6	0.2438	2	0.4876	Self Clinching Stud for peg in arm (new) Price from McMaster-Carr
6-32 #2 screws	N/A	6	N/A	screws for connector and rail block
NPN-PEM_SO_6440-10	N/A	4	N/A	Rail block to tray connection (in original tray)
Right and Left Sub Assembly	14.71	1	14.71	Quote from NIC Global. (tumble deburred)
			15.73048	Total Assembly Cost

Injection Molding Rails Design				
Part No.	Part Cost	Quantity	Total Part Cost	NOTES
IUA-632-1	N/A	4	N/A	Connector to chassis connection (in original chassis)
94887A136	1.638	2	3.276	Binding barrel screw for arm to connector piece (new)
6-32 #2 screws	N/A	6	N/A	screws for connector and rail block
NPN-PEM_SO_6440-10	N/A	4	N/A	Rail block to tray connection (in original tray)
Right and Left Sub Assembly	2.94	1	2.94	Quote from NIC Global. (tumble deburred)
			6.216	Total Assembly Cost

## User Testing and Feedback

The final component of design analysis was user testing and feedback. This took place in two stages. The first was formal testing with a timed component. Users were presented with two chassis, one equipped with a sheet metal model and one with a 3D printed model. They were asked to use the mechanism to eject and inject the tray without any instruction. After completing the action and learning how the mechanism worked, the user was timed for both the sheet metal and 3D printed models. Timing started when the user moved to eject the tray, and ended after the tray was ejected, removed, and reinserted. It should be noted that the users were either presented with the original model or flipped design, but not both. The users were also asked to give feedback both in a ranking format and free answer, which can be seen in Figure 36. The metal designs generally took less time to insert and eject, however the plastic models were more comfortable for users.

The second component of user testing occurred at Engineering EXPO. Throughout the day many people used all of the arm designs. The overwhelming feedback was that the plastic models were more comfortable to use and behaved more reliably. The metal versions would creak and grind, sometimes alarming users. Over time, this grinding caused the parts to shift, generating a lot of friction and causing the mechanisms to jam regularly. They also had sharper edges and caused some scrapes to hands. The 3D printed components would flex a lot which was occasionally alarming, however they did not break. The flipped design did not experience as much flex, but it was more comfortable than the metal versions.

Compiling the input from both user testing stages, the recommended design is the flipped injection molded design.

Design	How Accessible is the insertion and ejection mechanism? (1-5, Cannot Access-Easily Accessible)	How Comfortable is it for you to use the mechanism? (1-5, It Hurts-Could Use it All Day!)	Recommendations to improve accessibility	Recommendations to improve comfort	Time Required
Sheet Metal Original	4	3	Sharp edges cut fingers	Use less sharp metal and pads to push on	6s
	5	4	N/A	Have the arms be a little softer	7s
	3	3	Visibility of handles isn't immediate, perhaps additional labelling?	Smoother slider, maybe rollers?	8s

Plastic Original	5	4	N/A	Have the arms stop at a closer point	24s
	4	4	Use springs of some sort to prevent the handles from slipping back too far	Very smooth already	10s
	5	4	Label to show how to operate	Make it easier to grab, tighter hole or notch	6s
Sheet Metal Flipped	5	5	Add grippy cover to thumb anchor on arm.	Grippy rubber covers	N/A
	4	4	Keep the lever arms flush	Make the pivot of the lever arms smoother	20s
	4	4	Have something to brace your hands against while pulling handles out	N/A	N/A
Plastic Flipped	3	3	More difficult to pull out than metal one	N/A	N/A
	5	4	N/A	Make larger thumb pads to make insertion easier	27s
	5	5	The handles were colored so easier to see	Rubber handle covers	N/A

Table 5: User Feedback Data

## Future Work

Overall, the team was able to generate and refine an idea that would work well for ejecting circuit board trays in SEL relays. If SEL intends to move forward with one of these designs, a more accurate estimate of the cost for modification of the tray and chassis would need to be gathered. This would consist of figuring out whether or not the assemblies could be attached while the sheet metal chassis is in production. Longevity analysis should also be conducted to ensure that the production material will last the required number of cycles. This will help minimize premature failure in the design. It is also recommended that SEL continue to conduct user testing to ensure that ergonomic standards are continuously met. Vibration testing is part of SEL's requirements and lastly, a full-scale production and implementation plan will need to be put together. This will help ensure that the products are made, assembled, and operated correctly by both SEL personnel and customers. Some potential design improvements are spring loading the lever arms to return to an ideal angle for proper alignment upon insertion and to adjust the angle of slot in flipped Rails design to maximize the mechanical advantage.



## References

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UNITED STATES DEPARTMENT OF LABOR. (n.d.). Retrieved from <https://www.osha.gov/SLTC/ergonomics/>

## Appendices

### Appendix A: WI-11751

#### Thumb Presses

Force Exertions Thumb Push	Frequent ( $\geq 2/\text{min}$ )		Infrequent ( $<2/\text{min}$ )	
	Recommended	Acceptable	Recommended	Acceptable
1 thumb	5.3 lb.	8.0 lb.	13.3 lb.	17.3 lb.
2 thumbs	10 lb.	15 lb.	25 lb.	32.5 lb.

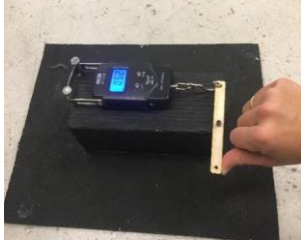

#### Hand/Palm Press

Force Exertions	Frequent ( $\geq 2/\text{min}$ )		Infrequent ( $<2/\text{min}$ )	
	Recommended	Acceptable	Recommended	Acceptable
Press down at elbow height – 1 hand	12.8 lb.	19.2 lb.	30.0 lb.	41.6 lb.
Push out at elbow height – 1 hand	7.4 lb.	11.1 lb.	18.5 lb.	24.1 lb.
Push out at elbow height – 2 hands	11.8 lb.	17.7 lb.	29.5 lb.	38.3 lb.

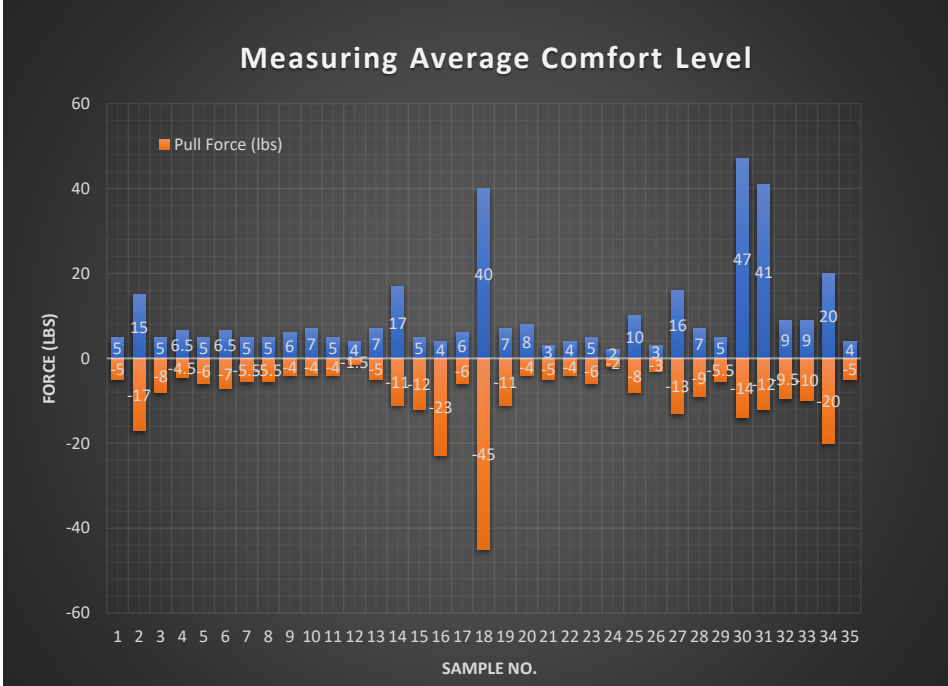
Reference: The Handbook of Ergonomic Design Guidelines (Humantech, 2012)

### Appendix B: EZ-Ject User-Testing Data Collection

A more detailed report can be found in the compiled work flash drive.

Test 1:	What is an acceptable push and pull force required to eject and insert a tray?
Apparatus:	1 fish scale (max 110 lbs), a center pivoted lever arm, 4x4 wood block.  <div style="display: flex; justify-content: space-around;">   </div>
Subjects:	Snapshot#1 attendees who stopped at our table and were willing to complete our exercise.

Directions:	Push/pull on the end of the lever until you feel it is a comfortable amount of force to use on an ejection/insertion mechanism repeatedly throughout the day.
Date:	10/9/18



<b>Using values within the Standard Deviation:</b>		
push avg(lbs)=	5.642857143	
pull avg(lbs)=	-4.785714286	
total avg(lbs)=	5.214285714	
<b>Using values after manually eliminating outliers</b>		
push avg(lbs)=	5.095238095	
pull avg(lbs)=	-4.785714286	
total avg(lbs)=	4.94047619	
avg=	10.11428571	-9
mode=	5	-4
SD=	10.93973177	7.980675189

## Appendix C: Priority Calculator

Participant Name:	Category:	Cost		Manufacturability	Space
	Sub-Category:	Cost(Tooling)	Cost(Materials)	Complexity of Design	Low Profile
	Notes:	Cost of tooling.	Cost of materials used for final product if not tooled.	Quantity of separate parts needed to be manufactured. Minimize complex parts (threads, gears, high tolerances).	Is the tool aesthetically pleasing and conservative with available space?
Nikki	Weight	2.10	3.70	3.10	8.20
	Rank	10	8	9	5
Jaime	Weight	9.60	6.40	4.50	11.90
	Rank	5	8	10	3
Davis	Weight	3.20	10.80	3.10	6.20
	Rank	8	4	9	6
Emily	Weight	1.30	8.30	5.90	4.20
	Rank	9	5	6	7
Average	Weight	4.05	7.30	4.15	7.63
	Rank	9	6	8	5
User Friendly					
Ease of Access	Simplicity	Ergonomic	Repairability	Operation Time	
Can the user access the tool without difficulty?	The user does not have to think to use the tool.	It is comfortable to use the tool to eject and insert trays.	How easily can the tool be accessed for repairs, and how easily can it be repaired?	How long does it take the user to eject and insert the tray with the tool?	
13.20	14.80	19.30	6.10	24.10	
4	3	2	6	1	
9.50	9.80	24.10	6.80	12.70	
6	4	1	7	2	
10.90	17.30	32.40	2.60	10.30	
3	2	1	10	5	
21.70	12.80	31.80	1.30	10.10	
2	3	1	9	4	
13.83	13.68	26.90	4.20	14.30	
3	4	1	7	2	
Current System Modification					
Mod. Complexity					
How difficult is it to add or subtract to the existing parts of the assembly?					
5.40					
7					
4.70					
9					
3.30					
7					
2.70					
8					
4.03					
10					
	Average Order	Category	Weight		
	1	Ergonomic	26.9		
	2	Operation Time	14.3		
	3	Ease of Access	13.83		
	4	Simplicity	13.68		
	5	Low Profile	7.63		
	6	Cost(materials)	7.3		
	7	Repairability	4.2		
	8	Complexity of Design	4.15		
	9	Tooling Cost	4.05		
	10	Mod. Complexity	4.03		

Appendix D: Quotes  
Sheet Metal Rails Design



10000 SE Woodinville WA 98072

QUOTE LETTER

QUOTE NUMBER:  
EZ Ject

TO:	FROM:
Jaime Ayala	Kim Rhode
University of Idaho	Kim.Rhode@nicglobals.com
DATE:	Office: 425-489-4300
April 15, 2019	Direct: 425-489-4371

PART NUMBER	REV	DESCRIPTION	NOTES / EXCEPTIONS	PRICING			ESTIMATED LEAD TIME
				EAU	MOQ	PRICE EA	
1	EZ-Ject	-	Left & Right Sub Assembly	PROTOTYPE RUN		3	\$364.05
2							
3	EZ-Ject	-	Left & Right Sub Assembly	PRODUCTION QUOTE	10,000	540	\$14.71
4				<b>QUOTE DIMENSION EXCEPTION:</b> (1) DIMENSIONS BASED ON FORMING QUOTED PER SEL ER-0008 SECTION 8.1. (2) 01-02a & 01-02b 164° OBTUSE BEND QUOTED @ ± 2° ANGULAR TOLERANCE. (3) PARTS WILL BE PRODUCED PER CAD MODEL DIMENSIONS; FLAT DIMENSIONS ON DRAWINGS WITH FORMING ARE QUOTED AS REFERENCE ONLY.			
5				<b>QUOTE FINISH NOTES</b> (1) PARTS WILL BE PRODUCED PER SEL COSMETIC CLASS IV, PER ER-0006. PARTS WILL BE TUMBLE DEBURRED. (1) PARTS ARE (CONVERSION COAT) CHEM FILM ONLY PER MIL-DTL-5541F, TYPE II, CLASS 3 PER ER-0008 SECTIONS 12.2.1.1.			
6				QUOTED WITHOUT ASSEMBLY OR DETAIL PART ID.			
7				QUOTE PACKAGING NOTE: QUOTE TO FOAM WRAP COMPONENTS AS A KIT FOR SHIPPING.			
8				SEW-3-1.6-LZ HAS LIMITED AVAILABILITY; IF NO FACTORY STOCK ON HAND, SPOTFAST FASTENERS HAVE NINE WEEK LEAD TIME.			
9				QUOTE EXCLUDES PRICING FOR 02-00b (SHEET METAL RAIL BLOCK, RIGHT). PART IS NOT SHOWN ON CUSTOMER DRAWING, ONLY ON CAD MODEL.			
10							

PROJECT REQUIREMENTS ARE		
DESCRIPTIONS & NOTES	QTY	PRICE

TERMS & CONDITIONS (unless otherwise specified and in writing by NIC Global)	
GENERAL	SPECIFIC
Proposal valid for 30 days from quote letter date, and delivery taken within 90 days.	MOQ Applies
Acceptance subject to final review of purchase order, drawings, and associated documents.	
Pricing will be based on the lot quantity not the blanket quantity.	
Blanket Purchase Orders are valid for one year from date of purchase.	
Shipping quantity tolerance of +/- 5% may apply.	
Net due 30 days from invoice date, quote based on USD.	

Sheet Metal Flipped Rails Design



23518 63rd Ave SE Woodinville WA 98072

QUOTE LETTER

QUOTE NUMBER:  
Flipped rail arm

TO:	FROM:
Jaime Ayala	Kim Rhode
University of Idaho	Kim.Rhode@nicglobalms.com
DATE:	Office: 425-489-4300
April 18, 2019	Direct: 425-489-4371

PART NUMBER	REV	DESCRIPTION	NOTES / EXCEPTIONS	PRICING			ESTIMATED LEAD TIME AND
				EAU	MOQ	PRICE EA	
1		Flipped rail arm	Quote for producing 3 prototype units		3	\$157.68	
2			PRODUCTION QUANTITIES QUOTED SEPARATELY.				
3			QUOTED WITHOUT CAD MODEL; PRICING IS BUDGETARY, SUBJECT TO CHANGE UPON RECEIPT OF FINALIZED DRAWINGS AND CAD MODELS.				
4			QUOTE DIMENSION EXCEPTIONS: (1) DIMENSIONS BASED ON FORMING QUOTED PER SEL ER-0098 SECTION 8.1. (2) PARTS WILL BE PRODUCED PER CAD MODEL DIMENSIONS; FLAT DIMENSIONS ON DRAWINGS WITH FORMING ARE QUOTED AS REFERENCE ONLY.				
5			QUOTE FINISH NOTES (1) PARTS WILL BE PRODUCED PER SEL COSMETIC CLASS IV, PER ER-0098. PARTS WILL BE TUMBLE DEBURRED. (2) PARTS ARE (CONVERSION COAT) CHEM FILM ONLY PER MIL-DTL-5541F, TYPE R, CLASS 9 PER ER-0098 SECTIONS 12.2.1.1.				
6			QUOTED WITHOUT ASSEMBLY OR DETAIL PART ID.				
7			QUOTE PACKAGING NOTE; QUOTE TO FOAM WRAP COMPONENTS AS A KIT FOR SHIPPING.				
8			SEW-3-1.6-LZ HAS LIMITED AVAILABILITY; IF NO FACTORY STOCK ON HAND, SPOTFAST FASTENERS HAVE NINE WEEK LEAD TIME.				
9							
10			QUOTE EXCLUDES INSTALLATION AND PIECE PRICE FOR TPS-125-6 PILOT PINS. PART IS NOT SHOWN ON CUSTOMER DRAWING, SENT AS PART OF "PEM FASTENERS" DOCUMENT FILE.				
11							
12							

PROJECT REQUIREMENTS / NRE			QTY	PRICE
NOTE: Pending Section 232 & 301 Legislation: The federal government is considering adding additional tariffs to foreign made steel and aluminum, NIC Global reserves the right to adjust the price of our product to reflect any additional tariffs or duties resulting from any new legislations.				

TERMS & CONDITIONS (unless otherwise specified and in writing by NIC Global)	
GENERAL	SPECIFIC
Proposal valid for 30 days from quote letter date, and delivery taken within 90 days.	MOQ Applies
Acceptance subject to final review of purchase order, drawings, and associated documents.	
Pricing will be based on the lot quantity not the blanket quantity.	
Blanket Purchase Orders are valid for one year from date of purchase.	
Shipping quantity tolerance of +/- 5% may apply.	
Net due 30 days from invoice date, quote based on USD.	

CAF-0100-4 Quote Letter - TRT-7/17/19



23518 63rd Ave SE Woodville, WA 98072

**QUOTE LETTER**

QUOTE NUMBER  
Flipped rail arm

TO:	FROM:
Jaimie Ayala	Kim Rhode
University of Idaho	Kim.Rhode@nicglobal.com
DATE:	Office: 425-489-4300
April 18, 2019	Direct: 425-489-4371

PART NUMBER	REV	DESCRIPTION	PRICING	NOTES / EXCEPTIONS	EAU	MOQ	PRICE EA	ESTIMATED LEAD TIME AND
1	N/A	Flipped rail arm		Quote for 10,000 units a year	10,000	710	\$7.54	
2				PROTOTYPE (PILOT RUN) MOQ 3 QUOTED SEPARATELY.				
3								
4				QUOTED WITHOUT CAD MODEL; PRICING IS BUDGETARY, SUBJECT TO CHANGE UPON RECEIPT OF FINALIZED DRAWINGS AND CAD MODELS.				
5				QUOTE DIMENSION EXCEPTIONS: (1) DIMENSIONS BASED ON FORMING QUOTED PER SEL ER-0008 SECTION 8.1. (2) PARTS WILL BE PRODUCED PER CAD MODEL DIMENSIONS; FLAT DIMENSIONS ON DRAWINGS WITH FORMING ARE QUOTED AS REFERENCE ONLY.				
6				QUOTE FINISH NOTES (1) PARTS WILL BE PRODUCED PER SEL COSMETIC CLASS IV, PER ER-0006. PARTS WILL BE TUMBLE DEBURRED. (2) PARTS ARE (CONVERSION COAT) CHEM FILM ONLY PER ML-DTL-0541F, TYPE II, CLASS 3 PER ER-0008 SECTIONS 12.2.1.1.				
7				QUOTED WITHOUT ASSEMBLY OR DETAIL PART ID.				
8				QUOTE PACKAGING NOTE: QUOTE TO FOAM WRAP COMPONENTS AS A KIT FOR SHIPPING.				
9								
10				SEW-3-1-6-2 HAS LIMITED AVAILABILITY; IF NO FACTORY STOCK ON HAND, SPOTFAST FASTENERS HAVE NINE WEEK LEAD TIME.				
11								
12				QUOTE EXCLUDES INSTALLATION AND PIECE PRICE FOR TFS-125-6 PILOT PINS. PART IS NOT SHOWN ON CUSTOMER DRAWING, SENT AS PART OF "PEM FASTENERS" DOCUMENT FILE.				
13								
14				NRE 01-01s & 01-01ns BUDGETARY PRICE FOR CUSTOM U-CHANNEL BRAKE TOOL USE ON BOTH FLIPPED RAIL ARMS, QUOTED EIGHT WEEK LEAD TIME, EXCLUDES SHIPPING.	1 SET		\$5,825.00	
15				NRE RAIL ARM FLIPPY (L & R FLAT) BUDGETARY PRICE FOR TURRET SPECIAL SHAPE TOOL, SIX DAY LEAD TIME EXCLUDES SHIPPING.	1 SET		\$1,419.60	
16				NRE CONNECTOR (L & R FLAT) BUDGETARY PRICE FOR TURRET SPECIAL TOOLING (BLANKING TOOL), SIX DAY LEAD TIME EXCLUDES SHIPPING.	1 SET		\$769.25	
17								
18								

PROJECT REQUIREMENTS / NRE		
DESCRIPTIONS & NOTES	QTY	PRICE
NOTE: Pending Section 232 & 301 Legislation: The federal government is considering adding additional tariffs to foreign made steel and aluminum, NIC Global reserves the right to adjust the price of our product to reflect any additional tariffs or duties resulting from any new legislations.		

TERMS & CONDITIONS (unless otherwise specified and in writing by NIC Global)		
GENERAL	MOQ Applies	SPECIFIC
Proposal valid for 30 days from quote letter date, and delivery taken within 90 days.		
Acceptance subject to final review of purchase order, drawings, and associated documents.		
Pricing will be based on the lot quantity not the blanket quantity.		
Blanket Purchase Orders are valid for one year from date of purchase.		
Shipping quantity tolerances of +/- 5% may apply.		
Net due 30 days from invoice date, quote based on USD.		

## Injection Molding Rails Design

### Injection Molding Quote for On-Demand Manufacturing

Prepared for: University of Idaho  
Process: Plastic Injection Molding  
Quote Number: 682242  
Quote Date: 4/19/2019  
Part Name: Arms - Injection - Ibeam rev 2  
Extents: 115.252 mm x 9.906 mm x 12.065 mm



Thank you for the opportunity to quote your parts. We look forward to working with you on this project. If you have any questions, please contact us at 877.479.3680.

#### 1 Confirm or Modify Specifications and Review Pricing

Cavities:	<input type="text" value="8 cavity"/>
A-side (green) finish:	<input type="text" value="PM-F1 (Low-cosmetic - most toolmarks removed)"/>
B-side (blue) finish:	<input type="text" value="PM-F0 (Non-cosmetic - finish to Protomold discretion)"/>
Tooling Price: <b>\$8,410.00</b>	
Sample Quantity:	<input type="text" value="25"/> Sample Parts 25 @ \$1.49: <b>\$37.25</b>
Material:	<input type="text" value="Nylon 6, Natural (Nymax 1010 A)"/> <input type="button" value="Change Material Color"/>
Manufacturing Time:	<input type="text" value="Sample parts ship in 15 business days (standard price)"/>

With On-Demand manufacturing, our part price for your design is as low as \$0.54 for a mold with 8 cavities and a single order of 20,000 parts or more.

Total USD:   
[currency calculator](#)

#### Production Parts Calculator

This calculator shows estimated piece part pricing for future production orders.

Qty 1,000:	\$1.19 ea	<b>Custom Lot Size Pricing</b>	
Qty 3,500:	\$0.64 ea	Enter Lot Size:	<input type="text" value="20000"/>
Qty 5,000:	\$0.57 ea	Qty 20000:	\$0.54 ea
Qty 20,000:	\$0.54 ea		<input type="button" value="Go"/>

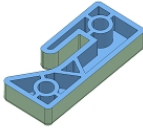
Production pricing in USD based on the material selected: Nylon 6, Natural (Nymax 1010 A)

Add \$500.00 setup charge to each lot of production parts.



## Injection Molding Quote for On-Demand Manufacturing

Prepared for: University of Idaho  
Process: Plastic Injection Molding  
Quote Number: 682242  
Quote Date: 4/19/2019  
Part Name: Right Rail - Injection rev 6  
Extents: 35.56 mm x 15.24 mm x 6.35 mm



Thank you for the opportunity to quote your parts. We look forward to working with you on this project. If you have any questions, please contact us at 877.479.3680.

### 1 Confirm or Modify Specifications and Review Pricing

Cavities:	<input type="text" value="8 cavity"/>
A-side (green) finish:	<input type="text" value="PM-F1 (Low-cosmetic - most toolmarks removed)"/>
B-side (blue) finish:	<input type="text" value="PM-F0 (Non-cosmetic - finish to Protomold discretion)"/>
Tooling Price: <b>\$5,945.00</b>	
Sample Quantity:	<input type="text" value="25"/> Sample Parts 25 @ \$1.24: <b>\$31.00</b>
Material:	<input type="text" value="Nylon 6, Natural (Nymax 1010 A)"/>
<input type="button" value="Change Material Color"/>	
Manufacturing Time:	<input type="text" value="Sample parts ship in 15 business days (standard price)"/>

With On-Demand manufacturing, our part price for your design is as low as \$0.41 for a mold with 8 cavities and a single order of 20,000 parts or more.

Total USD:   
[currency calculator](#)

#### Production Parts Calculator

This calculator shows estimated piece part pricing for future production orders.

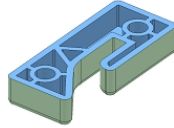
Qty 1,000:	\$0.98 ea	Custom Lot Size Pricing	
Qty 3,500:	\$0.50 ea	Enter Lot Size:	<input type="text" value="10000"/>
Qty 5,000:	\$0.44 ea	Qty 20000:	\$0.41 ea
Qty 20,000:	\$0.41 ea		<input type="button" value="Go"/>

Production pricing in USD based on the material selected: Nylon 6, Natural (Nymax 1010 A)

Add \$500.00 setup charge to each lot of production parts.

## Injection Molding Quote for On-Demand Manufacturing

Prepared for: University of Idaho  
Process: Plastic Injection Molding  
Quote Number: 682242  
Quote Date: 4/19/2019  
Part Name: Left Rail - Injection rev 6  
Extents: 35.56 mm x 15.24 mm x 6.35 mm



Thank you for the opportunity to quote your parts. We look forward to working with you on this project. If you have any questions, please contact us at 877.479.3680.

### 1 Confirm or Modify Specifications and Review Pricing

Cavities:	8 cavity		
A-side (green) finish:	PM-F1 (Low-cosmetic - most toolmarks removed)		
B-side (blue) finish:	PM-F0 (Non-cosmetic - finish to Protomold discretion)		
Tooling Price: \$5,935.00			
Sample Quantity:	25	Sample Parts 25 @ \$1.24:	\$31.00
Material:	Nylon 6, Natural (Nymax 1010 A)		
<a href="#">Change Material Color</a>			
Manufacturing Time:	Sample parts ship in 15 business days (standard price)		

With On-Demand manufacturing, our part price for your design is as low as \$0.41 for a mold with 8 cavities and a single order of 20,000 parts or more.

Total USD: **\$5,966.00**  
[currency calculator](#)

#### Production Parts Calculator

This calculator shows estimated piece part pricing for future production orders.

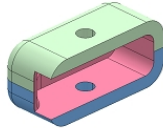
Qty 1,000:	\$0.98 ea	Custom Lot Size Pricing		
Qty 3,500:	\$0.50 ea	Enter Lot Size:	<input type="text" value="10000"/>	<input type="button" value="Go"/>
Qty 5,000:	\$0.44 ea	Qty 20000:	\$0.41 ea	
Qty 20,000:	\$0.41 ea			

Add \$500.00 setup charge to each lot of production parts.

Production pricing in USD based on the material selected: Nylon 6, Natural (Nymax 1010 A)

## Injection Molding Quote for On-Demand Manufacturing

Prepared for: **University of Idaho**  
Process: **Plastic Injection Molding**  
Quote Number: **682242**  
Quote Date: **4/19/2019**  
Part Name: **Connector - Injection - I beam rev 2**  
Extents: **33.02 mm x 13.97 mm x 15.24 mm**



Thank you for the opportunity to quote your parts. We look forward to working with you on this project. If you have any questions, please contact us at 877.479.3680.

### 1 Confirm or Modify Specifications and Review Pricing

Cavities:	8 cavity		
A-side (green) finish:	<input checked="" type="radio"/> PM-F1 (Low-cosmetic - most toolmarks removed)		
B-side (blue) finish:	<input checked="" type="radio"/> PM-F0 (Non-cosmetic - finish to Protomold discretion)		
Tooling Price: <b>\$20,005.00</b>			
Sample Quantity:	25	Sample Parts 25 @ \$1.33:	\$33.25
Material:	<input checked="" type="radio"/> Nylon 6, Natural (Nymax 1010 A)		
	<input checked="" type="radio"/> <a href="#">Change Material Color</a>		
Manufacturing Time:	<input checked="" type="radio"/> Sample parts ship in 15 business days (standard price)		

With On-Demand manufacturing, our part price for your design is as low as \$0.46 for a mold with 8 cavities and a single order of 20,000 parts or more.

**Total USD:**   
[currency calculator](#)

### Production Parts Calculator

This calculator shows estimated piece part pricing for future production orders.

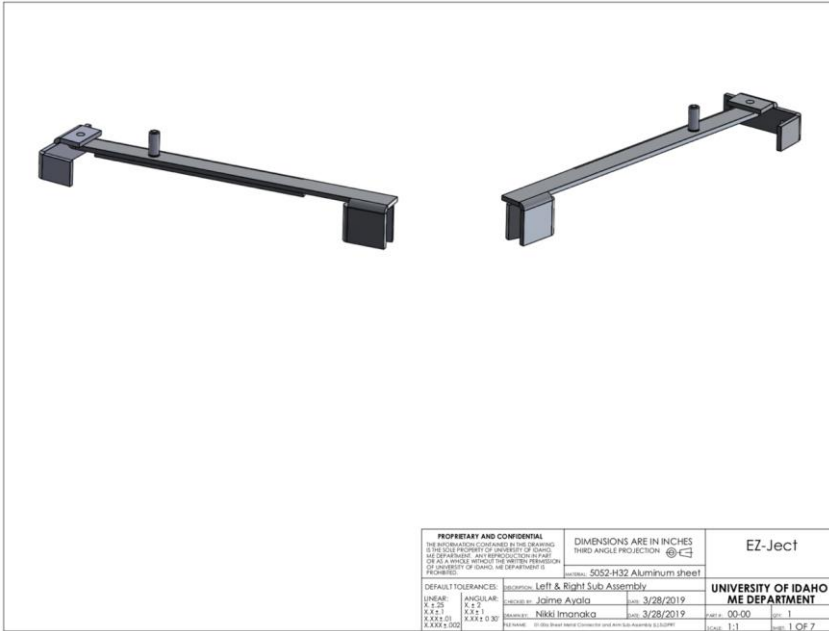
Qty	Price	Custom Lot Size Pricing
Qty 1,000:	\$1.05 ea	Enter Lot Size: <input type="text" value="20000"/>
Qty 3,500:	\$0.55 ea	<input type="button" value="Go"/>
Qty 5,000:	\$0.48 ea	Qty 20,000: \$0.46 ea
Qty 20,000:	\$0.46 ea	

Production pricing in USD based on the material selected: Nylon 6, Natural (Nymax 1010 A)

Add \$500.00 setup charge to each lot of production parts.

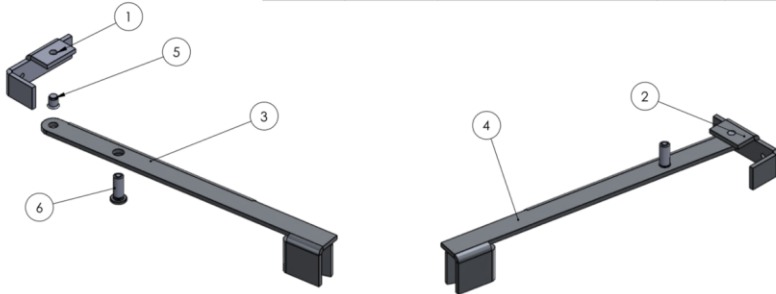
# Appendix E: Drawing Packages

## Sheet Metal Rails Design



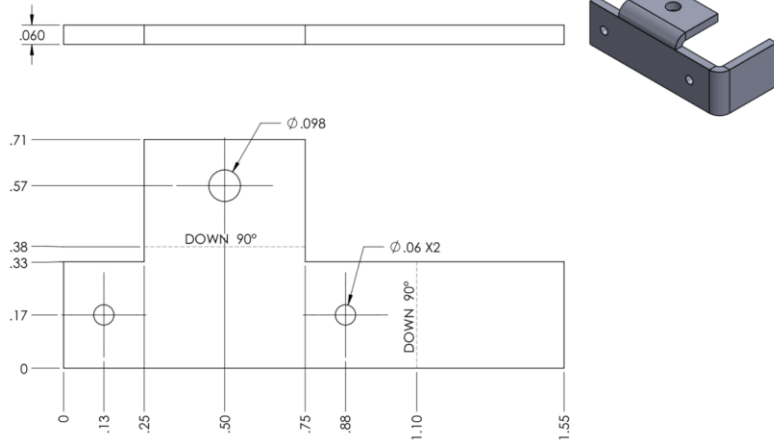
<b>PROPRIETARY AND CONFIDENTIAL</b> <small>ALL INFORMATION CONTAINED HEREIN IS THE PROPERTY OF THE UNIVERSITY OF IDAHO. IT IS TO BE KEPT CONFIDENTIAL AND NOT TO BE REPRODUCED OR TRANSMITTED IN ANY FORM OR BY ANY MEANS, ELECTRONIC OR MECHANICAL, INCLUDING PHOTOCOPYING, RECORDING, OR BY ANY INFORMATION STORAGE AND RETRIEVAL SYSTEM.</small>		DIMENSIONS ARE IN INCHES <small>THIRD ANGLE PROJECTION</small>		EZ-Ject	
		Material: 5052-H32 Aluminum sheet			
DEFAULT TOLERANCES:		Description: Left & Right Sub Assembly		UNIVERSITY OF IDAHO ME DEPARTMENT	
LINEAR: X.XX	ANGULAR: 0.01	Author: Jaime Ayala	Date: 3/28/2019	Part: 00-00	Rev: 1
R.XX	R.01	Revised: Nikki Imanaka	Date: 3/28/2019	Sheet: 1 of 7	
X.XX ± .005	X.XX ± 0.01	REVISIONS		Sheet: 1 of 7	

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.	PAGE NO.
1	01-01 a	Left Connector	1	3
2	01-01 b	Right Connector	1	4
3	01-02 a	Left Lever Arm	1	5
4	01-02 b	Right Lever Arm	1	6
5	SFW-3-1.6-LZ	PEM Single Point Hinging Fastener	2	NA
6	TPS-125-6	PEM Self-Clinching Stud	2	NA
7	02-00a	Rail block	2	7

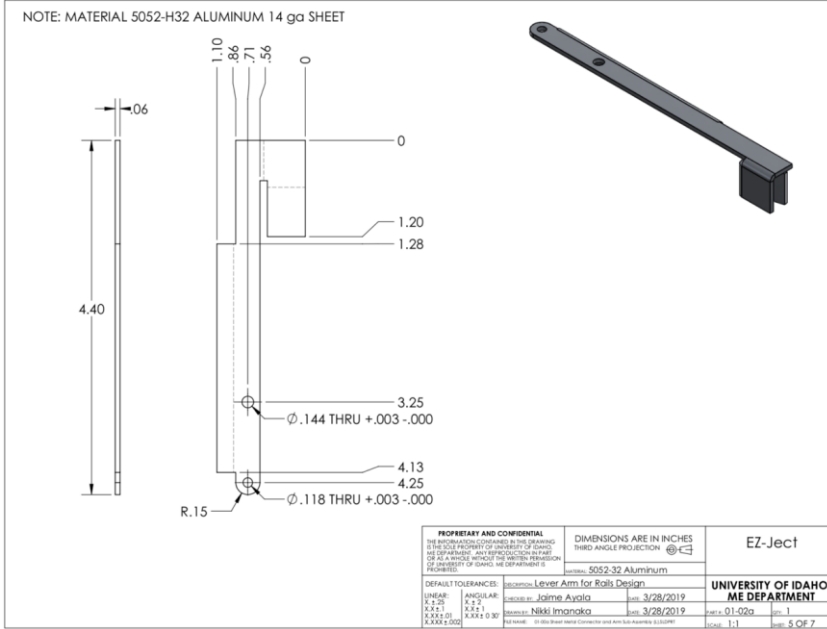
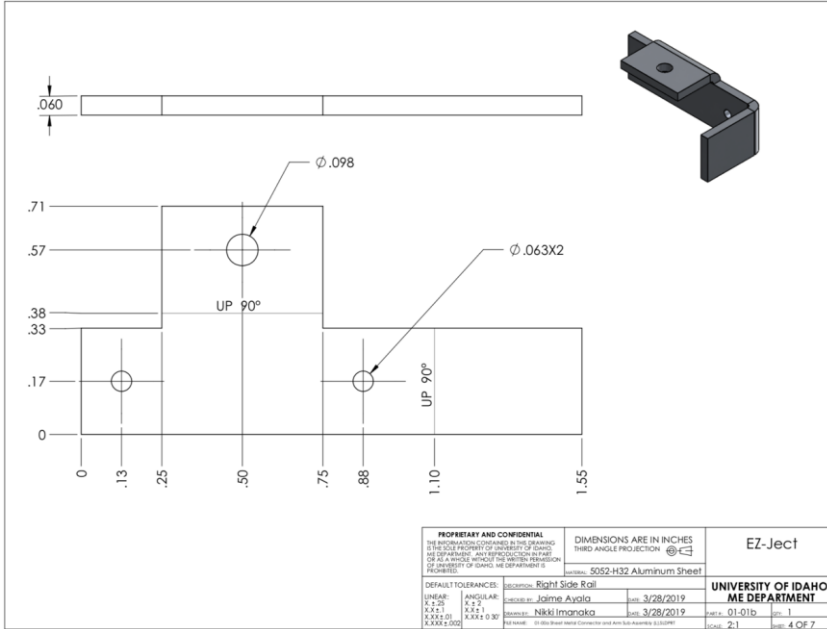


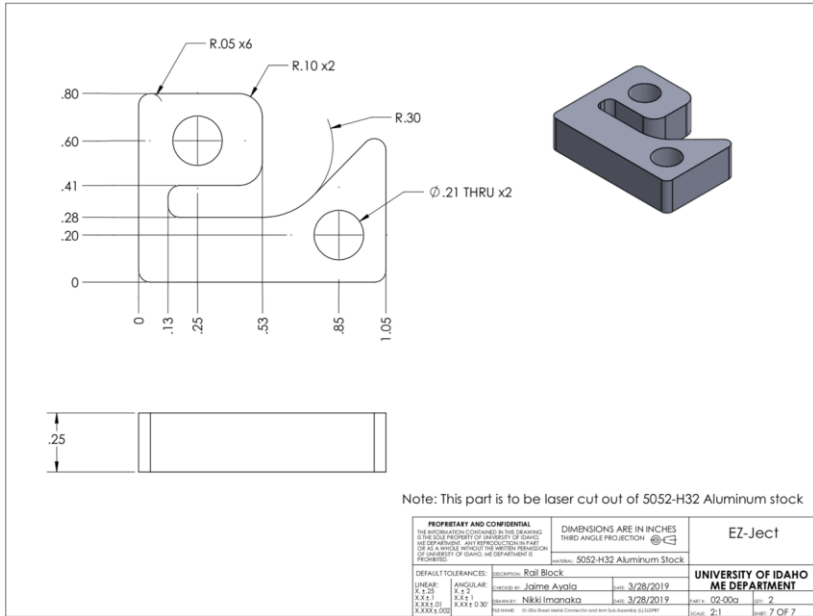
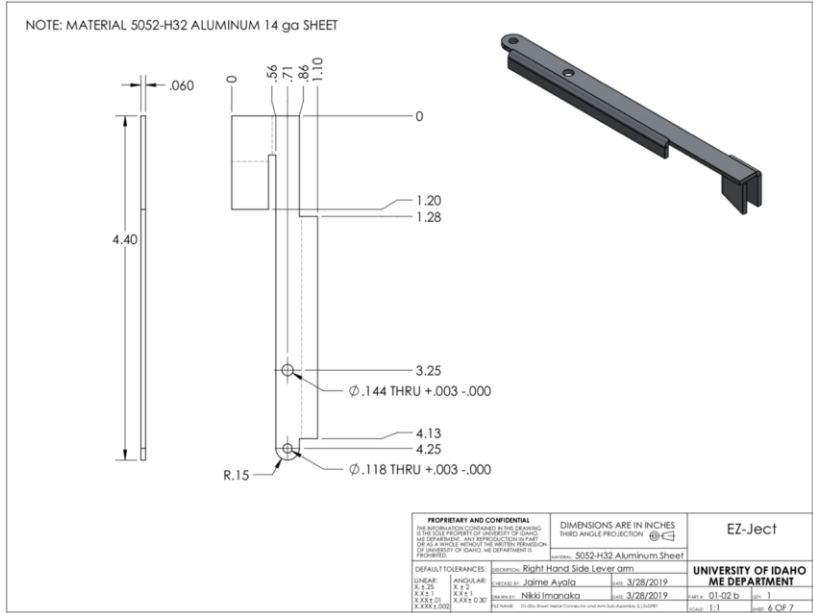
<b>PROPRIETARY AND CONFIDENTIAL</b> ALL INFORMATION CONTAINED HEREIN IS THE SOLE PROPERTY OF UNIVERSITY OF IDAHO. NO PART THEREOF MAY BE REPRODUCED OR TRANSMITTED IN ANY FORM OR BY ANY MEANS, WITHOUT THE WRITTEN PERMISSION OF UNIVERSITY OF IDAHO, ME DEPARTMENT OF MECHANICAL ENGINEERING.		DIMENSIONS ARE IN INCHES THIRD ANGLE PROJECTION @		EZ-Ject	
DEFAULT TOLERANCES:		MATERIAL: 5052-H32 Aluminum Sheet		UNIVERSITY OF IDAHO ME DEPARTMENT	
LINEAR: X.XX X.XX ± .01 X.XXX ± .002	ANGULAR: X ± .1 X.X ± .1 X.XX ± .05	DESIGNED BY: Jaime Ayala	DATE: 3/28/2019	DRAWN BY: Nikki Imanaka	DATE: 3/28/2019
		DESCRIPTION: Exploded view of left & right sub-assembly		PART NO: 00-00	
		REVISION: 01-00 (Start with Connector and Arm Sub-Assembly 11/2017)		SCALE: 1:1	
				PAGE: 2 OF 7	

NOTE: MATERIAL 5052-H32 ALUMINUM 14 ga SHEET



<b>PROPRIETARY AND CONFIDENTIAL</b> ALL INFORMATION CONTAINED HEREIN IS THE SOLE PROPERTY OF UNIVERSITY OF IDAHO. NO PART THEREOF MAY BE REPRODUCED OR TRANSMITTED IN ANY FORM OR BY ANY MEANS, WITHOUT THE WRITTEN PERMISSION OF UNIVERSITY OF IDAHO, ME DEPARTMENT OF MECHANICAL ENGINEERING.		DIMENSIONS ARE IN INCHES THIRD ANGLE PROJECTION @		EZ-Ject	
DEFAULT TOLERANCES:		MATERIAL: 5052-H32 Aluminum Sheet		UNIVERSITY OF IDAHO ME DEPARTMENT	
LINEAR: X.XX X.XX ± .01 X.XXX ± .002	ANGULAR: X ± .1 X.X ± .1 X.XX ± .05	DESIGNED BY: Jaime Ayala	DATE: 3/28/2019	DRAWN BY: Nikki Imanaka	DATE: 3/28/2019
		DESCRIPTION: Left Side Connector		PART NO: 01-01a	
		REVISION: 01-00		SCALE: 2:1	
				PAGE: 3 OF 7	

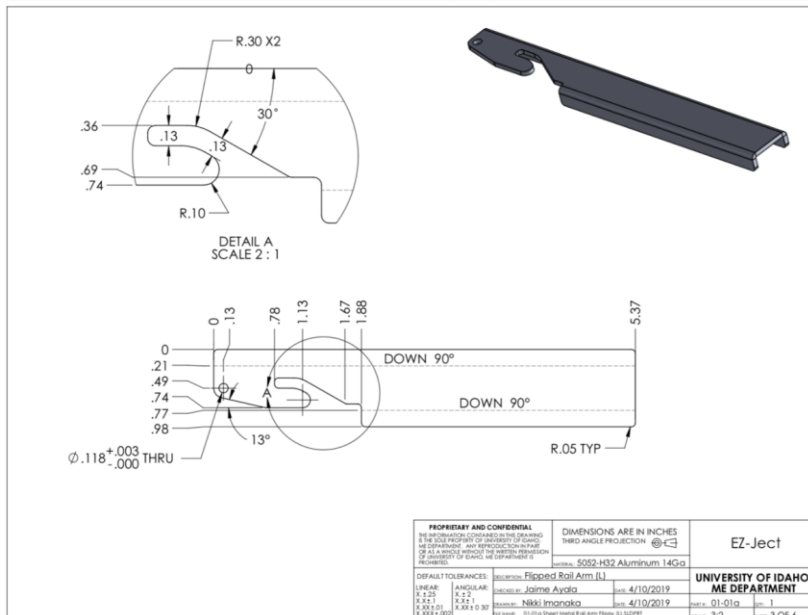
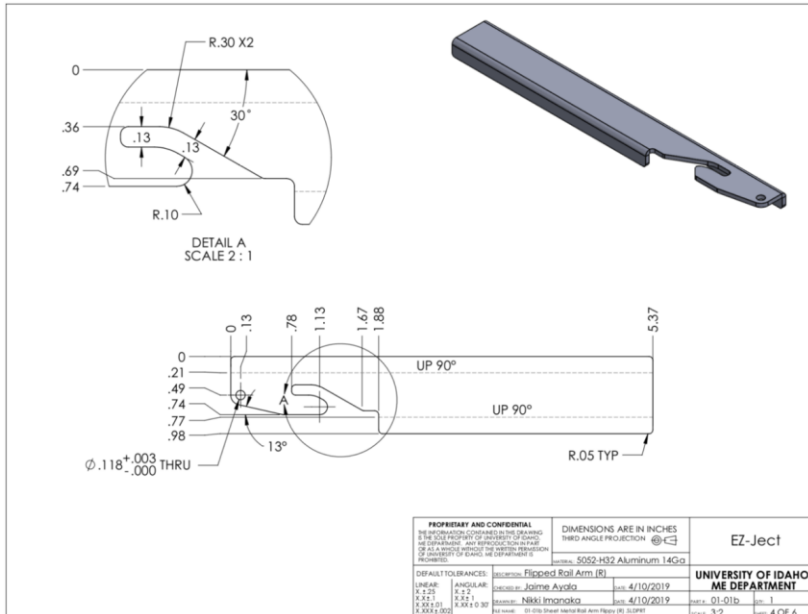




The rail block could be stamped out of 14-Ga Al instead to reduce the cost, but 8 total pieces of this part will be needed (4 on each side) to achieve the same thickness.

## Flipped Sheet Metal Arms

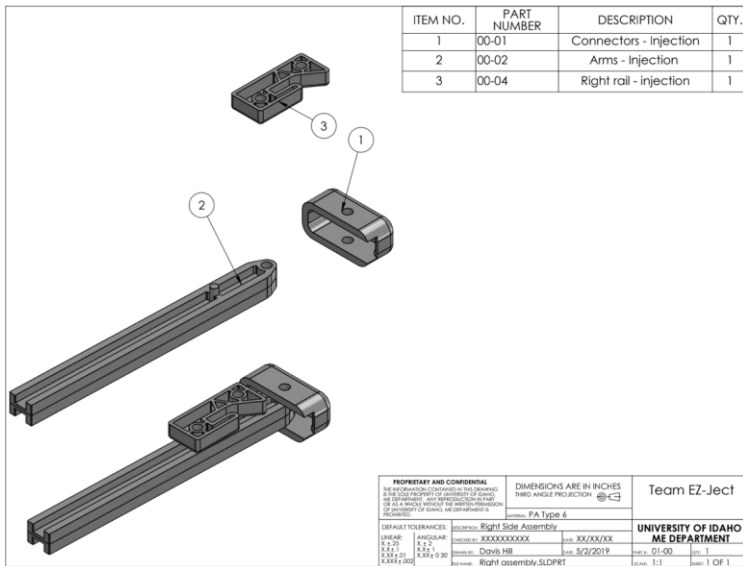
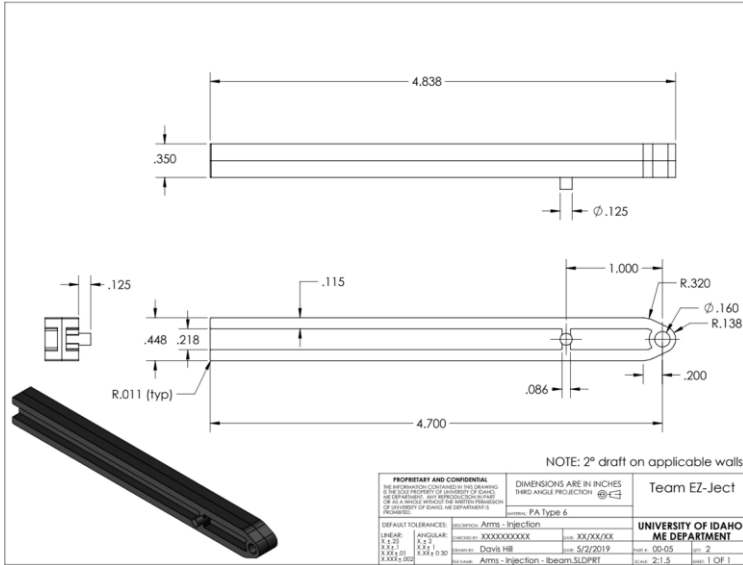
The flipped assembly uses the same drawing with a different arm design and no peg.





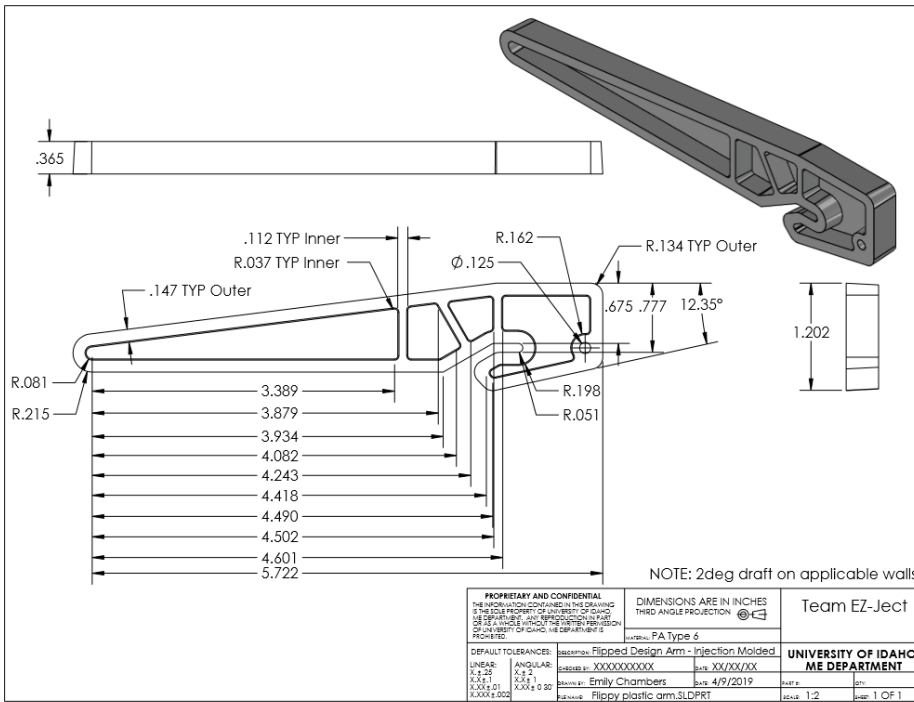






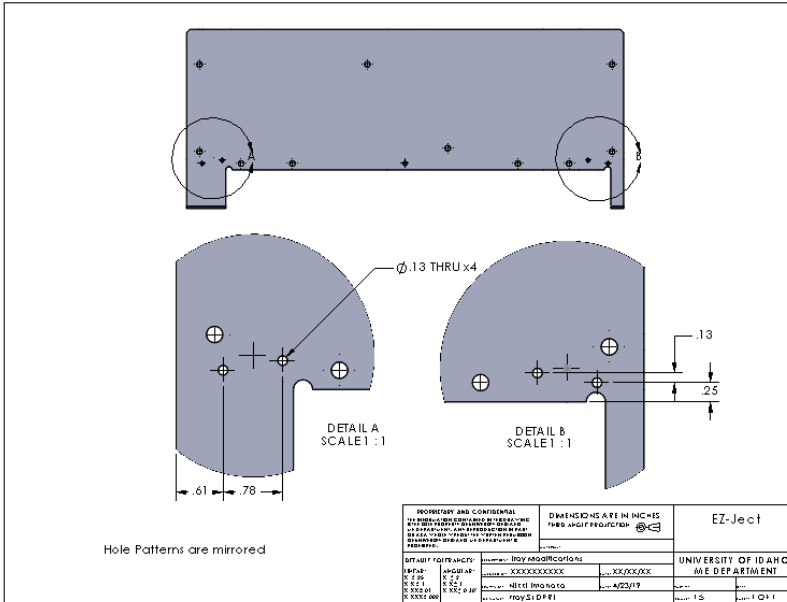
### Flipped Injection Molding Arms

The flipped injection molding assembly uses the same connectors as the original injection molding design.





Tray Modifications



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