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Injection Mold Alignment Jig

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Abstract

The objective of this project is to design and produce an alignment and installation jig for an injection molding machine's mold frame at SABIC's Mt. Vernon, Indiana plant. This jig will reduce the ergonomic risk experienced by the operator during the installation of the mold inserts and assist with alignment of the insert within the mold frame. To begin the design process, past projects that solved a task using a jig were researched for insights to incorporate and improve upon in this design. Using this research, three designs were conceptualized and are presented along with a pros and cons list of each. A final design was chosen from the proposed designs based off expected performance in meeting design requirements. The jig was modeled in SolidWorks and finite element analysis was conducted on the load bearing elements to determine the performance under expected loads. The design was physically constructed and tested on site. Finally, improvements to the design going forward are discussed.

Acknowledgements

I would like to recognize some individuals who assisted with this project. First, I would like to thank my project advisor Dr. Todd Nelson. His SolidWorks, engineering knowledge and guidance aided the project through each phase. I would also like to thank the employees at SABIC, Tony Philipps and Steve Sheffer. They assisted with design decisions, installation and honest feedback. Additionally, I would like to thank the University of Southern Indiana Engineering Department. Finally, Mariah Edwards and Calvin Edwards, my wife and son, thank you for supporting me through this journey.

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σ	Maximum Bending Stress	psi
M	Bending Moment	in·lb
c	Centroid of the Cross Section	in
I	Area Moment of Inertia	in^4
b	Base	in
L	Length	in
h	Height	in
F	Force	lb_f
R_x	Reaction Force in X Direction	lb_f
R_y	Reaction Force in Y Direction	lb_f
P	Force	lb_f
a	Distance from Point of Fixation	in
E	Young's Modulus	ksi
ν_{max}	Maximum Deflection	in

1.0 Introduction

Injection molding is a popular manufacturing process that takes thermoplastics in the form of pellets and turns them into molded parts. These parts can vary in size, requiring appropriately sized tooling and machines to produce an adequate part. While some manufacturers create the parts, some manufacturers evaluate the thermoplastics they are producing themselves by creating a limited number of test parts. These manufacturers test parts such as impact test specimen's for IZOD tests, tensile bars and four-inch disks. These parts are typically made on a mold insert that is placed in a larger mold frame. Figure 1, below, shows a mold frame (left) and an insert being installed into a mold frame (right). This mold frame allows for inserts to be interchanged at the user's discretion. Performing an insert change causes an ergonomic safety issue. Because of this, SABIC's technology department has asked for a way to alleviate this ergonomic risk.

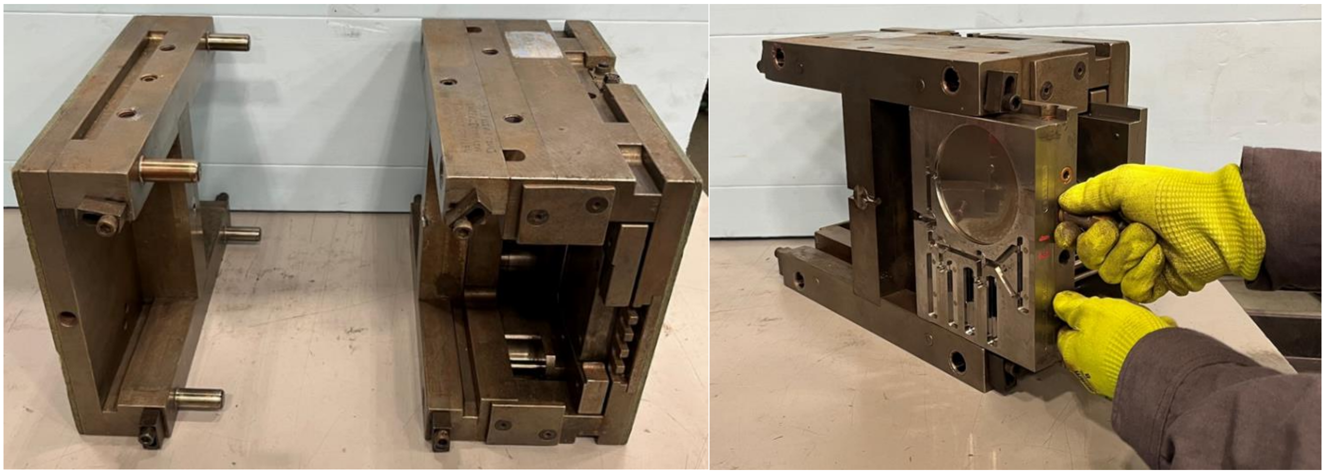

Figure 1. Mold frame (left) and insert being placed into mold frame (right).

SABIC is a chemical manufacturing company that also produces plastics. SABIC has 65 manufacturing and compounding plants, one of which is located in Mount Vernon, Indiana. The Mount Vernon location mainly produces plastics in bulk forms such as pellets, and any chemicals associated with plastic production. The technology department at this plant is dedicated to creating and validating new thermoplastics. Within the technology department is an injection molding lab that molds all the test parts needed for testing.

An injection molding machine diagram, Figure 2, is labeled below for reference later in the report. Terms such as "platen" and "tie bar" will be referenced at times. This is provided as a visual to have an understanding on what is being referenced. Dried plastic pellets are placed in a hopper, melted and pushed by the screw trough the barrel and the stationary platen into a mold. Once cooled, the moving platen slides along the tie bars to open the mold enough for the part to be ejected out.

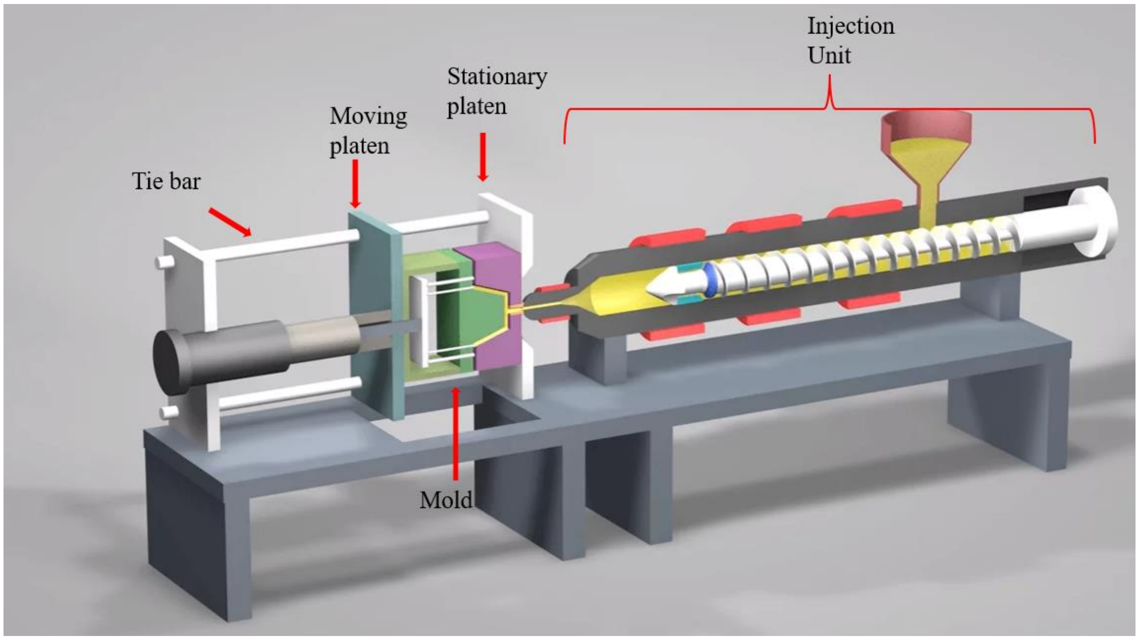

Figure 2. Injection mold machine diagram [2].

This report includes the objective and deliverables outlined in Section 1. Section 2 includes the background and motivation for this project along with similar projects researched. It also summarizes the findings from the projects researched. Section 3 discusses conceptual designs that were considered and the decision-making process for each. Section 4 will present engineering calculations, simulations, and any other engineering work to justify decisions made. Section 5 describes the final design produced and verifies feasibility. In section 6, the manufacturing process is covered along with installation and use. Testing and feedback are discussed in Section 7. The disposal plan and lessons learned are covered in Sections 8 and 9, respectively. Teamwork and future work are discussed in Sections 10 and 11. Finally, Section 12 will be the conclusion to summarize all that was found or decided.

1.1 Objective

The objective for this project is to:

Design and produce a jig to align and install a mold insert into a mold frame to alleviate any ergonomic risk during installation.

1.2 Deliverables

The deliverables determined for this project are the following:

- Design of jig
- Constructed, working jig

2.0 Background

2.1 Motivation

The process of performing an insert change on the machine in question at SABIC causes an ergonomic safety issue. Inserts for this machine can be changed from 1-5 times a day. This process takes 8.5 minutes on average to complete per insert change. The process of changing an insert requires an operator to lift the insert, which weighs approximately 40 lbs., avoid stepping on piping and reach into the machine 26 inches, placing the body in a strenuous position (Figure 3), and putting it into the mold frame that only has a tolerance of 0.003-inches between the mold frame and insert. Figure 3 also shows the piping to be avoided and the location of the mold frame to place the insert. This hazard only exists on one side of the molding machine. A jig will only be made for one side of the mold frame to avoid this hazard as it only exists on one the molding machine. "Ergonomic injuries account for 33% of all worker injury and illness cases" [2]. Creating a jig that changes where the operator must place his or her body can remove the potential for a body strain injury occurring. This pertains to OSHA Standard Section 5(a)(1), Appendix D. This states that if a hazard is known by the employer, it should be removed. Creating a jig saves the company an OSHA recordable incident and saves the operator from loss time at work and medical bills associated with an injury.

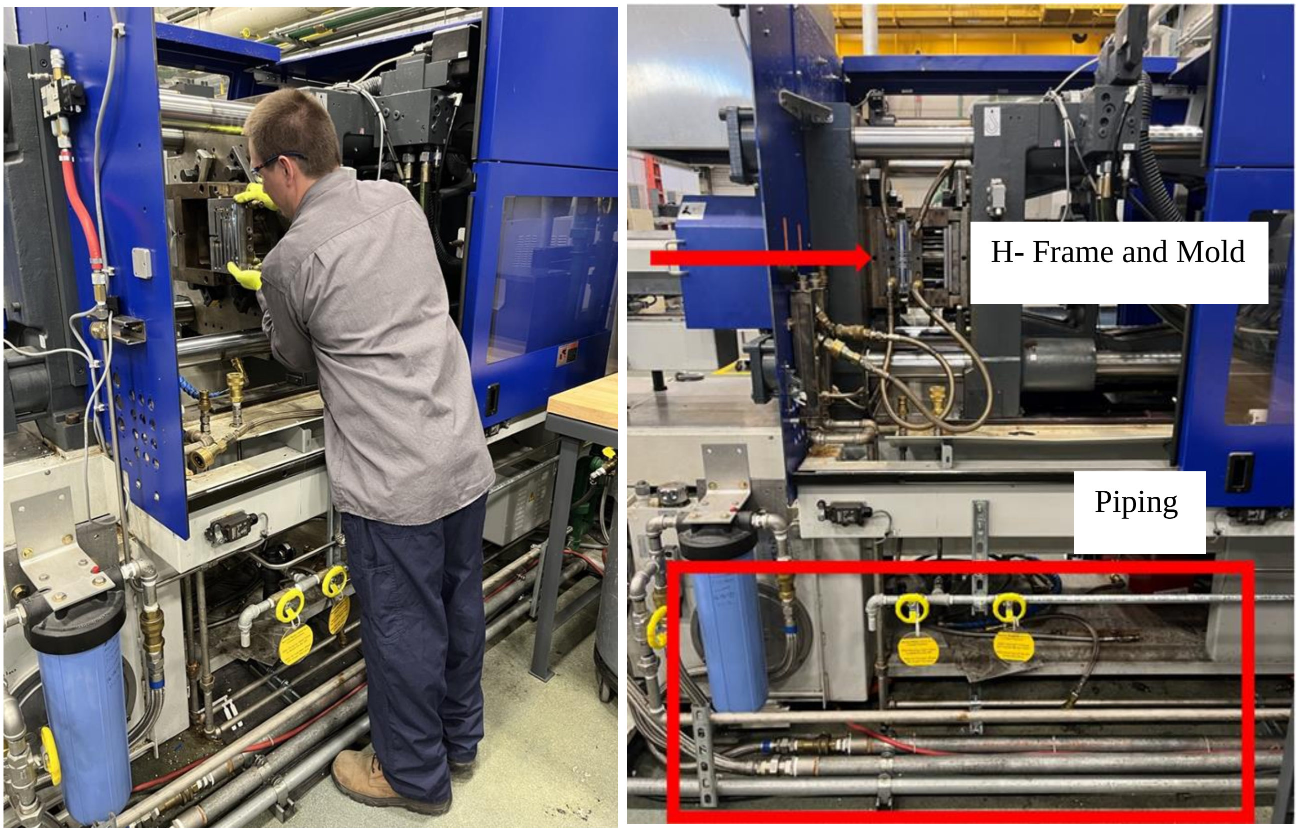

Figure 3. Operator body position (left) Piping operator needs to avoid at bottom and location of mold frame at top (right).

2.2 Requirements

Based on the constraints conveyed by the technicians at SABIC, the following requirements for the Injection Mold Alignment Jig was determined.

The jig system shall:

1. Not change the orientation of mold or location of mold placement.
2. Hold a minimum weight of 40 pounds.
3. Align with the mold frame.
    3.1. Must meet a tolerance of 0.003 inch on the top and bottom of mold insert within mold frame.
4. Not interfere with molding machine operation.
5. Take 5 minutes or less to change inserts.

6. Protrude no more than 24 inches from the mold.
    6.1. Must not interfere with safety interlocks of the access door to mold area.

2.3 Similar Projects

2.3.1 California Polytechnic State University

California Polytechnic State University architectural engineering students designed and created a jig for dowel laminated timber (DLT) [3]. This allowed the students to construct their own DLT. The students constructed a jig from a 2" x 4" piece of lumber to serve as a construction jig. This would allow them to drill holes in other pieces of lumber in the exact same spot each time. Figure 4, below, shows their construction jig. During their testing phase, their construction of DLT encountered challenges in multiple areas due to holes being drilled too closely together and timber impurities. The importance of hole placement and tolerances was gained by reviewing this team's experience.

Figure 4. Construction Jig [3]

2.3.2 University of Cincinnati

Mechanical engineering students from the University of Cincinnati set out to create a jig/alignment table to combine two tools into one [4]. The design would set out to reduce costs and save time for faster assembly of a bicycle. The final design for the stand is shown below in Figure 5. One challenge the team encountered was that alignment table and jig had multiple possible points of failure due to stress. There were buckling issues of the stand and high stress in the setting pin. This team's experience helped show the importance of sizing components to be appropriate for expected loads.

Figure 5. Bicycle jig/alignment table [4].

2.3.3 Florida International University

Florida International University mechanical engineering students entered the Formula SAE design competition. This group's focus was on the chassis and suspension. A jig was designed to help build the chassis for the vehicle. Figure 6, below, shows a vehicle chassis placed into the jig, denoted by blue. The jig featured leveling feet that would allow the fabricators to adjust if needed. The tubing would be placed into the jig and welded into place once they achieved the accuracy required for the frame. Once the chassis was built the jig would be destroyed the get the chassis out. Because destroying the jig is not an option with the jig for the mold frame, this approach was avoided.

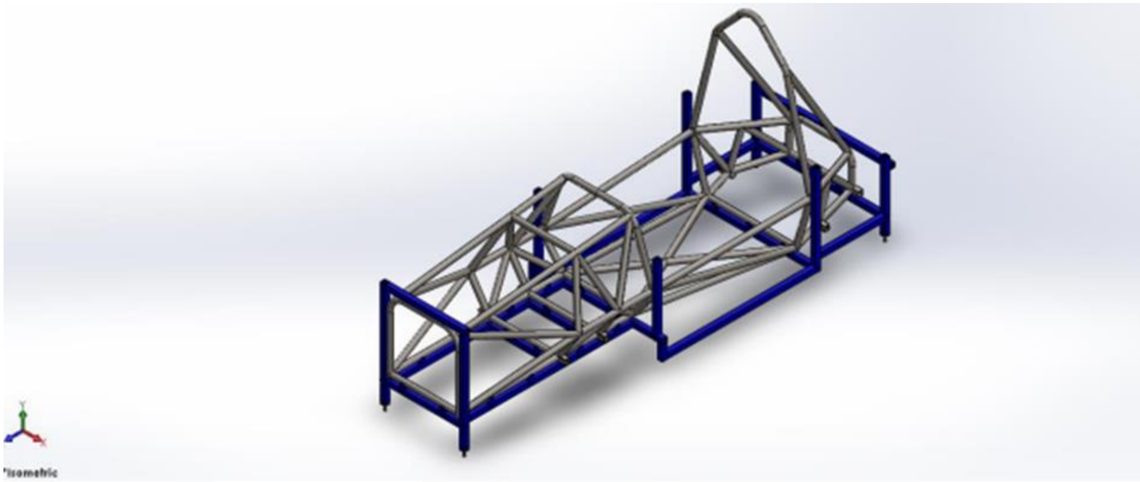

Figure 6. Jig in blue [5].

3.0 Conceptual Design

After reviewing the above jig designs, several concepts were generated for the jig design to place the mold onto the mold frame.

3.1 Design 1

Design 1, shown in Figure 7 below, was one of the simplest designs considered. It was meant to bolt to the existing bolt holes on the sides of the mold frame and use alignment pins to locate the correct mounting location. This design featured alignment bolts that could be adjusted at the operator's discretion.

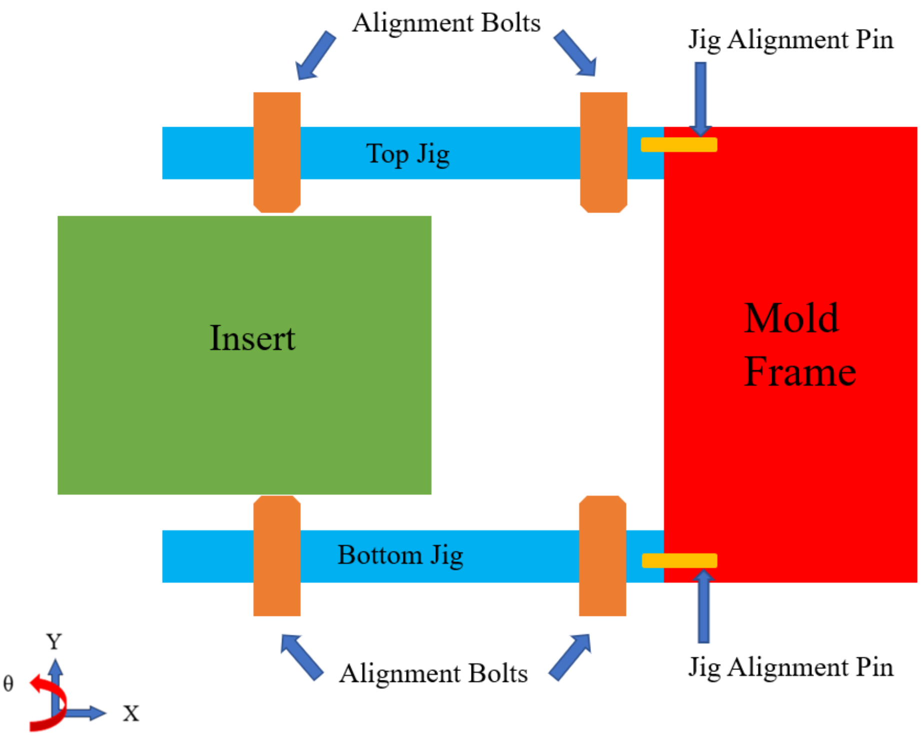

Figure 7. Design 1 featuring alignment bolts.

Table 1. Pro and con of Design 1.

Pro	Con
Alignment bolts can be adjusted as needed.	More force required to install insert into mold frame compared to other designs.
Easily fabricated and repeatable if necessary.	Possible to jar the insert and damage it.
Simple design.	

3.2 Design 2

Design 2, Figure 8, below illustrates a change of mechanism differing from Design 1. Where Design 1 uses alignment bolts, Design 2 uses ball transfer bearings. This design was considered because the jig should be in alignment with the mold frame using the existing mounting location and the alignment pins. The bearings will provide a smooth transfer for the insert to get from one side of the jig to the mold frame.

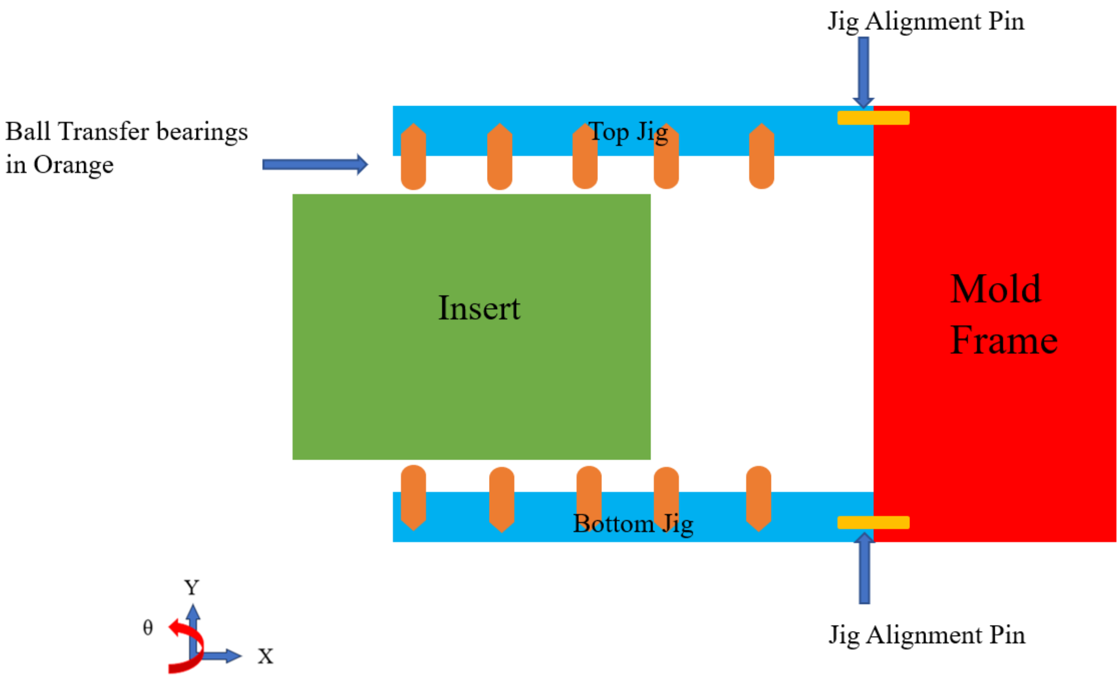

Figure 8.Design 2 featuring transfer bearings.

Table 2. Pro and con list of Design 2.

Pro	Con
Transfer bearings for less force needed to install insert into mold frame.	Alignment cannot be adjusted.
Multiple transfer bearings to avoid jarring.	

3.3 Design 3

Figure 9, below, shows the third design considered. This design was based off the thought of conserving material and space within the molding area. One jig would be able to install an insert on both halves of the mold frame by moving across an existing structure, the tie bar, on the mold machine.

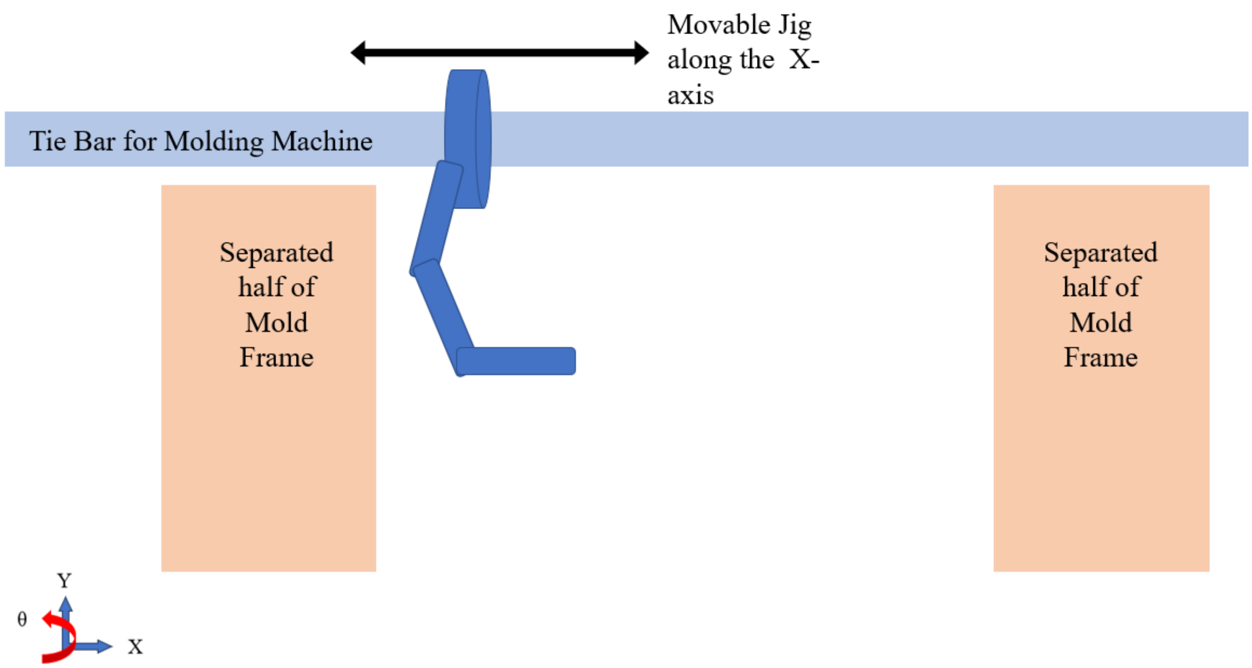

Figure 9. Design 3 features a single jig to install inserts of both mold halves.

Table 3.Pro and con list of Design 3.

Pro	Con
Only one jig to be built.	Moving parts could cause damage to machine, inserts or mold frame. The hanging jig must move out of the way as the mold closes. The mold surfaces are very precise and cannot have objects striking them.
Conserved space within utility area.	Complex design.
	More to account for during installation for operator.

4.0 Preliminary Engineering Design

Design 2 was chosen to continue the preliminary design process. The ability to align the insert with the mold frame with a small amount of physical force was desirable over the conservation of space within the molding area. Design 2 will protrude out towards the operator illustrated in Figure 10, below. Figure 10 also shows the mounting locations circled in red that the preliminary design calculations will be based off. Figure 11, below, is the final preliminary design for the jig. It was chosen to be constructed of 6061-T6 Aluminum because this aluminum is readily available at the plant at SABIC and is easy to machine. This design features 5/8-inch ball transfer bearings. The aluminum stock's initial dimensions will be 2 inches by 6 inches wide and 2 inches tall. The stock will be milled down to dimensions that will work for the mold frames. This process will be sent to an outside machine shop. It will be notched so the insert has a place to seat securely. Table 7, Appendix E, displays the estimate for the mass for the entire jig as 120.60 lbs. being added to the molding machine. The materials required for this system will cost a total of $1,387.68, as shown in Appendix B.

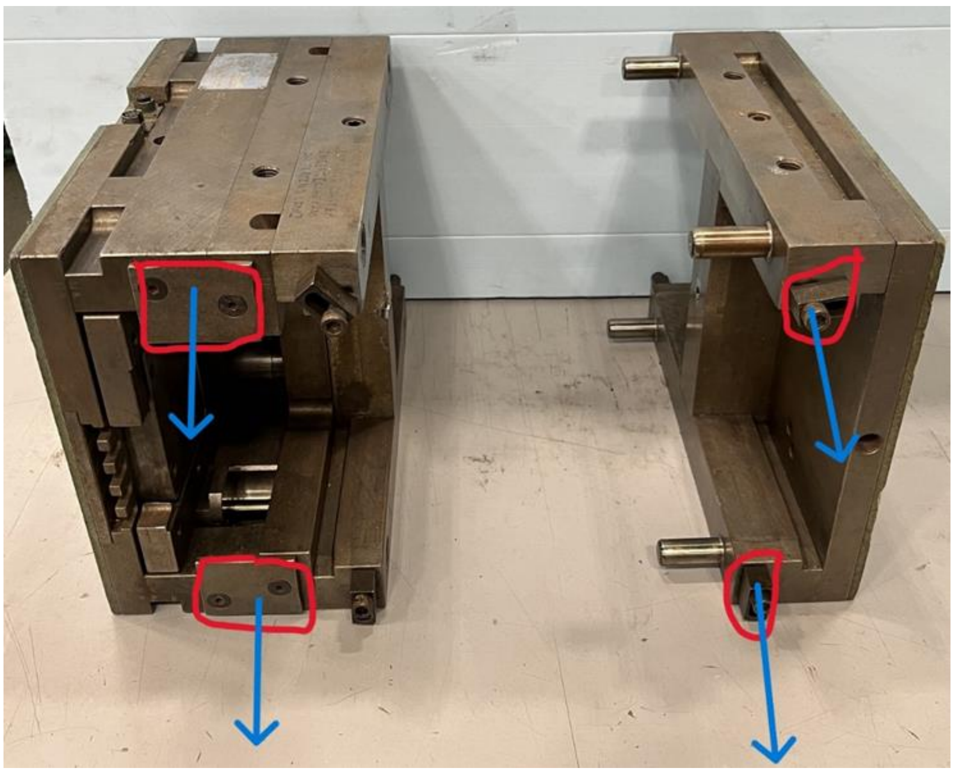

Figure 10. Mold frame with direction of jig placement (blue) and mounting location (red).

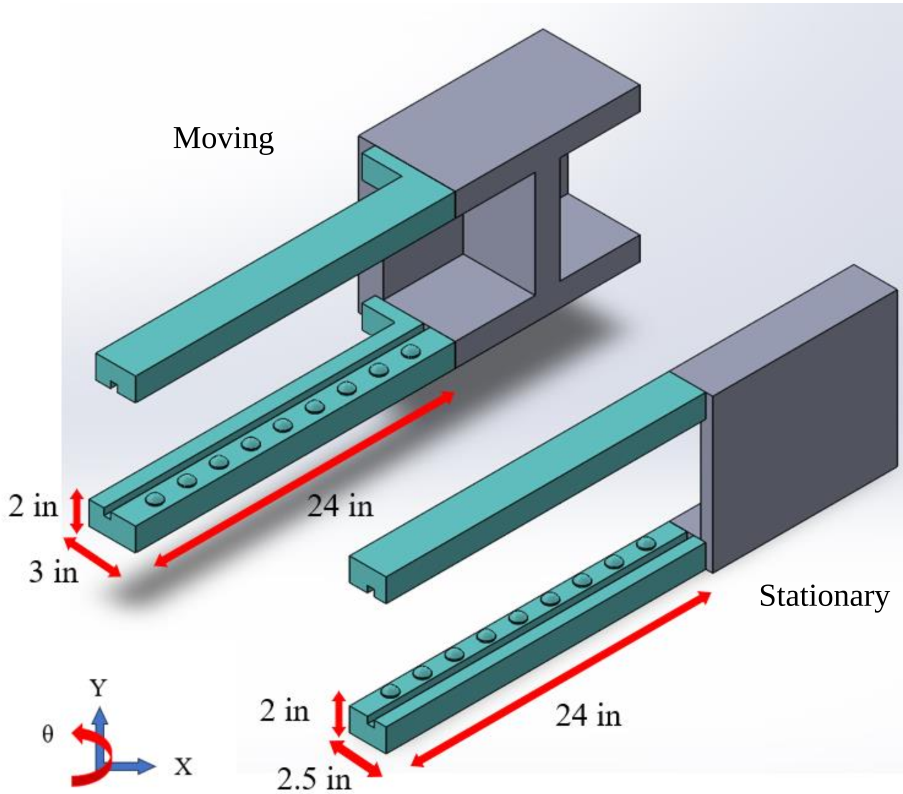

Figure 11. Final Preliminary Design with dimensions.

To determine if the dimensions chosen for the jig would result in appropriate stress levels and deflections, calculations for the final preliminary design were performed. The jig arms are cantilever beams with a point load applied at the furthest length from the fixed point. Below, Figure 12, is a free body diagram associated with this setup. It has reaction forces in the x and y directions, along with an applied moment. This diagram assists with calculating the maximum moment, and consequently the maximum bending stress and where it occurs. It will also help with calculating the maximum deflection. The inserts weigh from 20 lb_f to 40 lb_f. This range is due to the different dimensions of the insert between the moving and stationary halves. I used 40 lb_f to verify a worst-case scenario. The moving side jigs have dimensions of 24 inches length, 2 inches tall by 3 inches wide. While the stationary jigs are 24 inches length, 2 inches tall by 2.5 inches wide, as displayed in Figure 11, above. The half inch reduction in width is due to the thickness of the stationary half of the mold frame.

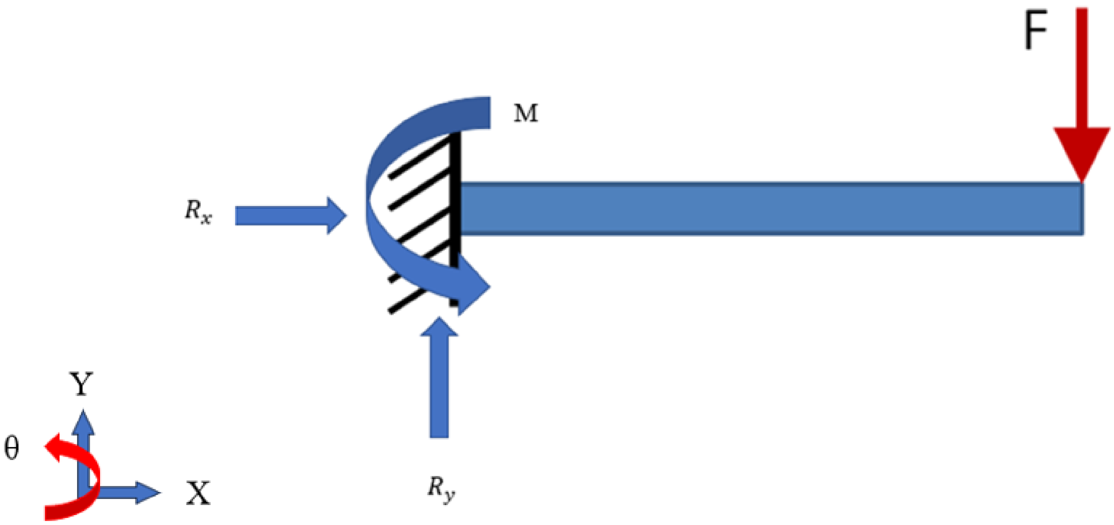

Figure 12. Free Body Diagram with reaction forces and bending moment.

Equation 1 will be used to calculate the maximum bending stress. Since the bottom jigs will be taking the force from the weight of the insert, these will be analyzed for calculations. Before the maximum bending stress can be calculated, M, c, and I need to be calculated. These are the bending moment, centroid of the cross section and the area moment of inertia, respectively. Using Figure 11, a summation of the moments about the fixed point gives Equation 2, below. The moment can be calculated with a result of 960 in·lb in the counterclockwise direction. Figure 13, below, shows the location where the moment is at its highest point. The value for c goes off the centroid of the cross section, primarily the height, since the cross section is 2 inches by 3 inches (moving side) and 2 inches by 2.5 inches (stationary). The value for c is 1 inch for both cases. The value for I is calculated from Equation 3, resulting in a value of 2.00 in^4 for the moving side jig and 1.67 in^4 for the stationary jig. Once all the values for M, c and I are found they can be put into Equation 1. The stationary jig resulted in a maximum bending stress of 574.85 psi and the moving jig gave 480 psi.

$$\sigma_{max} = \frac{Mc}{I} \quad (1)$$

$$\sum M = M - F(L) \quad (2)$$

$$I = \frac{1}{12}\, b\, h^3 \quad (3)$$

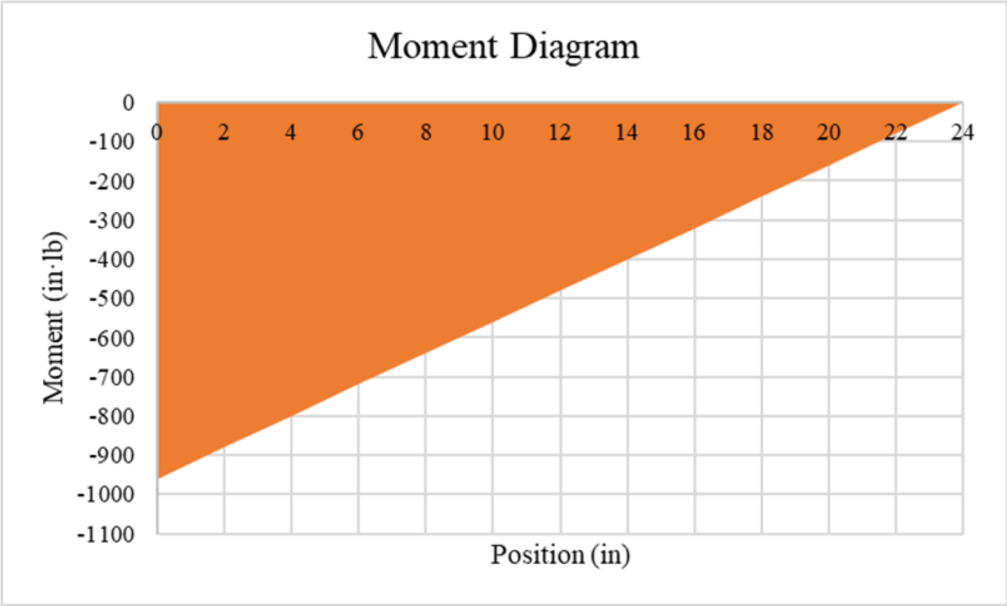

Figure 13. Moment Diagram

SolidWorks simulations were performed to verify hand calculations for maximum bending stress. Below in Figure 14, shows the simulation that was run for the stationary jig and Figure 15 shows the simulation for the moving jig. The stationary jig resulted in a value of 928 psi and the moving jig resulted in a value of 745 psi. There was about a 38% difference between the calculated and simulated values. This warrants some adjustments need to be made in the SolidWorks simulations.

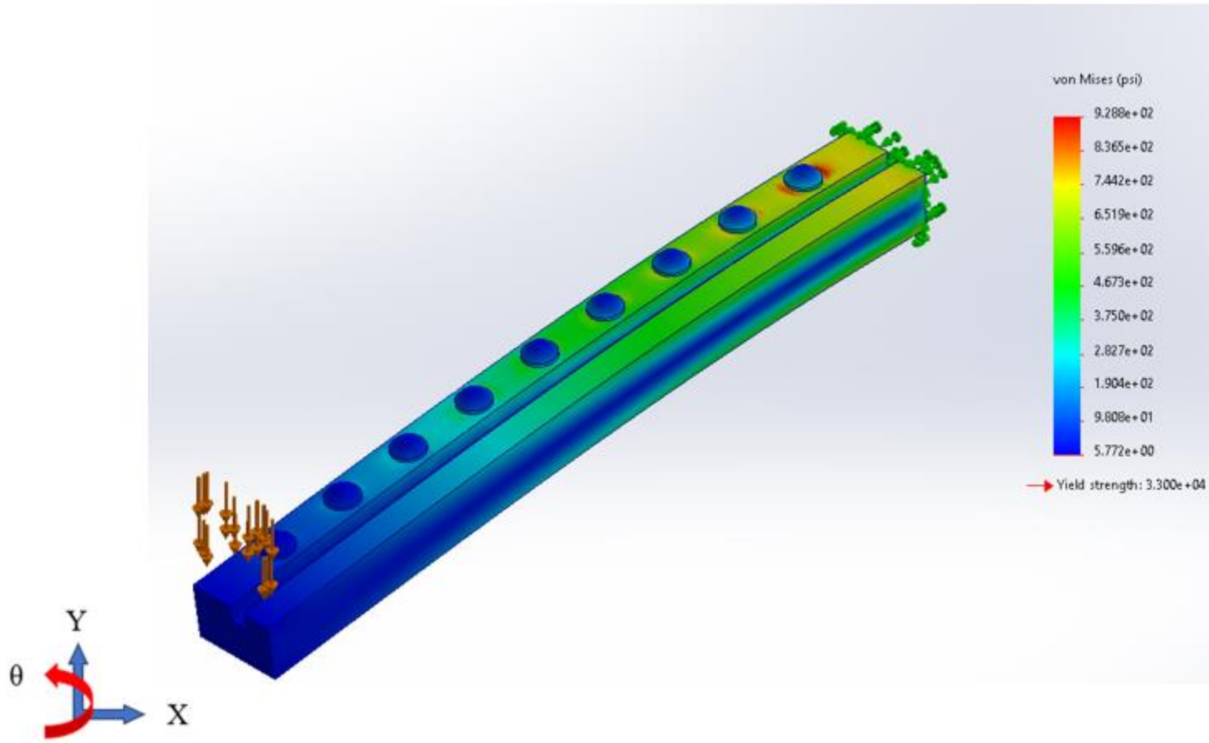

Figure 14. Stationary Stress Simulation.

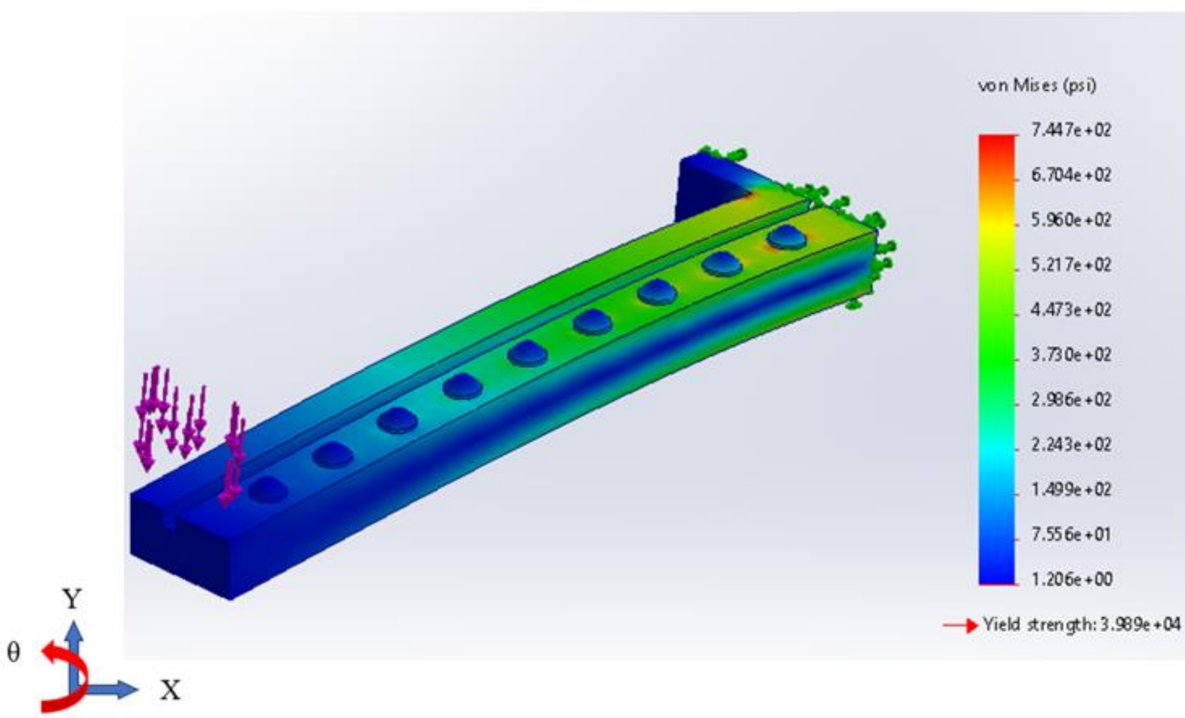

Figure 15. Moving stress simulation.

SolidWorks simulations were run to determine the deflection of the bottom jigs. They are shown in Figure 16 and 17. The stationary jig deflected 0.012 inches while the moving jig deflected 0.008-inches. These values were confirmed by hand calculations using Equation 4, below. The variables are P, a, E, I and L. The only values needed are E, which is Young's modulus for 6061-T6 Aluminum. This value is 10,000 ksi. The result for the stationary hand calculations is 0.0018-inches and the moving is 0.011-inches. These values are within reason of the 0.003-inches requirement because the deflection closer to where the insert meets the mold frame it deflects $3.937\ x\ 10^{-32}$ inches.

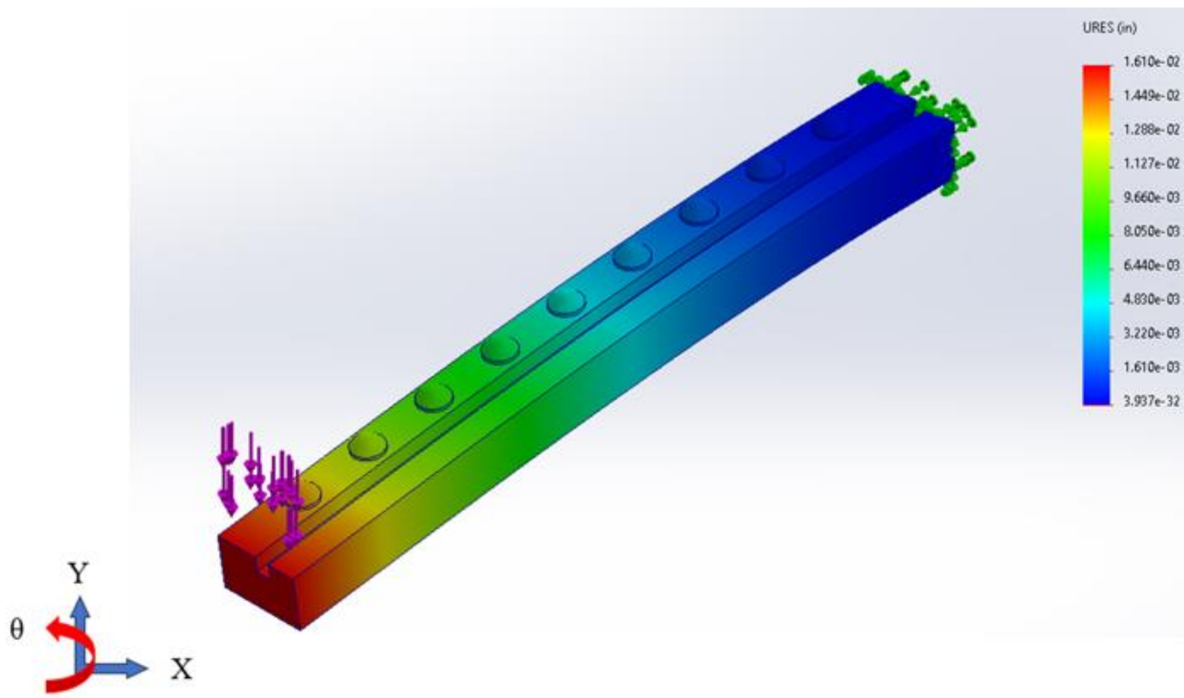

Figure 16. Stationary jig deflection simulation.

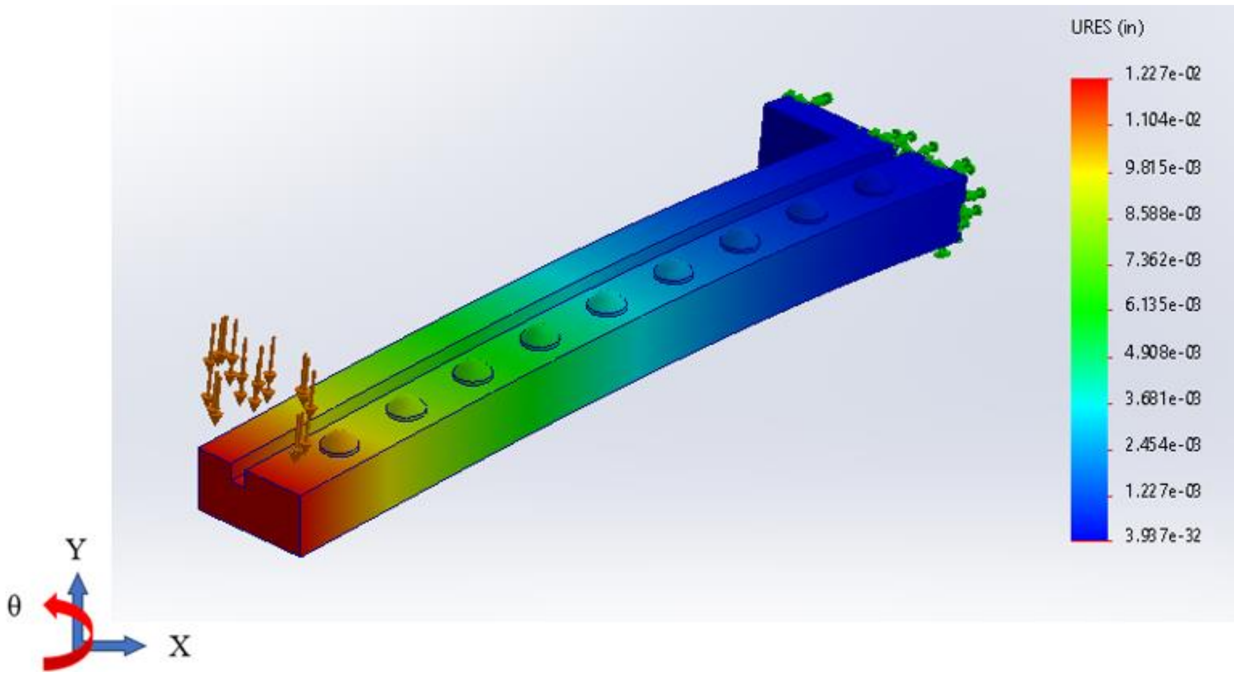

Figure 17. Moving jig deflection simulation.

$$v_{max} = \frac{Pa^2}{6EI}(3L - a) \quad (4)$$

These calculations and simulations help prove that this design will be able to withstand the force of the mold insert. The design currently fits all requirements in Appendix D. All requirements were verified by either material choice or by calculations and simulations. Requirement #4 required that the process take 5 minutes or less. This was verified by a mock insert change. It was recorded to take 4.5 minutes on average. This reduces the time by almost 4 minutes per insert change.

5.0 Final design and Validation

The final preliminary design was taken to the final design stage. Some iterations to the dimensions and mounting locations were made to produce this model, Figure 18 (below).

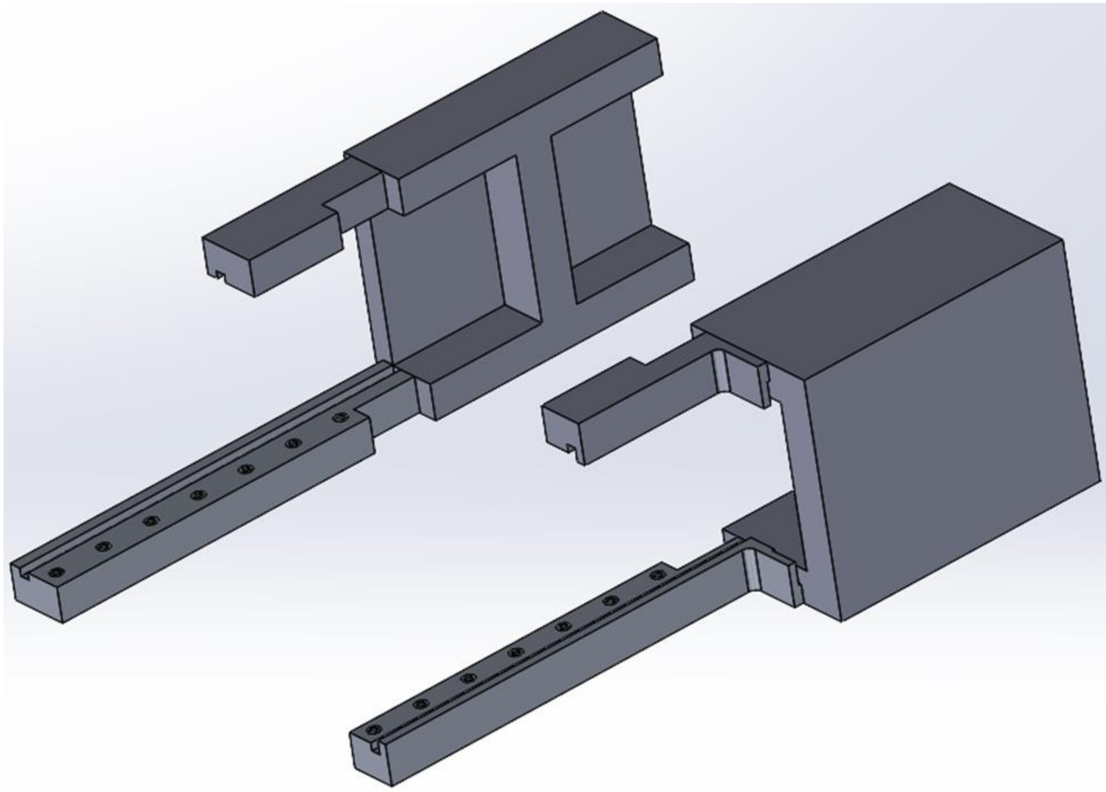

Figure 18. Final design.

A notched-out section was added to allow for tooling access to secure insert into mold frame. The overall length was changed to 20 inches on the bottom and 8 inches on the top. The top jig lengths were changed to this because of feedback after installation. The top jigs were creating an issue with line of sight and possible collision points causing a head injury. Fillets were added to help with abrupt geometry changes, reduce stress concentrations, and to make it easier to machine. The bearing sizes were changed from a 5/8-inch bearing to a 5/16-inch stud-mount bearing to accommodate the allowable space on the jig. This diameter size change was not a concern as the 5/16-inch stud-mount bearings are able to hold a maximum of 55 lbs. load each. Since the mold inserts maximum weight is 40 lbs. the bearings will not break due to the applied load. The height at the location of bearings was changed to make them coincide with the inside of the mold face. The mounting location of the stationary side changed to mount onto the stationary platen of the molding machine via pre-existing holes by using two L brackets. Both the mounting locations for the stationary side are shown below in Figure 19. These locations are 3 inches and 6 inches away from the mold frame face. Figure 20, below, are the mounting locations for the moving side. These mounting locations utilize pre-existing holes on the mold frame. The final design installed in the injection molding machine can be seen below in Figure 21.

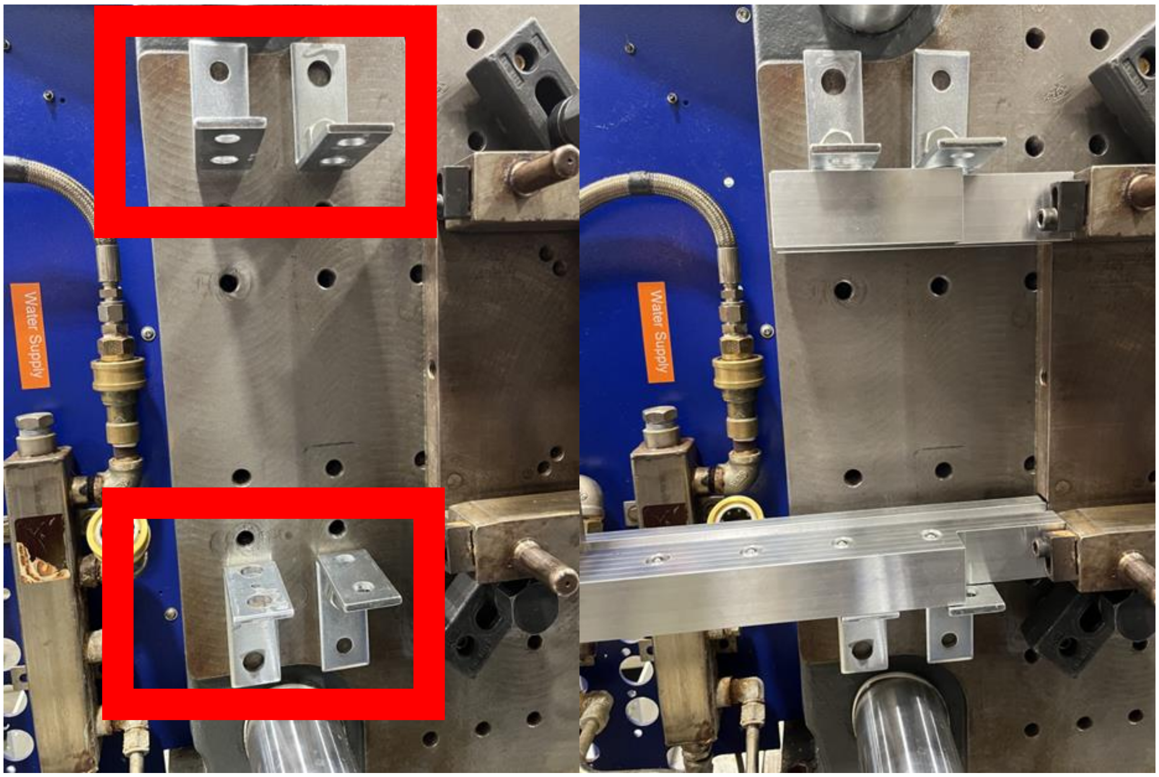

Figure 19. Stationary mounting location.

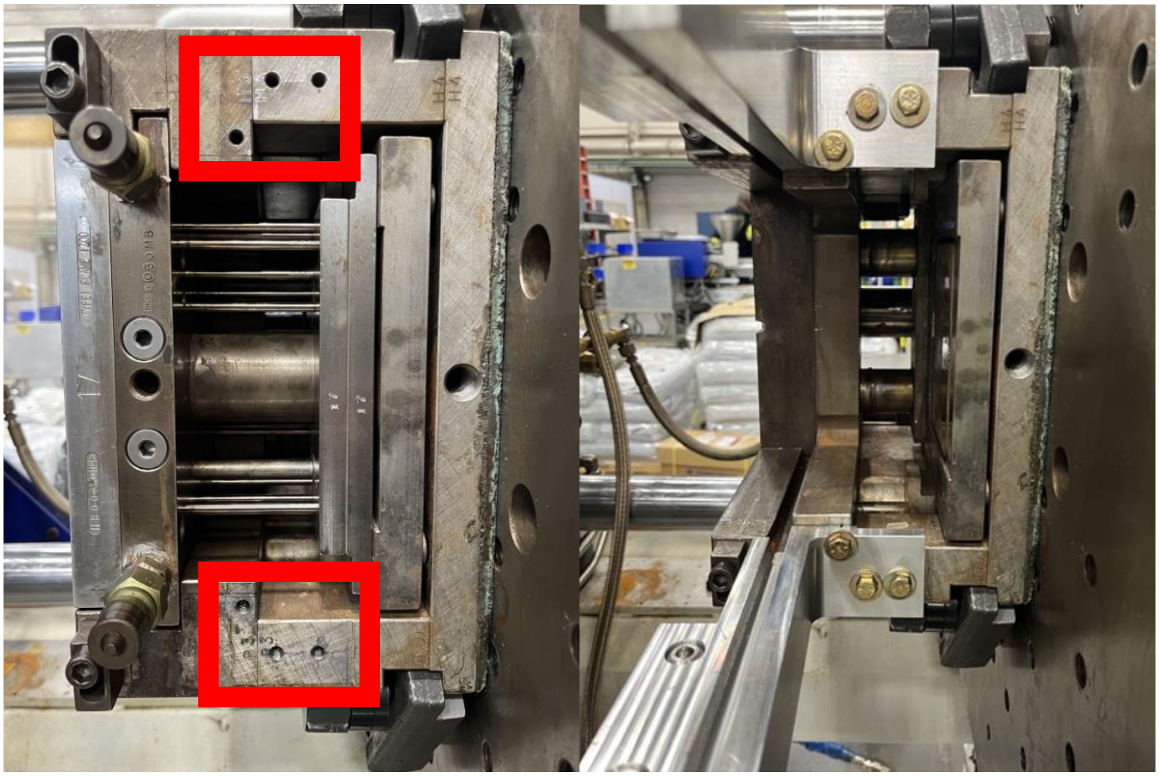

Figure 20. Moving side mounting location.

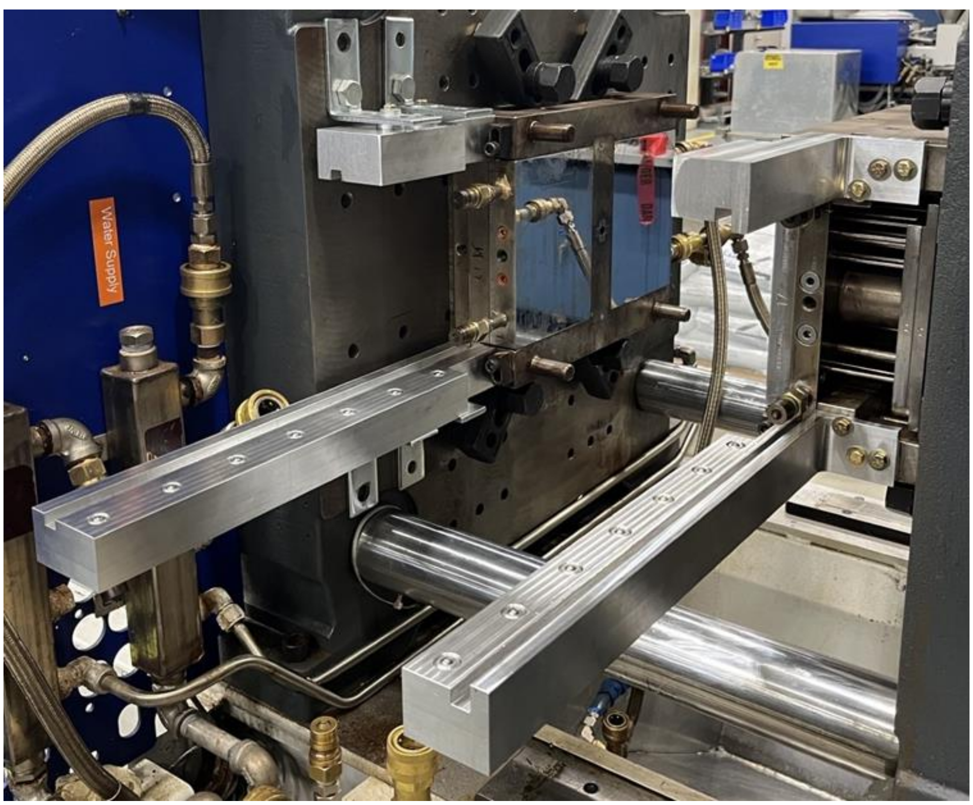

Figure 21. Final Design Installed

5.1 Analysis

The bottom, load bearing jigs were further analyzed to show the feasibility of the final design with the changes discussed from the previous section. These changes could not be satisfactorily captured in hand calculations, so finite element analysis was the primary tool for the analysis.

5.1.1 Stationary Side

Since the mounting locations change on the stationary side this resulted in a change to the displacement and maximum stress. A 40 lb_f load was added to the furthest point to see the worst-case scenario and to the bearing closest to the mold frame. This also is the area where the displacement is the most critical. The SolidWorks simulation for the maximum stress is shown below in Figure 22. This resulted in a maximum stress of 309 psi, which is within the yield strength of the 6061-T6 aluminum of 40,000 psi. This also resulted in a displacement of 0.003-inches at the furthest part from the mold frame, Figure 23. When the load was applied to the bearing closest to the mold frame the displacement is $6.375x10^{-6}$, Figure 24. This ensures that the jig will not bend close to the mold frame and will allow for the insert to be properly installed meeting the 0.003-inches clearance requirement.

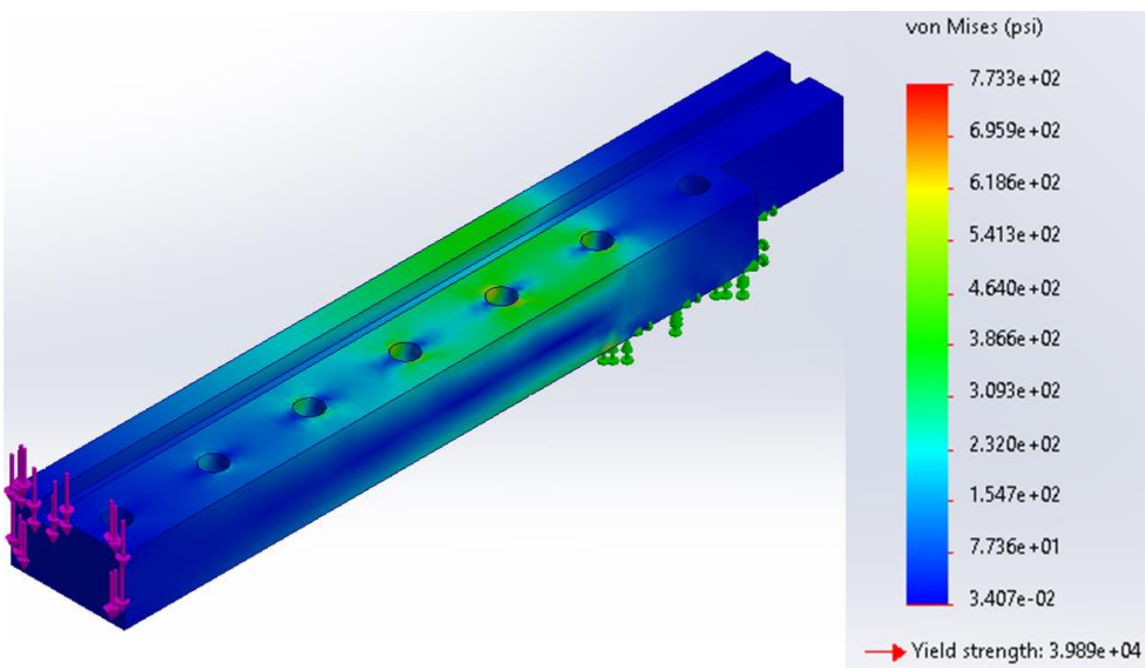

Figure 22. Final design stationary maximum stress.

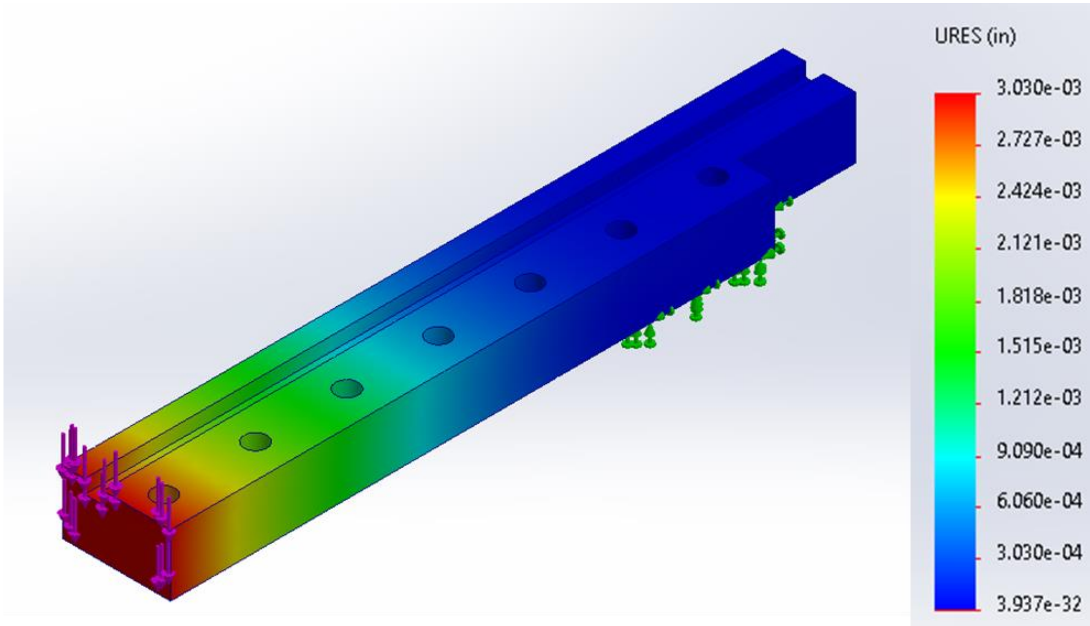

Figure 23. Stationary bottom jig displacement with load at operator end.

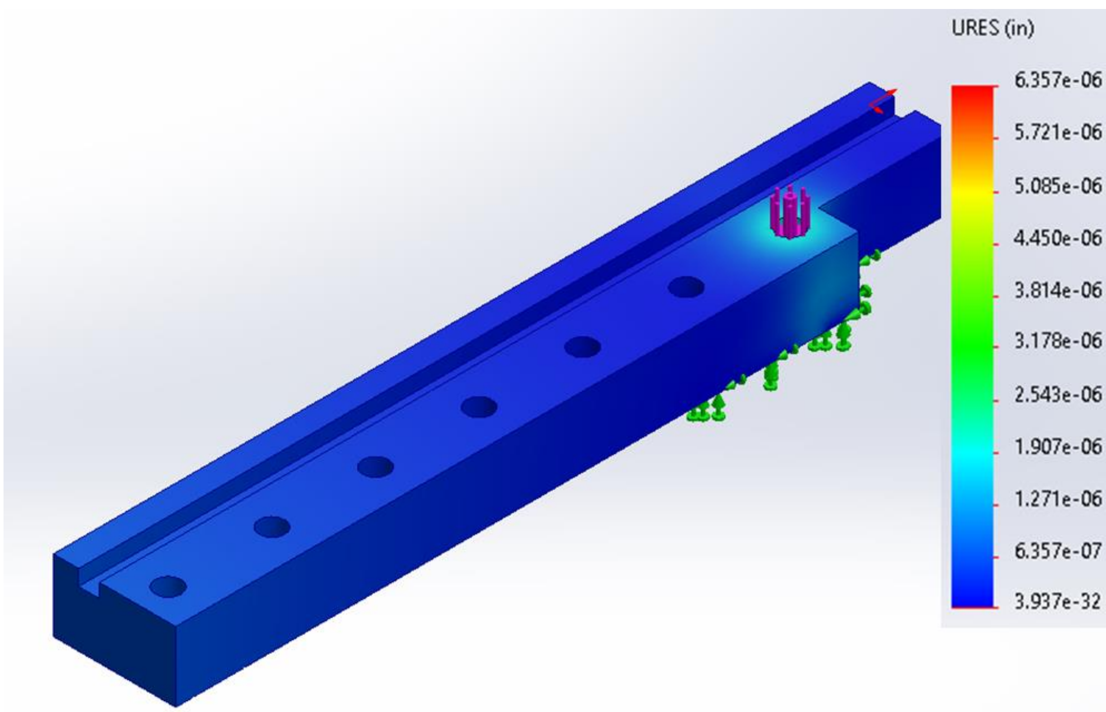

Figure 24. Stationary bottom jig displacement with load at the bearing closest to mold frame.

The displacement equations for the stationary jig have changed due to the change in fixturing method of the jig with the L brackets. The resulting problem is a simply supported beam with an over-hanging load. The resulting free body diagram is shown in Figure 25. For this structure Equation 5 is used. Where F is the applied load, a is the length to R_{y1}, l is the total length of the beam. This calculation turned out to be -0.00137-inches. Where the negative indicates in the downward direction. The maximum stress calculated from Equation 1 resulted in a value of 123.5 psi. Both of these results are within the 0.003-inches clearance and the yield strengths of the aluminum.

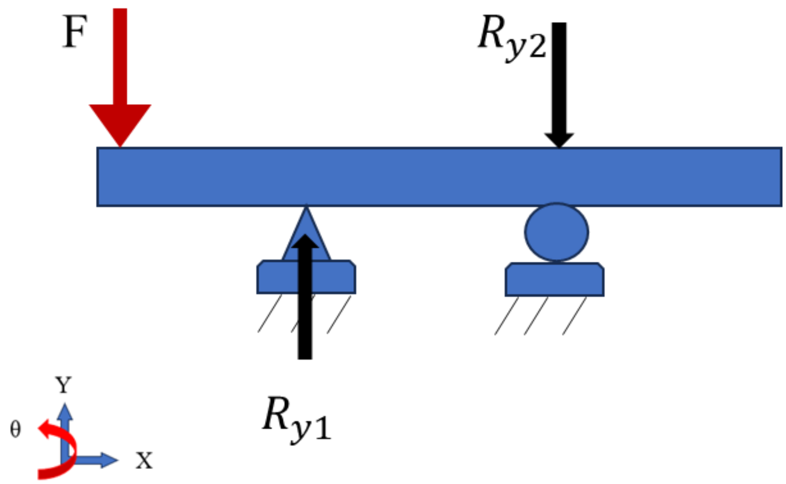

Figure 25. Simply supported beam with over-hanging load FBD.

$$v_{max} = -\frac{F\ la^2}{3EI} \tag{5}$$

5.1.2 Moving side

Simulations were run on the moving side as well. The maximum stress resulted in a value of 524 psi, Figure 26. The maximum stress is still well within the yield strength of the aluminum. The displacement resulted in a value of 0.013-inch at the furthest end from the mold frame, Figure 27. This displacement exceeds the 0.003-inch clearance but the value closest to where the jig and mold frame meet is a value of 0.0013-inch making it within this constraint.

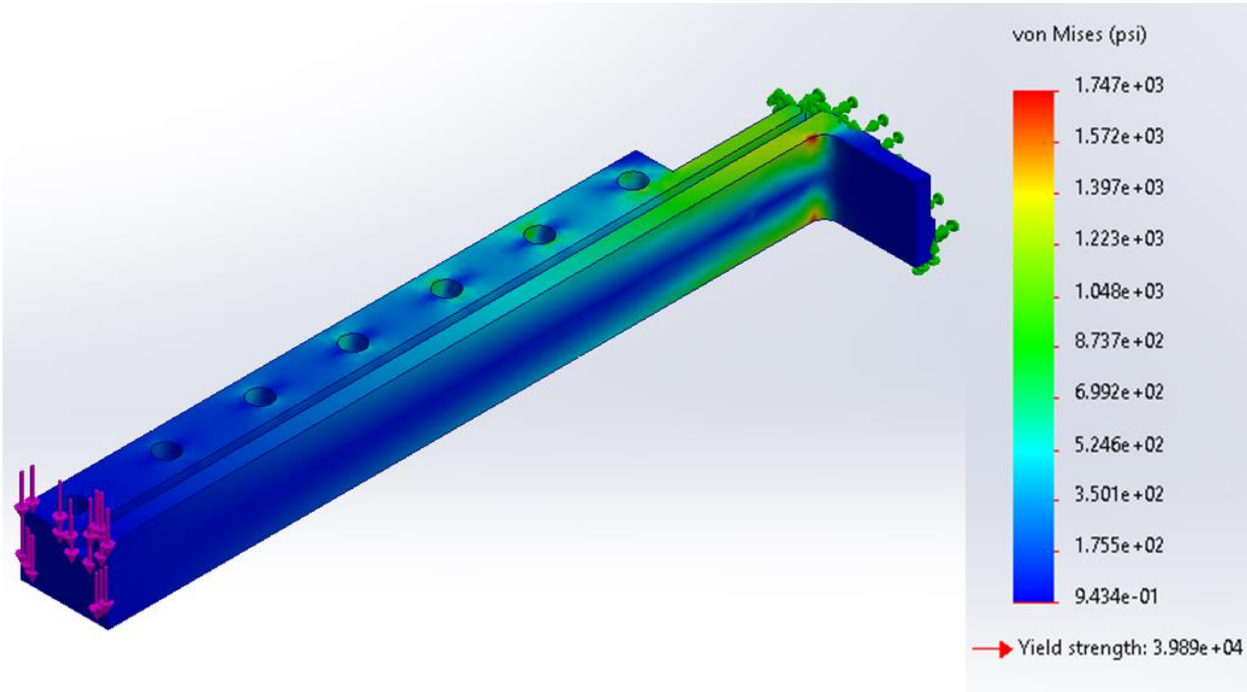

Figure 26. Moving bottom jig maximum stress.

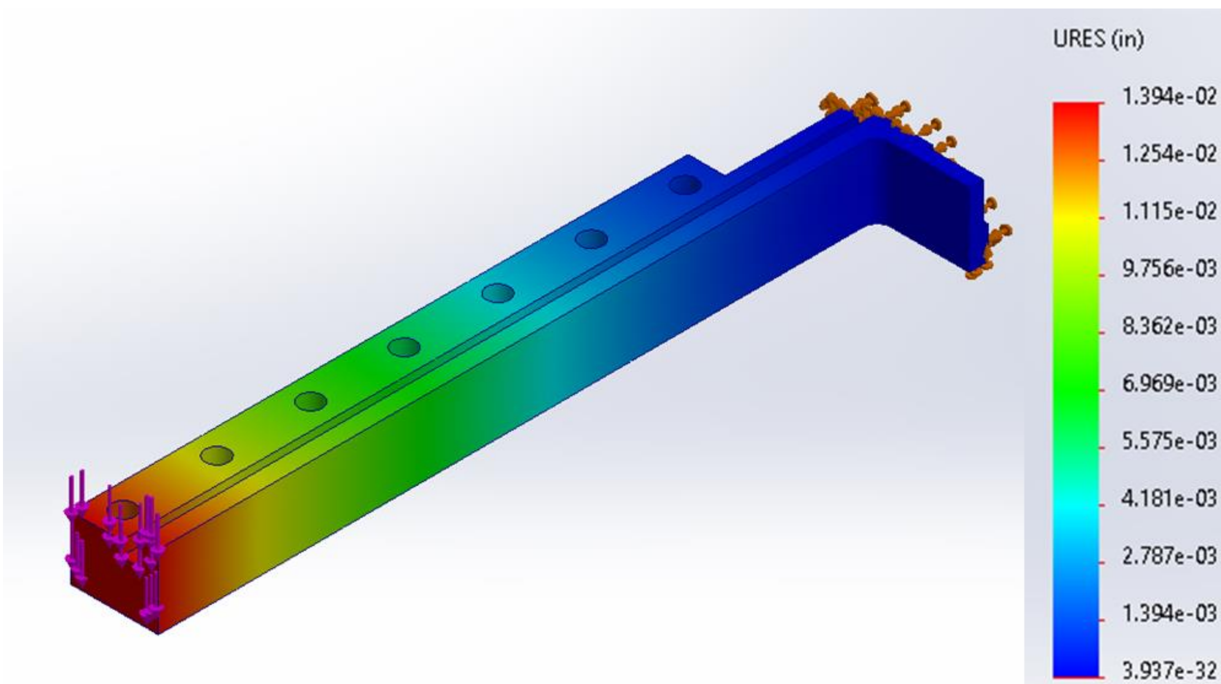

Figure 27. Moving bottom jig displacement.

6.0 Manufacturing

The fabrication of the Injection Mold Alignment Jig was completed by a machine shop in Evansville, Indiana. Drawings, shown in Appendix I, were given to them for construction. The fillets, hole size and tap size can be found on the drawings. In Figure 28 the final jigs of this design are displayed. Figure 28 also features the 8-inch length of the top stationary and moving jigs. The final cost of this project was $5,443.09. This cost included milling services and all materials that were purchased including taxes and shipping. Appendix K. The final weight is 23.08 lbs., Appendix L. This was considerably less than the previous weight of 120.06 lbs. The final weight was able to be reduced by reducing the size and quantity of the bearings, removing the sheet metal and reducing the overall dimensions of the jig.

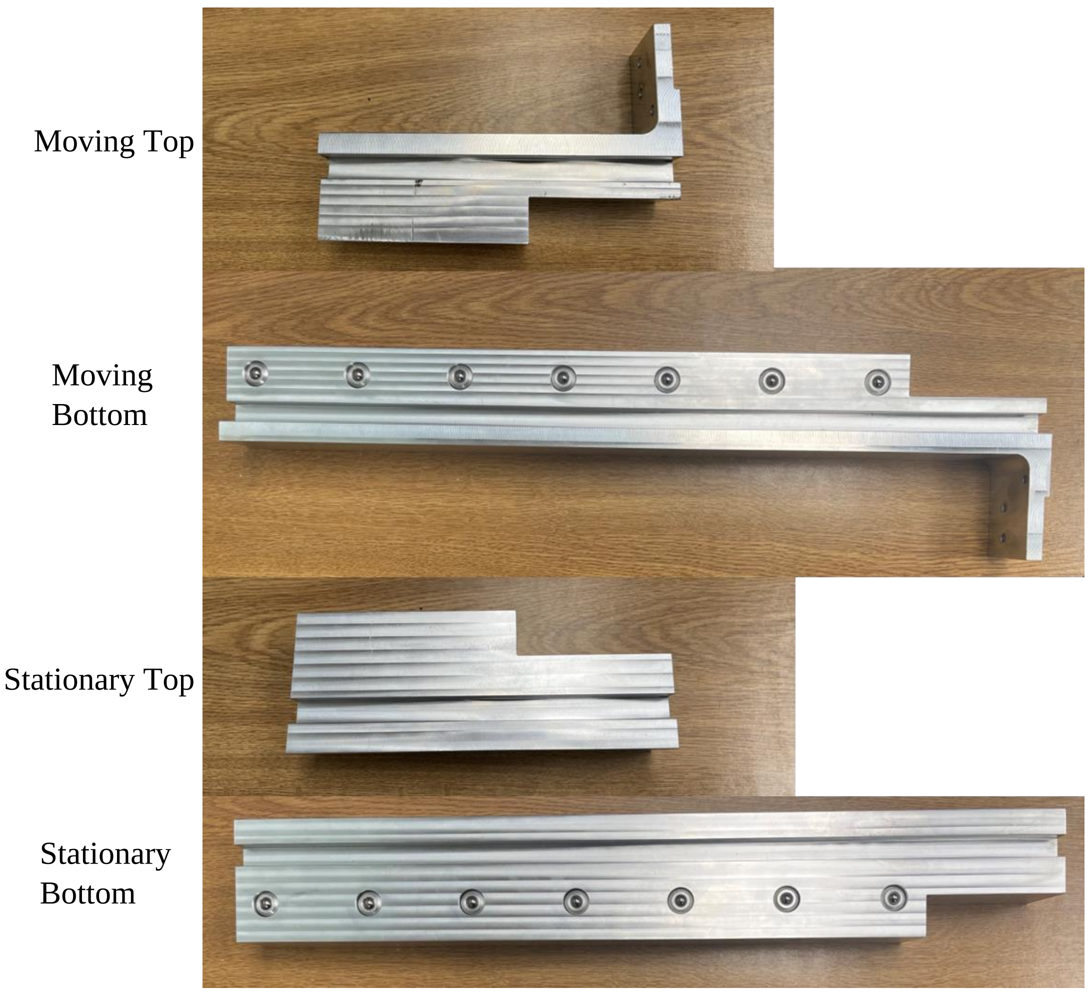

Figure 28. Final Jigs.

6.1 Installation

To install the jig system for use, a technician will only need three tools: a 15/16-inch socket, 7/16-inch socket and a 3/8-inch drive ratchet. The stationary side will be mounted to two L brackets each using a 1/4-inch bolt per bracket. Then the brackets will be bolted to the stationary platen on the molding machine, (Figure 19), using a 5/8-inch bolt per bracket. The moving side will need three 1/4-inch bolts per jig that will be bolted directly to the mold frame.

Once the jig system is installed and verified for correct alignment, inserts can be placed into the system for installation into the mold frame. From there, a technician can push the insert into the mold frame while still supporting the insert with both hands. Finally, the inserts can be secured into the mold frame with previously existing clamps. The only time this will need to be removed is if the workload requires a different type of mold set altogether. This event occurs 1-2 times every few months.

7.0 Testing

The jig system's ability to hold the force of the insert being applied on the system was verified by placing an insert of the maximum weight on the furthest point from the mounting location. It did not bind the system or break at any point. The insert was then transferred across the bearings and into the mold frame. The alignment was correct and allowed for easy installation. The mold insert change process was timed to take 6 minutes, on average. It also corrected the unnatural body position shown in Figure 29 below.

Figure 29. Before and after body position.

A survey was given to three technicians to review the before and after effects of the Injection Mold Alignment Jig. The survey captured what the technicians thought the ease of use was before and after the change. This was on a scale of 1-10, where 10 was the easiest. The technician's surveys average scores reported the ease of use before the change was a 2/10 and after the change was an 8/10. The first comment I got was, "I like that I no longer have to extend my arms with the mold. I only have to lift and set on the rails." While the other comment left showed how much this improved the ease of installation. "Simple design, very easy to put insert into mold frame. Once the insert is on the rail you can push it into the mold frame with just one finger."

8.0 Disposal Plan

Once the jig has reached its useful life or the machine it is designed for is decommissioned, SABIC will recycle the jig system and associated components. All the aluminum used in the design is recyclable if they choose to do so. The bolts and bearings used can be repurposed or sold for scrap.

9.0 Lessons Learned

Further knowledge has been gained since starting this project. Knowledge associated with the application of jigs in different settings, SolidWorks, and SABIC's molding capabilities. I also learned about machining processes and how to size holes for taps. If I were to go about anything differently, I would ask for feedback from the SABIC team at more points during the ideation, design and implementation phases and track how the feedback progressed.

10.0 Teamwork

Tony Philipps and Steve Sheffer with SABIC assisted with this project. We all work closely together on the day to day, so it was easy to keep in touch and get feedback when needed. I sought their input on designing the jig what key features to capture and testing of the final design. Tony was instrumental in designing the mounting locations and helping with the installation of the jigs. While Steve helped assess the final design and pointed out an improvement by shortening the top jigs on both the stationary and moving sides.

11.0 Future Work

Currently, future work would include adding additional bearings to make the transfer of insert from operator to mold frame a smoother action. Fastening the stationary jigs to the L brackets in a permeant way would decrease the chance of misalignment. Shaving down the L brackets to provide more clearance. Taking off 1/16-inch of the inside faces of the jigs to increase clearance. Using a machinist level while installing the mold frame into the machine can prevent misalignment between the jig system and the mold frame as well. Heating and cooling lines need to be connected to the mold insert for operations; these will require new fittings to be installed on the mold inserts to provide an easier connection.

12.0 Conclusion

The objective of this project was to design and produce a jig to align and install a mold insert into a mold frame to alleviate any ergonomic risk during installation. With the objective in mind, the driving requirements were made. The jig does hold a minimum weight of 40 lb_f, aligns with the mold frame and it does not interfere with the molding machines operation. It does not protrude more than 24 inches from the mold. The insert change process didn't meet the required 5-minute mark, but it only took 6 minutes. This is acceptable because the design does overcome the ergonomic safety risk the operators are put in while performing an insert change. It also helps achieve correct alignment between the insert and mold frame.

Previous literature helped point out desirable and undesirable design choices and how they affect different aspects of the project. These solutions helped motivate the design process. Three designs were developed and considered. The chosen design displayed a version that would reduce the ergonomic risk but also make it easier to push the insert from the operator to the mold frame.

SolidWorks simulations played a large role in assessing the maximum bending stress and deflection ensuring that the system would hold the load required and align with the mold frame. Calculations were made to verify that the simulations were accurate. The design was tested in the mold shop at SABIC and feedback was received from the technicians. Though it proved useful, it still needs to undergo continuous improvement.

13.0 References

[1] Ye, Ronan. "Anatomy of a Plastic Injection Molding Machine: Hopper, Screw, Clamping Unit & More." *Rapid Prototyping & Low Volume Production*, 15 Dec. 2022, www.3erp.com/blog/anatomy-of-a-plastic-injection-molding-machine-hopper-screw-clamping-unit-more/.

[2] Gitnux, "Ergonomic Injury Statistics and Trends in 2023 • Gitnux." *GITNUX*, 26 Sept. 2023, blog.gitnux.com/ergonomic-injury-statistics/.

[3] Akkari, Reiley, and Garcia, Bryan, and Looney, Sophia. "*The Project Management of investigating Dowel Laminated Timber".* California Polytechnic State University, San Luis Obispo. 2020. https://digitalcommons.calpoly.edu/arcesp/116/.

[4] Lamme, Max. *"Combination Bicycle Frame Jig/Alignement table".* University of Cincinnati. 2016. https://drc.libraries.uc.edu/server/api/core/bitstreams/4e37c0f9-6294-4e2a-babe-bff9b22a9abf/content.

[5] Diaz, Alejandro, and Fernandez, Osvaldo, and Gonzalez, Ricardo, and Ramos, Christian. "*FSAE 2015 Chassis and Suspension."* Florida International University. 2014. https://mme.fiu.edu/wp-content/uploads/2014/11/2014Fall-BS-Thesis-T09-FSAE-Chassis-Suspension.pdf.

[6] Budynas, R. G. (2014). *Shigley's Mechanical Engineering Design*. McGraw-Hill.

Appendices

Appendix A. System Hierarchy

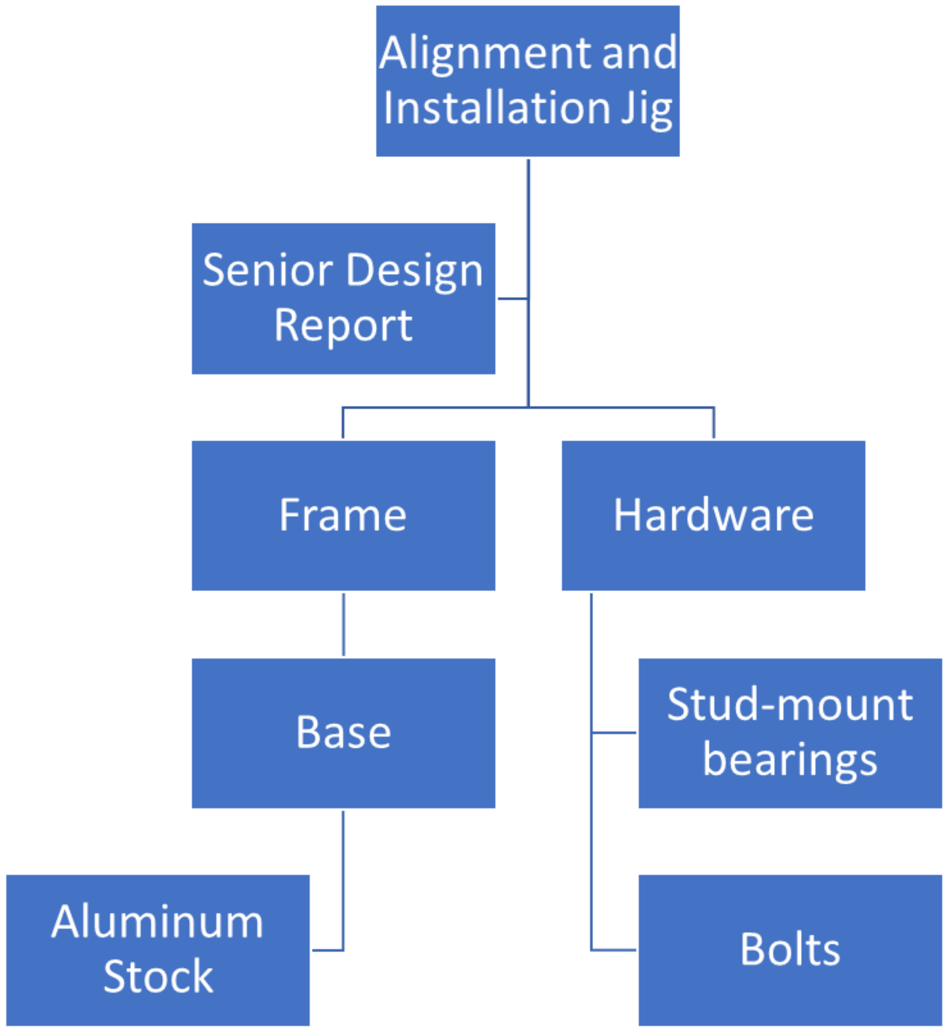

Figure 30. System Hierarchy.

Appendix B. Schedule

Table 4. Schedule

Task	Date
Fall 2023 Semester	
Start of Testing	8/21/2023
Initial Literature Research	9/11/2023
Detailed Literature Research	9/18/2023
Project Requirements	9/19/2023
Customer needs determined	9/19/2023
System Hierarchy	9/20/2023
First Draft of Senior Design Proposal Due	9/29/2023
Initial FMEA	10/4/2023
Final Senior Design Proposal Due	10/6/2023
Three concepts	10/11/2023
Choose a concept	10/15/2023
Literature Review and Concept Presentation	10/16/2023
Rough Calculations and Equation Sheet	10/23/2023
Mechanical Block Diagram	10/25/2023
FMEAs	10/30/2023
Updated Calculations and Equation Sheet	11/1/2023
Preliminary Design Review Oral Presentation	11/13/2023
Preliminary Design Review Oral Presentation	11/15/2023
Pre-Senior Design Report Due	12/7/2023
Spring 2024 Semester	
Arrange Weekly Meeting with Advisor	1/8/2023
Critical Desing Review	2/8/2024
Order Parts	2/10/2024
Begin Building Design	2/12/2024
Test Design	2/19/2024
Make changes if needed	2/21/2024
Complete Building and Testing	3/22/2024
Design Presentation Review	3/29/2024
Draft Report Due to Advisor	4/5/2024
Senior Design Presentation	4/19/2024
Senior Design Poster Session	4/25/2024
Final Report Due to Advisor	4/26/2024
Final Report Submitted to SOAR	5/3/2024

Appendix C. Budget

Table 5.Budget

Item	Quantity	Amount	Total
Aluminum Stock 2" x 6" x 12'	1	$ 926.72	$ 926.72
Aluminum Sheet 12" x 12" x 0.25"	2	$ 97.53	$ 195.06
5/8" x 1.5" cap screw (box of 25)	25	$ 73.50	$ 73.50
5/8" ball transfer bearing	20	$ 9.62	$ 192.40
		Grand Total:	$ 1,387.68

Appendix D. Standards

Table 6. Standards

OSHA	Section 5(a)(1)

Appendix E. Weight Table

Table 7. Weight Table.

Item	Weight (lbs)	Quantity	Total
Aluminum Stock 2" x 6" x 24"	14.12 per foot	4	112.96
Aluminum Sheet 12" x 12" x 0.25"	3.64 per foot	1	3.64
5/8" x 1.5" cap screw	0.05 each	8	0.40
5/8" ball transfer bearing	0.10 each	36	3.60
	Grand Total (lbs)		120.60

Appendix F. Concept of Operations

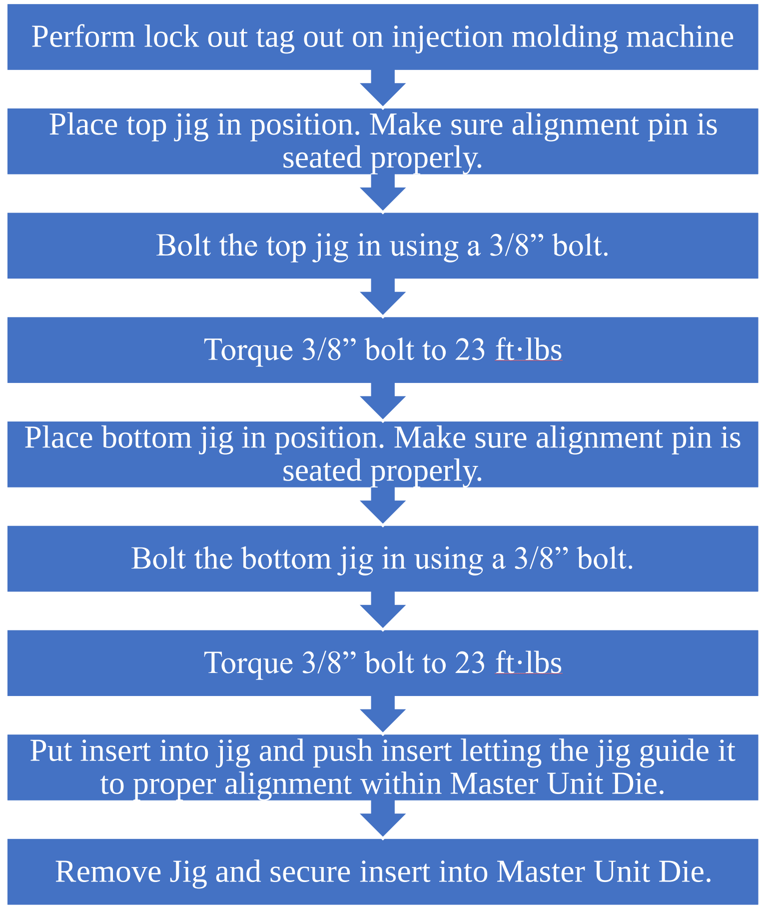

Figure 31. Concept of Operation.

Appendix G. FMEA

Table 8. FMEA between now and end of design

FMEA Now Till End of Design					
Item	Failure Mode	Cause of Failure	Possible Effects	Level	Possible action to reduce failure rate or effects
Materials	Wrong materials ordered or wrong materials came in.	A) Ordering error	Unable to complete build.	Medium	Order materials as soon as possible to have extra time if wrong part is delivered. Double check each order before it is placed to elimenate self error.
		B) Material manufacturer deivery error			
Top and Bottom Frame	Breakage	A) Material defect	Renders jig inoperable	Low	Inspect for material defect prior to installation. Create a preventative maintenance schedule for inspection. Test jig with with maximum weight capacity to observe if bending occurs. Have backup jigs redily available in the case of a failure.
		B) Bending of jig			
Top and Bottom Frame	Jig parts don't fit together	A) SolidWorks drwaing errors	Renders jig inoperable	High	Pay close attention to SolidWorks drawings double checking each dimension with coinsiding pieces.
Top and Bottom Frame	Damage delt	A) Milling machine crash	Renders jig defective and unsable.	Medium	Be careful when designing jig, paying close attention to measurements. If any difficult areas of design be sure to have open communication with milling company or personnel. In the event of taking damage to frame, have spare metal stock to start over.
		B) Milling machine user error			
Bearing	Go out/ Fail	A) Misuse	Renders jig inoperable	Medium	Inspect bearings before each use. Have extra bearings available.
		B) Overuse			
Alignment pins or bolts	Incorrect alignment	A) Damaged pins or bolts	Renders jig inoperable	Medium	Require a torque specification for bolts to be tightned to. Inspect pins before each use for any visual damage.
		B) Over torque of bolts			
Mounting plate	Breakage	A) Over or under torque of bolts to secure mounting plate	Renders jig inoperable	Medium	Require a torque specification for bolts to be tightned to. Provide insight for proper installation. Mounting plate can be reproduced easily.
		B) Incorrect installation			

Table 9. FMEA customer issues

FMEA Customer Issues					
Item	Failure Mode	Cause of Failure	Possible Effects	Level	Possible action to reduce failure rate or effects
Top and Bottom Frame	Breakage	A) Material defect	Renders jig inoperable	Low	Inspect for material defect prior to installation. Create a preventative maintenance schedule for inspection. Test jig with with maximum weight capacity to observe if bending occurs. Have backup jigs redily available in the case of a failure.
		B) Bending of jig			
Bearing	Go out/ Fail	A) Misuse	Renders jig inoperable	Medium	Inspect bearings before each use. Have extra bearings available.
		B) Overuse			
Alignment pins or bolts	Incorrect alignment	A) Damaged pins or bolts	Renders jig inoperable	Medium	Require a torque specification for bolts to be tightned to. Inspect pins before each use for any visual damage.
		B) Over torque of bolts			
Mounting plate	Breakage	A) Over or under torque of bolts to secure mounting plate	Renders jig inoperable	Medium	Require a torque specification for bolts to be tightned to. Provide insight for proper installation. Mounting plate can be reproduced easily.
		B) Incorrect installation			

Appendix H. Mechanical Block Diagram

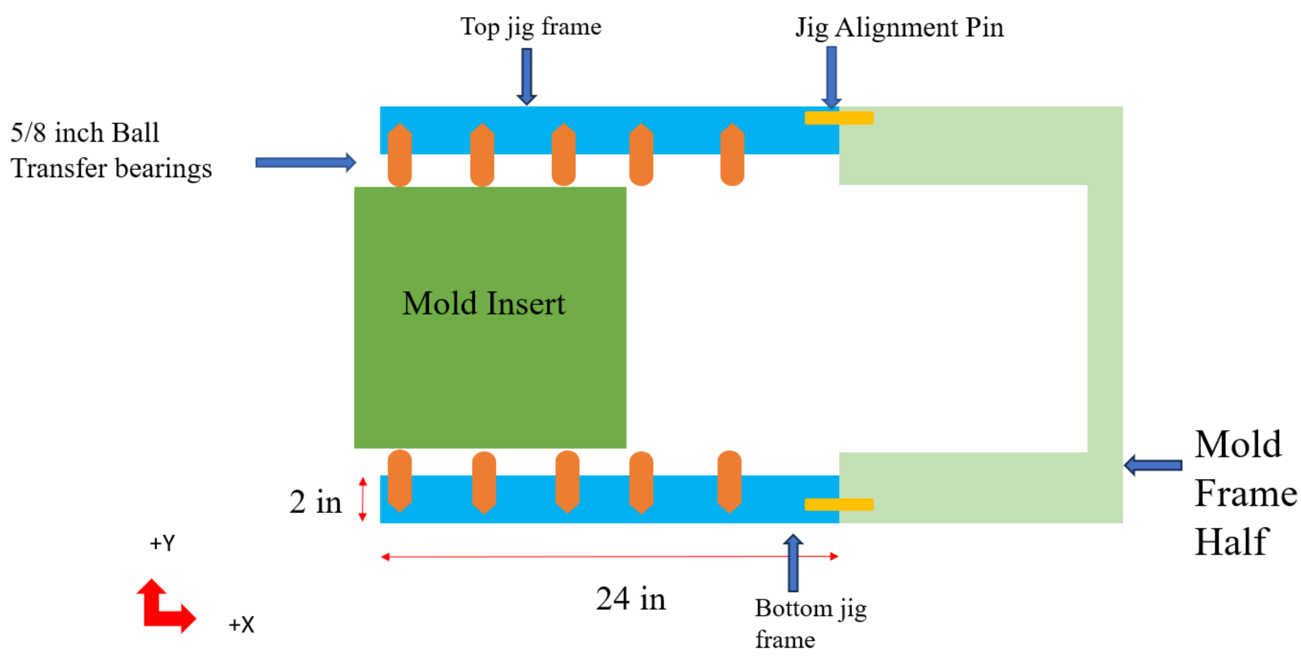

Figure 32. Mechanical Block Diagram, insert in jig.

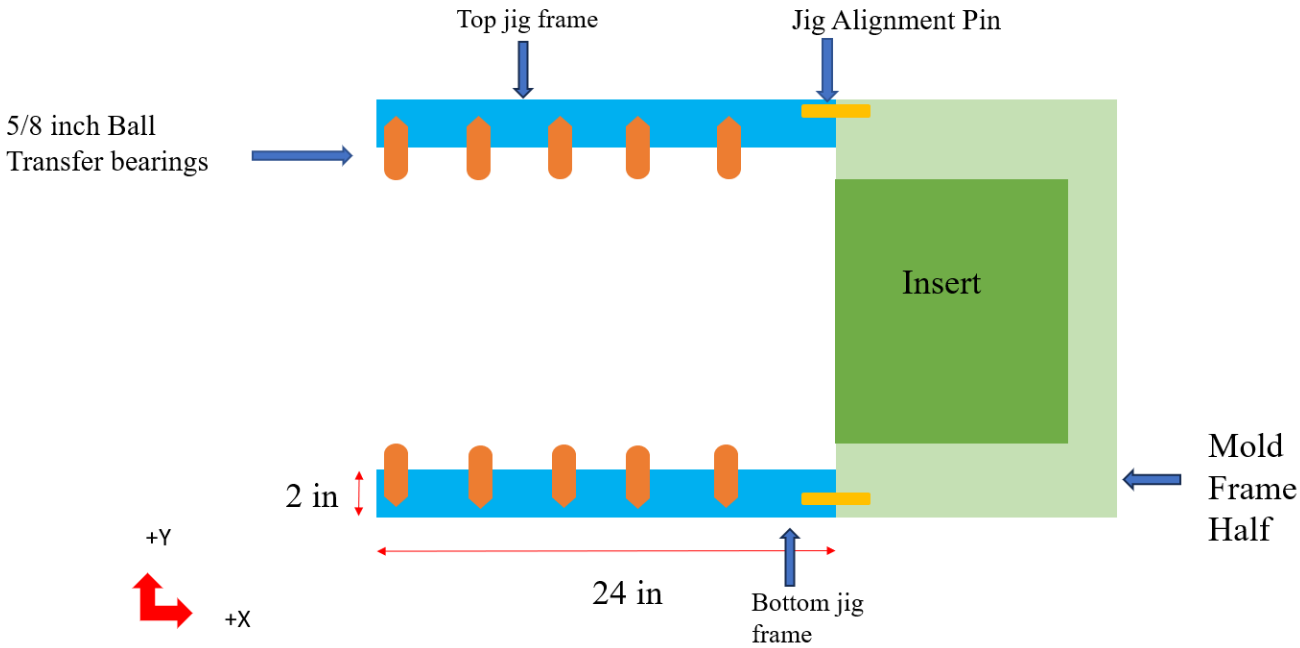

Figure 33. Mechanical Block Diagram, insert in mold frame.

Appendix I. Drawings

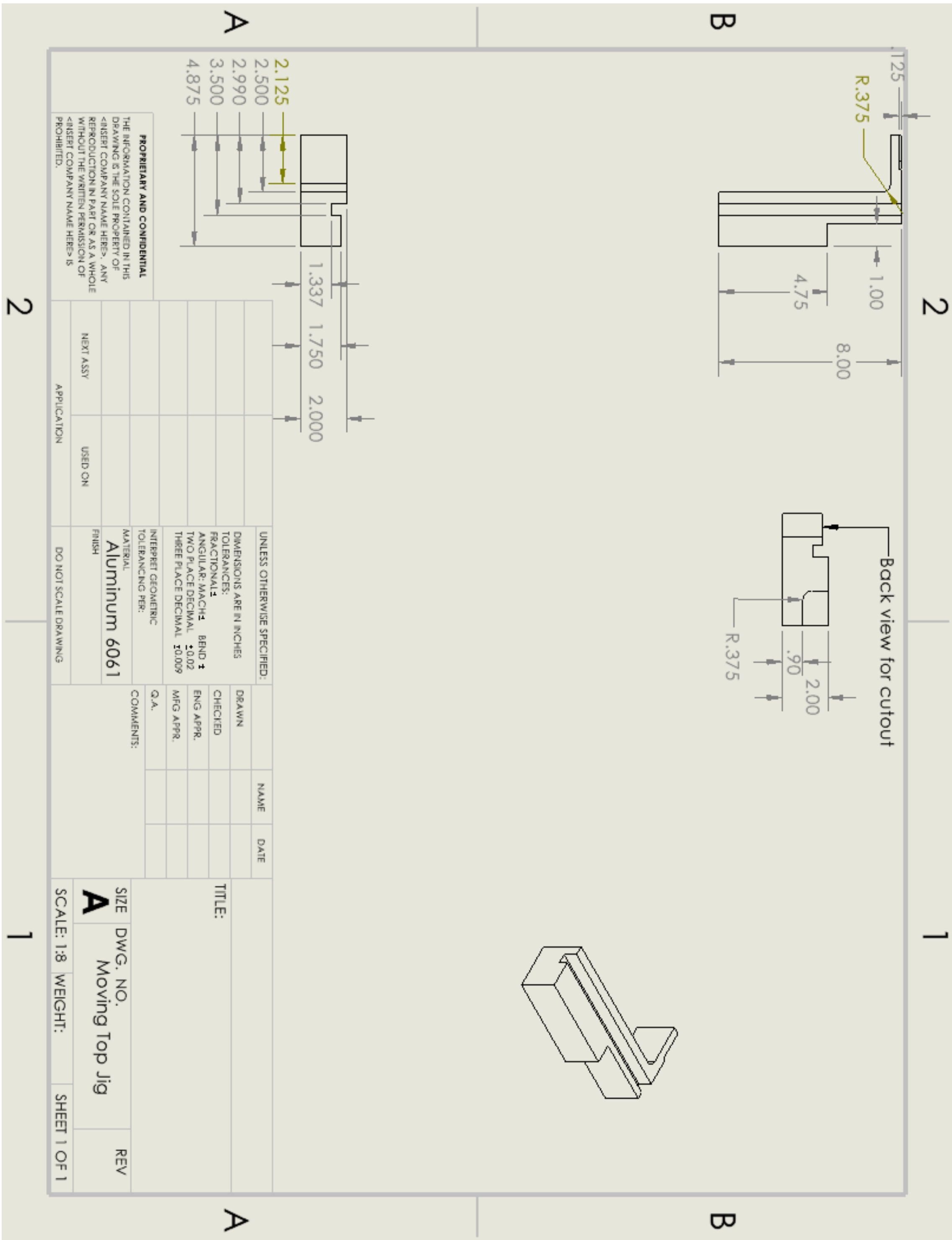

Figure 34. Moving top jig drawing.

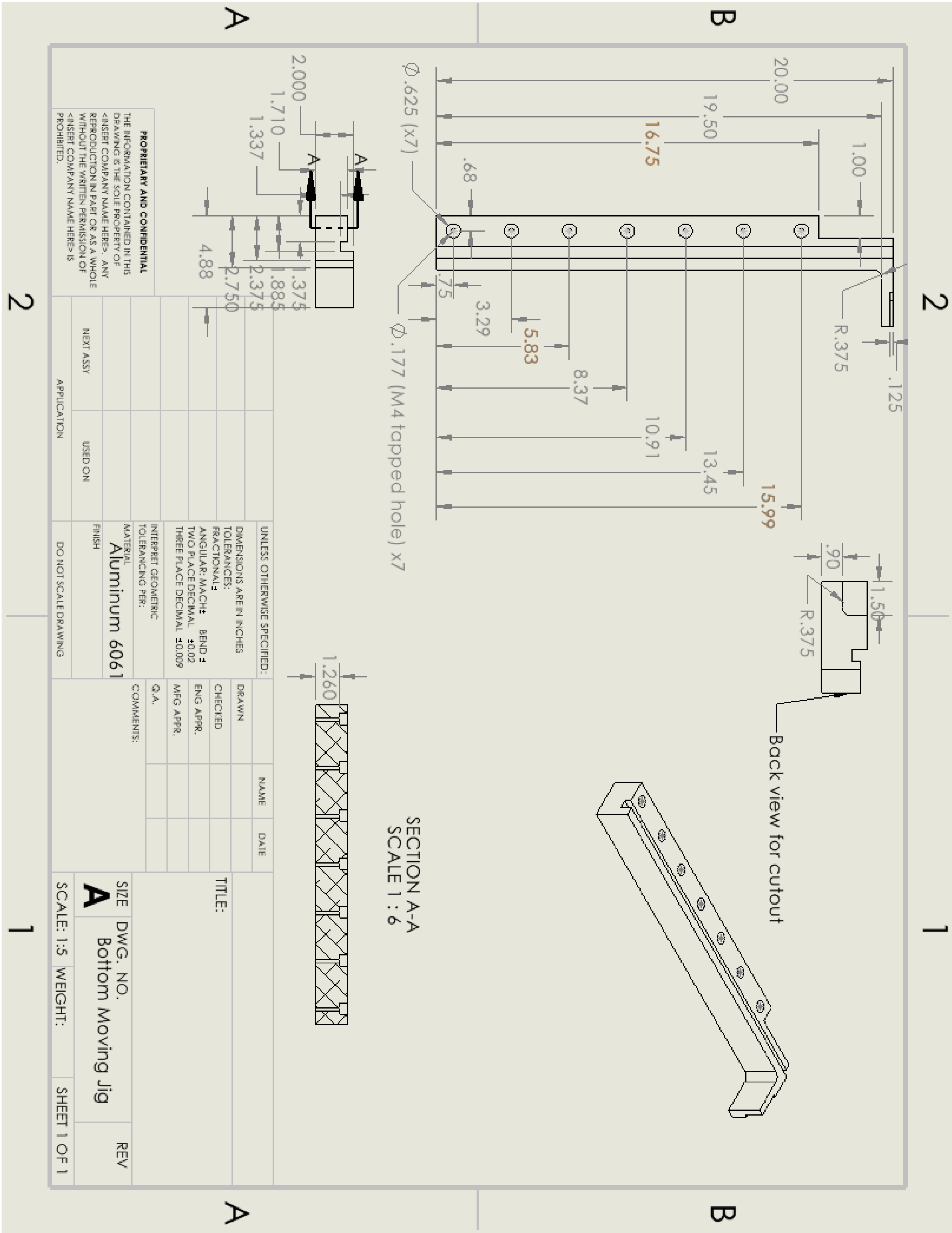

Figure 35. Moving bottom jig drawing.

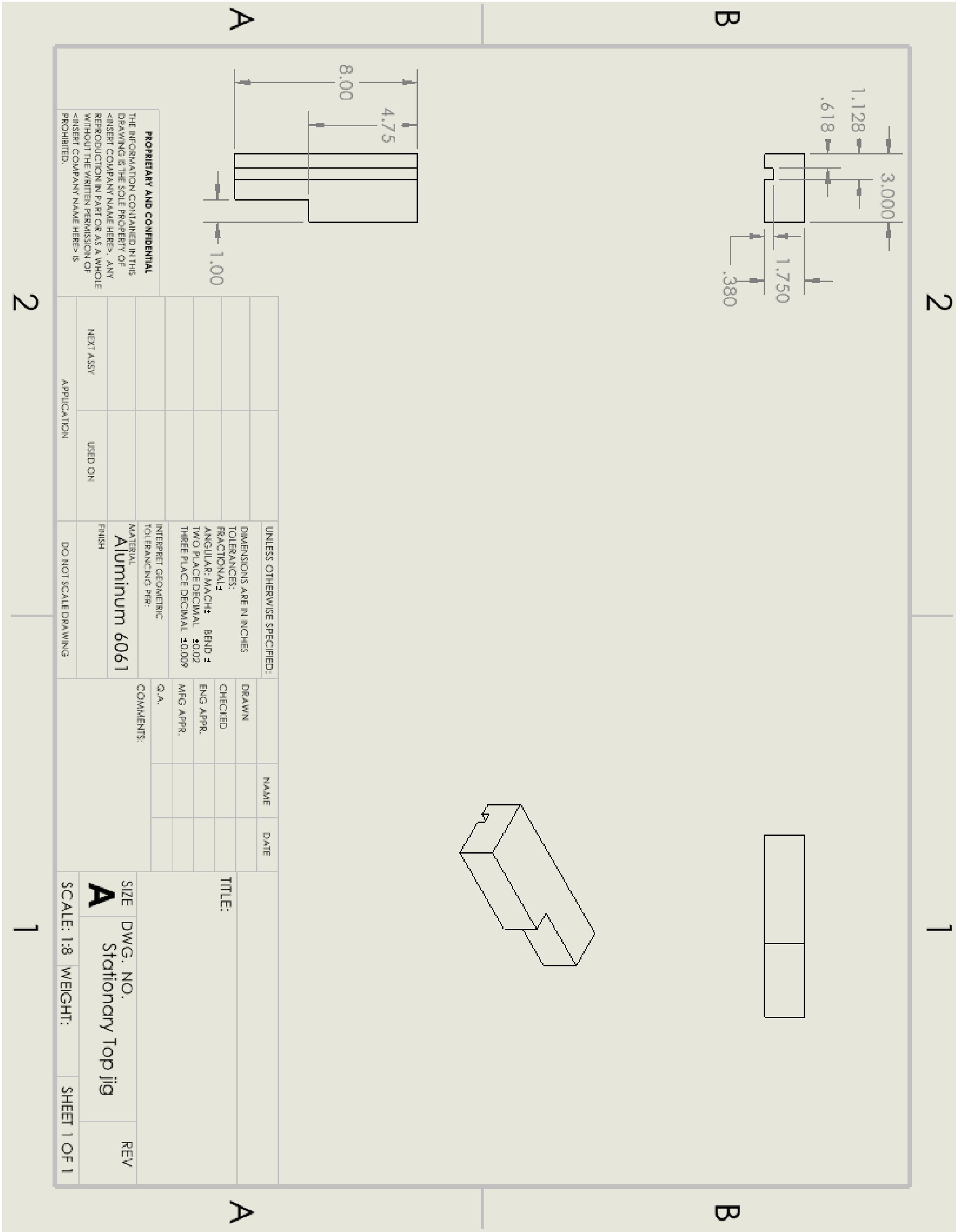

Figure 36. Stationary top jig drawing.

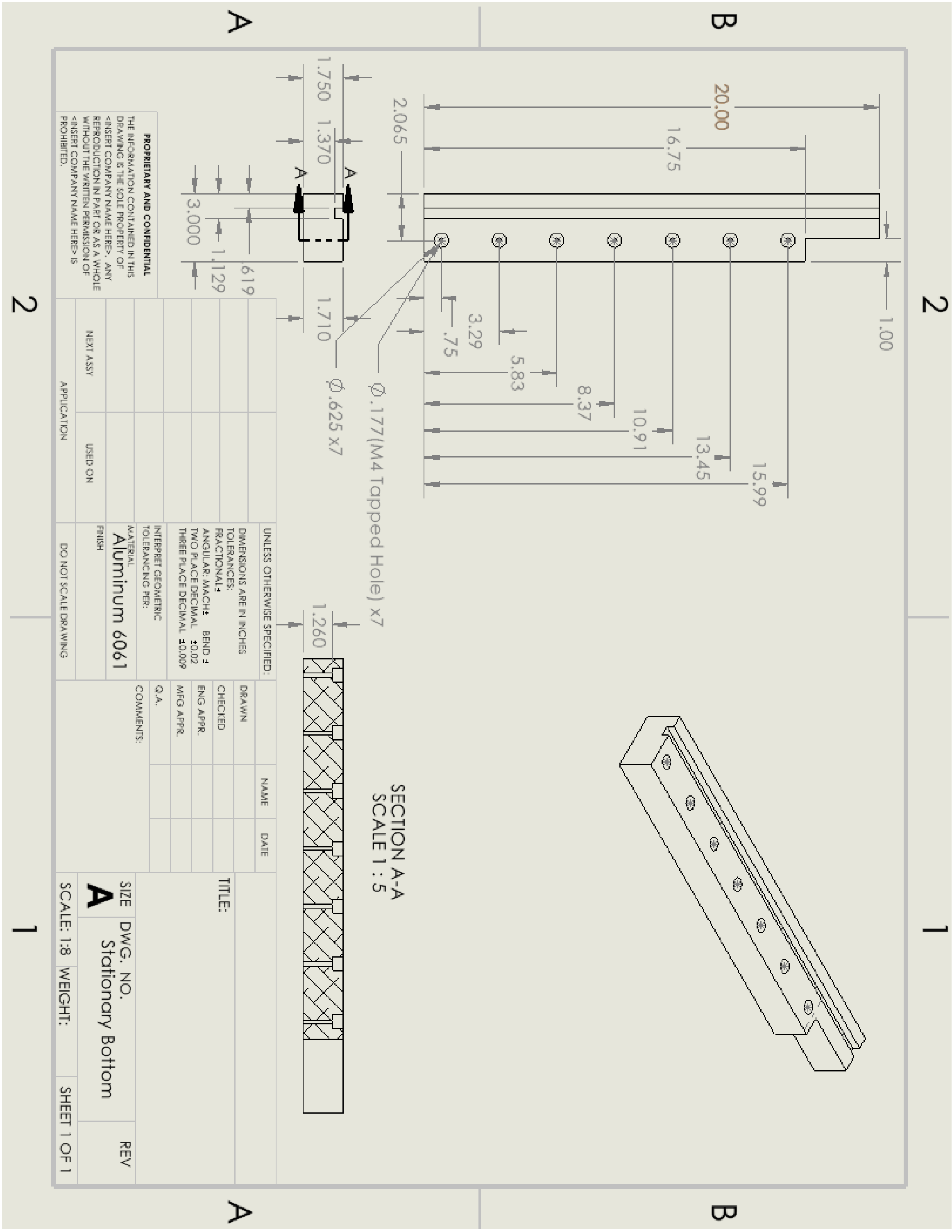

Figure 37. Stationary bottom jig drawing.

Appendix J. Design Factors Considered

Table 10: Design Factors Considered

Design Factor	Page number, or reason not applicable
Public health, Safety, and welfare	Section 1.0, page 1.
Global	Does not impact global.
Cultural	Does not impact cultural.
Social	Does not impact social.
Environmental	Section 6.1, page 24.
Economic	See Budget Appendix E.
Professional Standards	See Standards Appendix D.

Appendix K. Final Material Cost

Table 11. Final Material Cost

Item Description	Source	Quantity	Total	After tax and fees
Aluminum 6061-T6 Stock 2" x 6" x 48"	J&J Welding Inc.	1	$ 744.15	$ 744.15
Aluminum 6061-T6 Stock 2" x 3" x 48"	J&J Welding Inc.	1		
5/16" ball transfer bearing	McMaster-Carr	20	$ 1,940.00	$ 2,098.94
Milling service	Dexterous Mold	1	$ 2,600.00	$ 2,600.00
1/4" x 1" bolts	SABIC	10	$ -	$ -
5/8" x 1" bolts	SABIC	4	$ -	$ -
L brackets	SABIC	4	$ -	$ -
			Grand Total	**$ 5,443.09**

Appendix L. Final Weight

Table 12. Final Weight

Item	Pounds
Moving Bottom	7.60
Moving Top	2.82
Stationary Bottom	9.28

Stationary Top	3.38
Total:	23.08