GAF Glass Mat Splice Table Improvements

Final Design Report

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Sponsor:

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Statement of Disclaimer:

Abstract:

The GAF asphalt shingle production line in Shafter, CA requires continuous operation in order to maximize production efficiency. The assembly line process begins with feeding a large roll of fiberglass web into an accumulator. However, once the fiberglass roll approaches the end, it must be spliced with a new roll in order to maintain continuous feed into the production line. The splicing process must be fast and reliable to prevent any delay of the production line. Currently, this process is performed by two workers who manually feed the new fiberglass roll, align the two mats, cut the mats, apply glue between the mats, and press the mats together. In order to increase efficiency and reliability, GAF is looking to introduce automation to the splicing process and reduce the number of operators to one. The splices performed by the new automated process should also be at least as strong and reliable as the manual process to prevent an increase in splice failures down the production line.

The previous senior project team for GAF designed and built an automated gluing mechanism to be mounted on the existing press fixture. The objective of this project was to design, build, and test a system that will perform the cutting procedure of the splicing process without the need for two operators. This was achieved through a design that incorporates a rotary cutter to sever the mat and a limit switch to detect if there is a failed cut. This connects to the previous senior project's linear actuator. The design has been validated in is ready for use on the production line.

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1 Introduction:

GAF Materials Corporation is one of the nation's largest manufacturers of roofing products. At their facility in Shafter, CA, GAF produces roofing shingles as part of their Timberline Product Family. To manufacture these roofing shingles, the production line starts with a splicing process that joins two rolls of fiberglass mats together to achieve continuous feed. As part of this splice process, fiberglass mats are cut, glued, and pressed together at a splicing table. This process currently requires two workers to be present at the splicing table as the mats are too wide for one person to reach across and complete the previously mentioned steps. GAF is sponsoring this project to improve the table so that only one operator is required to do the entire splicing process.

This is the second Cal Poly senior project sponsored by GAF. The previous project began with the same initial goals. Due to the short time frame of the senior design sequence, the previous team eventually narrowed the project scope to focus on the gluing process. Our project will integrate the past senior project onto the production line as well as improve the splice table to meet the design requirements of GAF. Ron K'Miller is the point of contact for the project.

2 Background

The purpose of the glass mat splice operation is to join two different rolls of material to allow for continuous feed of fiberglass mat into the Timberline production line. The fiberglass mat arrives at the factory in large rolls. During production, as a roll approaches the end of its supply, a fresh roll of fiberglass must be spliced to the existing roll in the allotted time provided by the accumulator so that production line does not stop. Currently, there are a few other roofing production companies, such as Armor Metal Roofing and Owens Corning, which use a similar manual process to produce asphalt roofing shingles. The point of reference (POR) process currently in use on the production line at GAF has two operators complete the following actions:

- Cut the fiberglass mat near the end of the existing roll
- Apply hot glue in a uniform line on the freshly cut end of the mat
- Move the new fiberglass mat over the glued portion
- Press the mats together by rolling into position a pressing fixture that uses force to activate the adhesive

The previous senior project attempted to improve the process with the initial intention to fully automate the splice table operation. However, the scope of that project was eventually narrowed to only include a glue gun machine. The final product of this project is given in Figure 2-1. This gluing machine currently relies on an Allen-Bradley Control Logix PLC and uses optical sensors to detect the end of the mat to cease dispensing. The motion of the glue gun machine is operated by a Thomson Linear WM60S linear motion system on a gantry-type system. The gluing operation of the splicing table has been solved, but there are still conflicts, such as assembly and implementation, that remain unresolved. This gluing solution requires one operator to start the process.

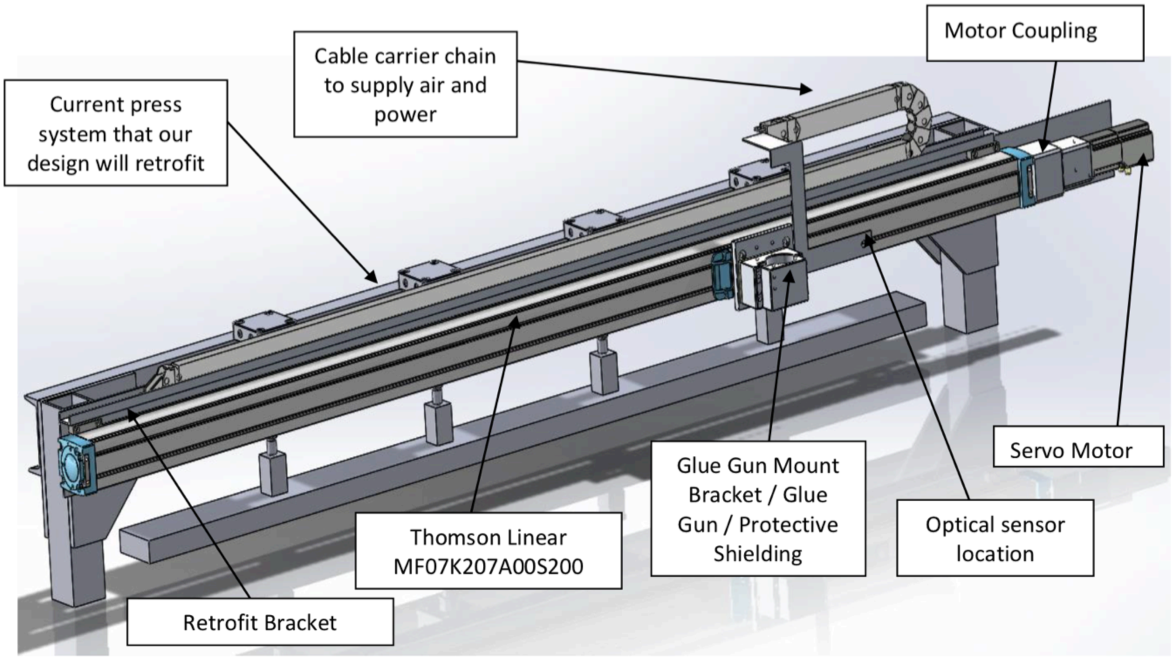

Figure 2-1: Senior Project Gluing System [1]

In order to gain a better understanding of our project, we researched existing adhesive and automations solutions that can be applied to this process. In regard to other adhesive options, there are other methods besides using hot glue to create a lap splice. Other manual methods of splicing non-woven fiberglass mats include using a tape system developed by 3M. This process uses a 3M™ Thermosetable Glass Cloth Tape 365 instead of using a hot glue gun.

As a fully automated solution, Martin Automatic, Inc. makes an automatic splicing machine called the MAS Series Lap Splicer. The machine is designed for heavy duty splices with large diameter rolls. The machine comes with options for tape and tapeless splicing. The machine is extremely large, expensive, and requires a large amount of shop floor space.[2] In addition, the process of moving, gluing, and cutting the rolls is performed internally; incorporation of this product into the previous senior project and the production line at GAF is not feasible.

Another fully automated solution is using a six-axis Cartesian robot with multiple end-effectors. Various robotic companies such as Fanuc, ABB, and Kuka (Figure 2-2) make durable and reliable robots for a multitude of applications.[3] The ability to use different end effectors makes these robots able to do multiple tasks with the same robotic arm. These robots are also expensive and the programing and customization of end effectors is an extremely involved process. Conventional six-axis Cartesian robots also require cages to prevent worker injury and can take excessive amounts of floor space.

Figure 2-2: Kuka KR30-3 Robot [3]

Many companies also offer different types of shears for long woven or non-woven fiber materials. Independent Machine Company, for instance, creates multiple types of shear presses that are designed for production line usage. Their solutions are expensive and need customization to properly integrate them with GAF's production line.

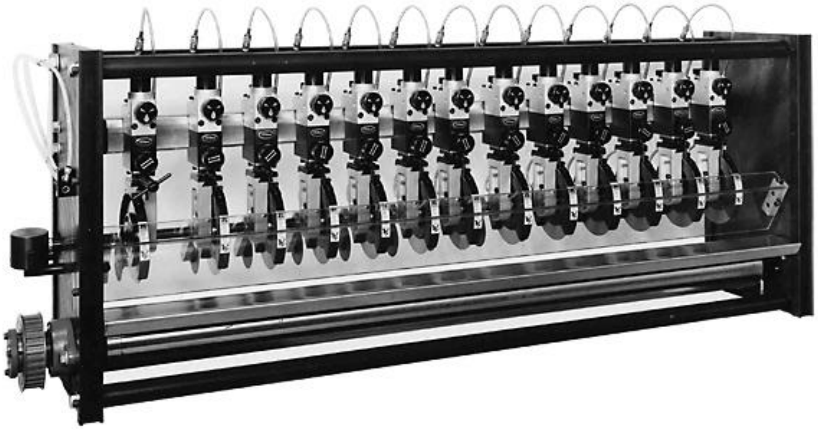

Figure 2-3: Pneumatic Shear from Independent Machine Company[4]

In regard to existing patents, patents US 20100224307 and US 20070095011 describe a fiberglass splicing method for roofing tiles that includes glue that is cured using ultraviolet light. Also, patent US 6627024 B2 describes a method and apparatus for splicing fibrous mats for applications in the tobacco industry.

There are significant advantages with automating a process such as the splice table. First, the elimination of an operator translates to more available manpower for the production line where needed. Second, with an automated process, consistency of the splicing will increase which will presumably reduce the amount of costly splice breaks that happen within the fiberglass mat accumulator. Third, fewer operators will be exposed to the hot glue guns and other moving machinery, which translates to a safer work environment. With GAF's particular excellence in worker safety, our designs will need to meet OSHA 1910 codes. Lastly, the use of automation can also decrease the cycle time of the splicing process. From this research, we have concluded that while there are other machines that perform similar splicing tasks, our project will be unique to GAF's production line.

3 Objective:

To complete the splicing operation described above, GAF currently uses a manual process conducted by two operators. In tandem, the two operators cut the fiberglass mat, pull it into alignment with the previous roll, apply glue, and activate the glue using a heat press. This process introduces safety hazards to the operators as well as inconsistencies in the splice quality. These inconsistencies can cause the splice to fail while the material is being processed.

In fall of 2014, GAF prompted a senior project team to improve the splice table by designing a process that has "hands-off" operation with only one operator. That senior project team was able to produce an offline prototype that completed only the gluing operation. The objective of this project is to integrate the past senior project into the production line and to continue to improve the Splice Table to the point at which only one operator is necessary to complete the splicing operation. This will be completed through either complete or partial automation of the individual steps of the splicing operation. Below is a complete list of the design requirements provided by GAF.

Customer Requirements:

- The system must integrate with the 2014 GAF Splice Table senior project
- The system must operate with a single operator
- The system must complete the splicing operation
- The system must position the fiberglass mat

- The system must complete the heat press operation
- The system must reduce the reliance on the operator through hands-off operation
- The system must produce splices of quality equal to or greater than the current process
- The system must be easy and safe to operate and maintain
- The design assembly must not impede access to the table for the operator
- The system must operate reliably in a high particulate, harsh production environment

The automation or partial automation of the splicing operation will increase the consistency of the splice produced. GAF proposed the target of decreasing the instance of splice break by 20%. Verifying this target will necessitate an investigation into the failure mode, the development of a test method, the fabrication of testing fixtures, and the completion of that testing plan. Because of the limited time frame of this project, our objective will be limited to continuing to increase the consistency of the splice operation through automation. While this consistency will likely reduce the instance of splice break, this project will terminate at the completion of the splicing fixture.

Table 3-1 provides the formal engineering specifications for the project. These specifications provide a measurable way of rating the compliance of the design solution to the given design requirements. The design specifications were derived using a House of Quality – Quality Function Deployment (QFD). The QFD is given in Appendix B. This process started through first rating the importance of the design requirements. As seen on the left side of the diagram, the importance of each of the design requirements is tabulated with respect to the "customer." From these ratings, it is apparent that having a single operator and creating a safe working environment are the most important design requirements. The specifications were then derived as a means of quantifying adherence to the design requirements. For instance, reliability will be measured by the splice break strength of the splice produced by the new process. The QFD also allows for the benchmarking of the current process and the last senior project. As one can expect, neither option fulfills all of the current design requirements. Lastly, the House of Quality shows the interactions between the different design specifications. For example, the chart provides that if you decrease the reliance on the operator, the fixture size will increase.

Table 3-1: Engineering Specifications

Spec. #	Parameter Description	Requirement or Target	Tolerance	Risk*	Compliance**
1	Reliance on Operator Input	Single or no Operator	Max	H	T,I
2	Splice Cycle Time	Max 40 seconds	Max	M	A,T,S
3	Splice Break Strength	Equal to or Greater than Current Process	Min	H	A, T
4	Splice Fixture Size	Not to Impede Operator Accessibility	N/A	L	A, I
5	Mat Placement Location and Tolerance	4 inch overlap	+/- .5 inch	M	A, T
6	Splice Cut Quality	Meets Visual Inspection Criteria	N/A	L	T, S
7	Stress on Operator	NTE Company Standard	N/A	L	T, S

*H=High, M=Medium, L=Low
**A=Analysis, T=Test, S=Similarity/Existing Design, I=Inspection
Note: Once the Standard Operating Procedure for the Splicing Table and other related documents are received from GAF, the target column of the table will be populated with numeric specifications where applicable.

Table 3-1 provides the engineering specifications. The compliance column provides the method by which the engineering specification will be met. For instance, the Splice Cut Quality will be met through testing trials of different cutting mechanisms and through comparison to the current process. The table shows that a considerable amount of testing will need to be conducted to properly qualify the design solution. The risk column provides the difficulty of achieving of each of the specifications. The Reliance on Operator Input and Splice Break Strength are the most important specifications for the design. This importance is confirmed in the bottom section of the QFD. Given this inherent importance, design changes that strongly affect these specifications will be discussed with GAF during period meetings.

In sum, a strong adherence to the engineering specifications will result in an effective design solution.

4 Design Development

4.1 Introduction

The Design Process began by dividing the scope of the project into sub components. From our factory visit, it became clear that the functions this project term would focus on are alignment, cutting, pressing, and integration with the past senior project. For the purpose of ideation, each of these components was then divided further into different actions. For example, there are two occasions when the mats need to be aligned: they need to be parallel when the cut is made and then they have to be parallel and overlap 4 inches before the press activates the adhesive. Therefore, ideation was completed to find design solutions that would force parallel alignment and consistent overlay. As to cutting, this action was divided into two different sub components/actions: cutting mechanism and deployment mechanism. Lastly, the pressing action is already completed by the existing fixture and simply needs to be automated. The final component of the design calls for integration of the above discussed mechanisms into the existing senior project. The final intent of the project is to integrate the two senior projects into one model that can be implemented on the line and used as is. Due to the reliance on two operators, the last senior project has yet to be integrated onto the production line.

4.2 Ideation, and Decision Making

After separating the project into different functions, we turned to brainstorming techniques to generate as many ideas as possible. To figure out ways to move the fiberglass mat along the table, we spent a few minutes jotting any ideas that came to mind on sticky notes, as shown in Figure 4-1. We employed similar ideation techniques to generate many rough solutions for cutting, alignment, and cut detection.

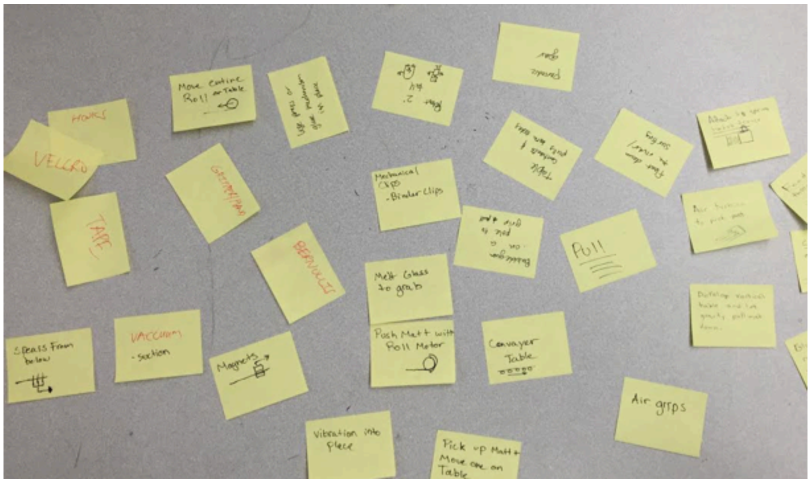

Figure 4-1: Sticky Note Brain Storming Method

Another tool used for idea generation and development was foam board prototyping, which gave us a visual tool to provide more feedback for our concepts. An example of this is provided in Figure 4-2. By creating quick models of the existing splice table and gantry, we could tinker with the different splice processes and the orientation of the system. After prototyping, we had a more refined view of which ideas were feasible.

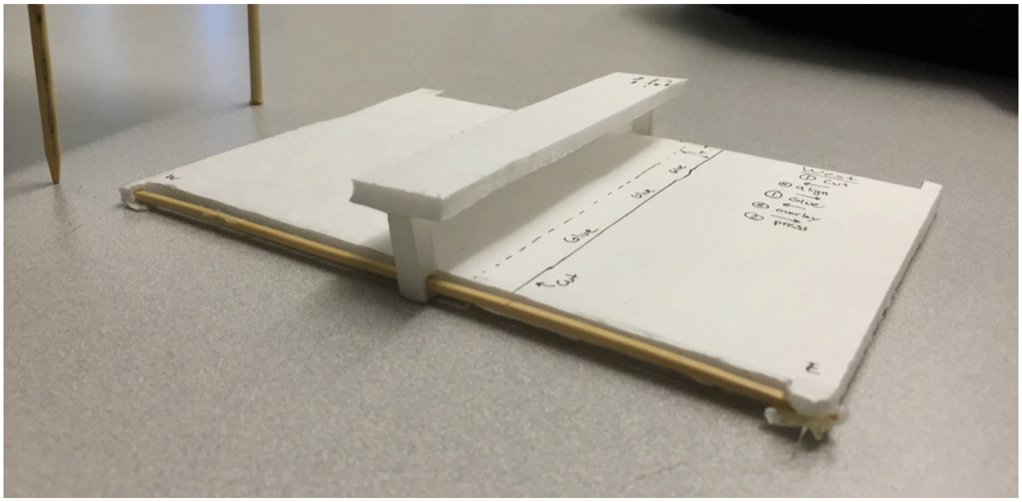

Figure 4-2: Foam Prototyping of Table Configuration

After generating multiple ideas for the different design functions, we used Pugh matrices to filter out unrealistic ideas and evaluate the plausible ones using the design requirements. The Pugh matrix functions by comparing our ideas to the current solution or a baseline product. If the concept outperforms the current solution in a certain criterion, it receives a "+" for that comparison. If the concept is as good as or worse than the current solution, it receives an "s" or "-", respectively. This method of idea evaluation tells us which concepts are worth pursuing and refining for further evaluation. The Pugh matrices for each of the components are available in Appendix D.

The next step in decision-making is using weighted decision matrices to pick a final idea. The decision matrix takes the better concepts determined by the Pugh matrix and gives us a detailed evaluation by weighting the importance of each design specification, given in the left column of the table, as well as assigning a quantitative score to each concept in how well it satisfies each specification. The weight of each design specification is determined by considering the customer requirements and deciding which specifications best fulfill these requirements for a given design component. Each score is multiplied by the weight of the requirement and then all weighted scores are added to give each concept a total score. The total scores do not guarantee us an automatic answer as to which concept is best for our design, but rather which concepts are worthy of intensive research and testing. For the purpose of our designs, all but one component was selected as the tope design in the decision matrix.

4.3 Cutting Mechanism Concepts:

Using the brainstorming and evaluation techniques discussed above, we generated a wide range of concepts for the cutting mechanism. The concepts can be divided into two categories: single action cutters and traversing cutters. The single action cutters contact the entire width of the mat at the same time while the traversing cutters contact the mat at one point and need to be carried over the width of the mat. The traverse cutters are advantageous from a force prospective because they localize the shearing force to one point, thus reducing the overall required force and stress on the system. The single action cutters are advantageous in their ability to complete the action quickly as they do not need to traverse the width of the table. The following discussion describes the proposed designs beginning with the traversing cutters.

4.3.1 Laser Cutting:

Research of the textile cutting industry revealed that laser cutting could accomplish the task of cutting fiberglass mats. To use a laser on the production line, the concept requires attaching a small laser unit to the current linear translator. To confirm that a laser can be used to cut the fiberglass mats, a HAAS ZA11 laser cutter, available in the IME fabrication and realization lab, was used to cut sample sheets. The laser cut the sample sheets with ease. The advantages of this design are in its consistency. First, once the proper laser parameters are selected, it is practically guaranteed to cut the mat consistently every time. Furthermore, there is a great reduction in the fraying on the cut edge. Its disadvantages include the general complexity of the concept as well as the cost and safety risks inherent in laser applications. A concept model is available in Figure 4-3.

Figure 4-3: Laser Cutter Concept

4.3.2 Rotary Cutter:

The rotary cutter concept, seen in Figure 4-4, was also inspired by the textile industry. The rotary cutter design incorporates a circular blade that is pressed against the splice table and traversed across the length of the mat while allowing the blade to spin about its central axis. This design can also include the incorporation of a guide groove in the table surface to reduce the risk of the cutter wandering away from the cut location. The advantage of this design is that it is simple and does not require the material to be held t tension.

Figure 4-4: Rotary Cutter Concept

4.3.3 Hook Knife:

Currently, the operators at the splice table use a hook knife to cut the fiberglass mat. This concept would simply attach the hook knife currently in use to the linear actuator of the previous project. An example of a hook blade is given in Figure 4-5.

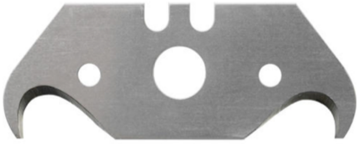

Figure 4-5: Example Hook Blade

4.3.4 Guillotine:

This design uses a blade that is as a long as the width of the table that is used to cut the entire width of the mat in a single actuation of the blade. The blade has to be a custom blade and require a new gantry or actuation method to be designed to support it. A sketch of this design is given in Figure 4-6.

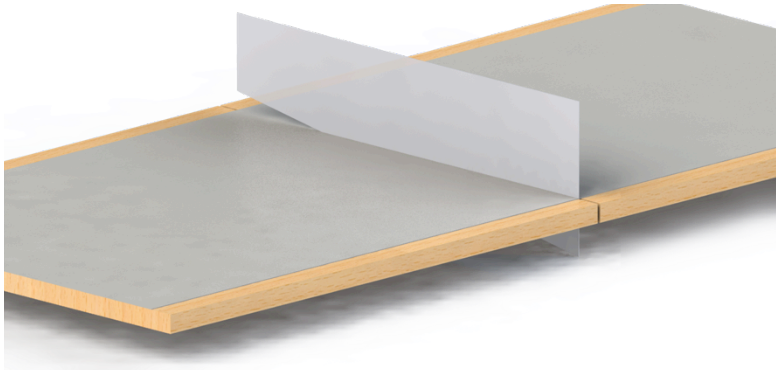

Figure 4-6: Guillotine Cutter Design Concept

4.3.5 Dremel:

This design uses a dremel-like, mechanically driven rotary blade to cut the mat. The spinning blade traverses across the width of the mat by attaching it to the existing linear translator or installing it underneath the table. The mechanism to drive the blade has to be incorporated into the traversing portion of the fixture creating more complication. This design would look very similar to the rotary cutter in Figure 4-4 just with the addition of a motor unit on the axis of the blade.

4.3.6 Hot Knife or Wire:

This design uses a heated blade or wire to cut through the fiberglass mat by burning it. Like the guillotine, the hot knife or wire is pressed along the width of the mat and left there until the material is removed. This design requires the construction of a new actuation carriage as well as the development of the safety features to protect the operator. Furthermore, testing has to be conducted to ensure that the burning of the fiberglass does not release any fumes that would otherwise deem the production line an unsafe working environment

4.4 Pugh Chart and Further Development:

By using the Pugh Chart method described above, it was determined that the rotary blade, laser cutter, the dremel cutter and hook knife designs were the most viable and should be developed further with preliminary concept testing. The Pugh Matrix is provided in Appendix D.

4.4.1 Preliminary Concept Testing and Analysis

In order to assess the feasibility of these designs, a testing plan was constructed to look at how blade type, cutting speed, pull force, and mat restraint affect the cut quality. The full design of experiment is given in Appendix F. From this testing, we learned that the hook and guillotine blade are highly dependent on the mat being held in tension; without this tension, the mat folds causing the blade to catch. The rotary blade, however, showed a good degree of success as this cutting method did not require the mat to be held in place even when the blade was dragged over the material at our "fast" cut speed.

One concern of the rotary blade was that we were not certain that the current linear actuator of the last senior project would be able to withstand the moment created by the vertical force required to cut the mat. The specifications of the Thompson Linear Thomson Linear MF07K207A00S200 Actuator are given in Appendix C In the given schematic, the x-axis is parallel with the axis of the drive screw. This axis is rated to withstand a movement of 18N·m. Assuming that the cutting force would act at most 20cm off the x axis, this allows for a cutting force of 98N or a fixture mass of about 4.4kg. These calculations are available in Appendix G. In order to estimate the vertical force required to cut the mat with the rotary cutter, we cut samples of the fiberglass on an electric scale as seen in Figure 4-7.

Figure 4-7: Cutting Force Testing Rig (lbf)

This scale gave us an approximate downward force of 15 N to successfully cut the mat at the fast speed. This is well under the rating of the linear actuator thus proving that this design is feasible.

As described above, the laser cutter was tested using the HAAS ZM100 laser cutter. These tests told us that the laser cutter is capable of cutting the fiberglass and doings so at high speeds

4.5 Cutting Decision

The design specifications for evaluating the effectiveness of the cutter design were based strongly on the original design specifications. The design specifications for the cutting blade are described below:

Cycle Time: The blade must be able to cut the mat quickly as time is limited during the splicing operation.

Reliability: The cutting mechanism must completely sever the mat. Failure to completely sever the mat will stop the production the line. This is the most heavily weighted design specification for this application.

Maintenance: The cutting mechanism must be easy and inexpensive to service.

Safety: The design is not to introduce hazards to the operator

Cost: The design should minimize development cost

Integration: The design should cleanly and simply integrate with the past senior project

Start Condition: The design is not to require a difficult starting condition (i.e. plunging)

Using these specific design specifications as the evaluation criteria of a decision matrix, it was determined that the rotary blade is the most successful cutter. This decision in seen in the decision matrix, Table E-1, given in Appendix E. The laser would be too complex and expensive to integrate for an application that could otherwise be done more simply. By that same principal of incorporating an overly complex design, the dremel cutter introduced too many unnecessary safety hazards while also creating a potentially detrimental amount of debris.

4.6 Cutter Deployment Concepts

In order for the press assembly to move between process locations on the line, the blade needs to be retracted from the table surface when it is not cutting. The following discussion discusses the possible design solutions for a method of deploying a blade from a safe home location to the cutting location on the table surface. As ideation for each of the four different design components took place simultaneously, a few designs were developed to deploy a wide guillotine blade. These designs are not discussed here but are present in the Pugh matrix given in Appendix D.

4.6.1 Drive Screw

This design, given in Figure 4-8, uses a very traditional drive screw method. This method of vertical translation can be seen in most mills and other 3 axis machines. The advantage of this design is that it is robust and easily adjusted. However, the design is heavy would require a potentially bulky motor to move quickly enough to meet the cycle time requirement. As discussed in the testing section of the cutter design development, the linear actuator is sensitive to moments about the axis of the drive screw thus weight is limited.

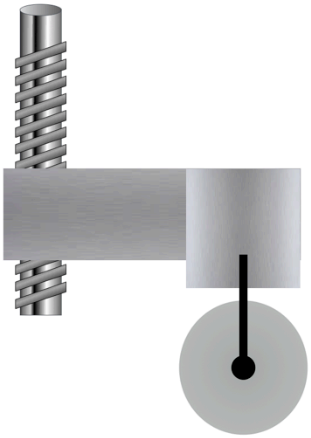

Figure 4-8:Drive Screw Z actuation method

4.6.2 Slider Crank

The next method is a simple crank and slider mechanism in which a motor would drive a system of linkages that retract and deploy the blade. This method requires a way to lock the joints to create a constant vertical force. Furthermore, like the drive screw design, this design requires that a motor be present on the gantry. This design is given in Figure 4-9.

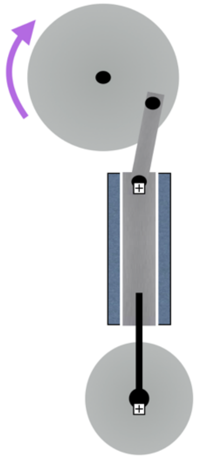

Figure 4-9: Slider Crank Design

4.6.3 Gravity

In an effort to reduce the number of moving parts, this design employs gravity as the actuation force. Weights can be added to the blade mechanism to increase the downward force on the blade. The blade is removed by winding a spool of wire or rope that would lift the blade off the table. This winding feature can exist closer to the axis of the drive screw thus reducing the moment on the linear actuator. This design is given in Figure 4-10.

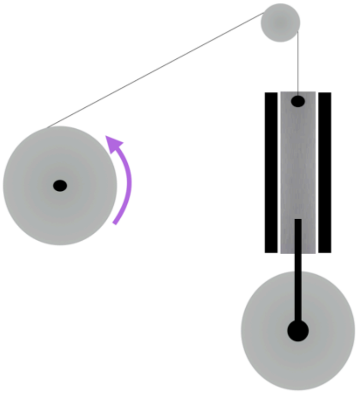

Figure 4-10: "Gravity" Z Actuation Method

4.6.4 Piston

For the final design method, given in Figure 4-11. we developed a method that employs using a 3 or 4 way solenoid to actuate a pressurized cylinder. Although this method requires a high-pressure airline, the vertical force applied to the table is independent of the table height. This design also allows for easy adjusting of the applied force by throttling down the pressure. Parker Pneumatic actuators are to be used at GAF in adherence with their product preferences.

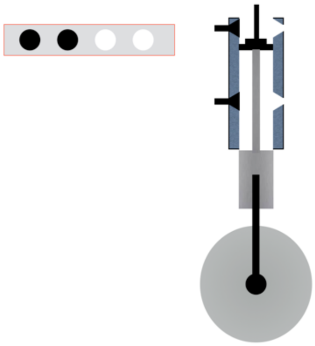

Figure 4-11: Pneumatic Z Actuation Method

4.7 Cutter Deployment Decision

The basic design specifications used to evaluate the deployment mechanisms are the same as those used to evaluate the cutters. In addition to Safety, Reliability, Cycle Time, Cost, the decision matrix for the cutter deployment mechanism, given in Table E-2, also includes the following design specifications:

1. Weight: The deployment mechanism is to be lightweight as to reduce the moment applied to the drive screw axis.
2. Force Adjustability: The applied cutting force is to be adjustable as to allow for optimization after construction.
3. Force: The applied cutting force needs to be sufficient to cut the matt
4. Integration: The design is to be compatible with the last senior project fixture.

Based on the customer requirements, we determined that the most important criteria are cycle time, reliability, and weight. The ability to adjust the amount of force applied, the actual applicable force, safety, and cost were weighted less as they are not critical to the function. Using the decision matrix, it was determined that the piston is the most successful design.

In regard to the drive screw, the cycle time and weight are the main issues. A drive screw needs to be extremely rigid and having a large lead screw and a large motor meant that the system would encroach on the load rating of the linear actuator. In order to reduce cycle time, a larger motor would be required to drive the lead screw increasing the weight even more.

The crank slider has similar problems with cycle time and weight. In order for the crank slider to work efficiently, the crank slider needs to have either a large disk or a very strong motor, both of which required an increase of system weight and cost. The other issues with using a crank and slider is that linkages such as a crank and slider are mostly designed for reciprocating motion, not motion that is held in a certain position. Furthermore, this design is very sensitive to changes in the relative location of the mat. Since it relies on a solid stack to create the applied force, if the blade were to traverse over a deep groove or imperfection on the table, the cutting force will drop below what is required.

In contrast to these above discussed designs, the piston concept allows for an extremely low cycle time as the pneumatic cylinder can move up and down quickly. The cycle time can be further reduced with the purchase of a 4-way solenoid. Furthermore, the pneumatic force is not sensitive to height imperfections on the table and can be adjusted using a valve. The availability of shop air already in use on the splice table increase the ease on integration. GAF's familiarity of the Parker pneumatic cylinders makes them a great candidate for implementation into this design.

4.8 Alignment Concepts

The automated splice operation requires the fiberglass mats to be in the correct position at two instances during the process. First, prior to the cutting process, the mats need to be parallel. Second, after the cut, the mat needs to be pulled to a point to achieve the desired overlap of 4 inches The following discussion describes the proposed alignment fixtures that would accomplish these tasks..

4.8.1 Trough

In this design, the table has a trough with the exact width of the fiberglass mats. During the process, the mats would exist within the recess and thus be fixed to be parallel. The advantages of this design include the absence of mechanical and electrical components. That being said, the edges of the trough could interfere with the cutting and gluing operations and are not able to be moved out of the way. The trough would also not be adjustable in size as it is cut into the table. The trough concept can be seen in Figure 4-12.

Figure 4-12: Trough Alignment Method

4.8.2 Piercing

For the piercing design, the gantry includes a series of pins that can pierce the top mat and move it into the correct position. This design is compatible with different mat sizes. However, the design is only able to adjust the placement of the top mat. The design also requires the gantry to detect the position of the top mat thus necessitating the inclusion more electrical and mechanical parts.

4.8.3 Printer alignment

In this design, the table assembly includes adjustable edges. These edges align the mats in the same way printer trays can align different sizes of printing paper. The positions of the edges can be adjusted manually before operation by mounting the alignment edges in slots. The design requires limited modification of the gantry. An example of this design concept is seen in Figure 4-13.

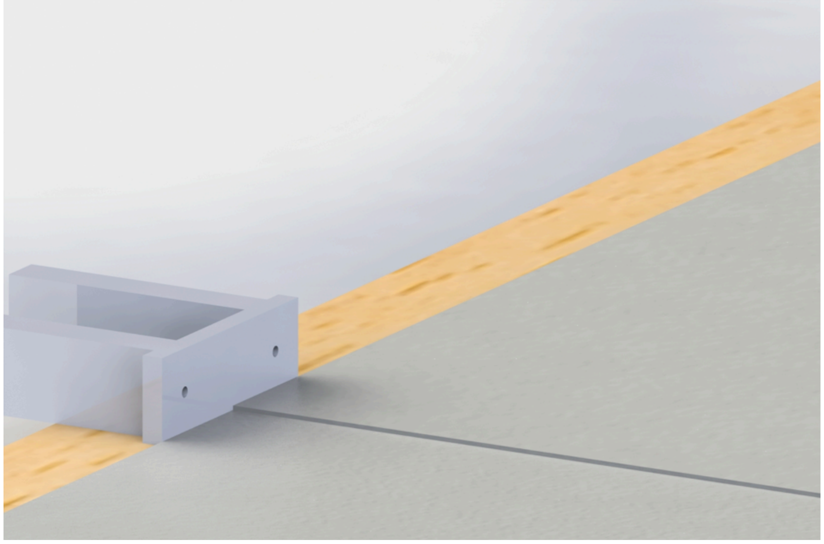

Figure 4-13: Printer Alignment

4.9 Alignment Design Selection:

The design specifications used to evaluate the alignment fixtures are identical to those already defined in the report. The decision matrix for the alignment fixture is given in Appendix E. From this decision matrix, it was determined that the printer alignment fixture is best suited for the design challenge. After consulting with the contact from GAF, it was concluded that position alignment can be achieved visually within the specified tolerance. As the printer mechanism achieves the parallel alignment most simply and allows for the adjusting for different mat widths, it was deemed the most successful give the design specifications. The gravity design would require modifying the whole gantry.

4.10 Cut Detection Concepts

Seeing that our design project will not be the last set of improvements to the splice table, we need to account for future developments that may include complete hands-off operation. One feature necessary for full automation is error detection. Error detection allows the system to stop and correct itself if it failed to perform the previous step. One design feature we will implement in regard to error detection is cut detection, in which our goal is simply to confirm that the assembly performs a thorough cut through the fiberglass mat. The ideation process led to concepts that utilize sensors to work with the existing Allen-Bradley ControlLogix PLC that is in use by the past senior project.

4.10.1 Vision System

Vision systems are frequently used in industrial automation systems and can be implemented in a variety of ways. Edge detection is a common implementation and allows our system to look for an edge or gap between fiberglass sheets, which the presences of which confirms that the mat has been cut all the way through. This is seen in Figure 4-14. Cognex Corporation, a major producer of machine vision products, sells products that give users "unprecedented flexibility to solve vision applications that rely on accurate edge detection."[5] The issue with using edge detection for our design is the narrow gap produced by cutting the mat. The width of the gap will be defined by the width of the cutting mechanism we use.

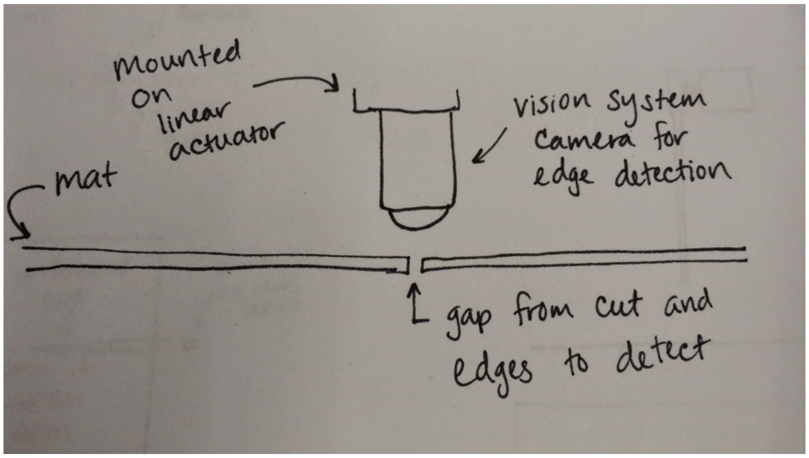

Figure 4-14: Vision System Diagram

4.10.2 Limit Switch

Limit switches are inexpensive and simple mechanisms that are used to detect movement of a lever arm. Our design for cut detection drags the arm behind the cutter and through the cutting path. The arm rotates or deflects if it catches a part of the mat that was not thoroughly cut and sends a signal to the PLC indicating the failed cut. While limit switches are inexpensive and easy to implement, our implementation of dragging the arm through the cut may require a small groove beneath the cutting path for the switch arm to travel through. Including the groove in the table may not be possible depending on the cutting method. The diagram of the limit switch is seen in Figure 4-15.

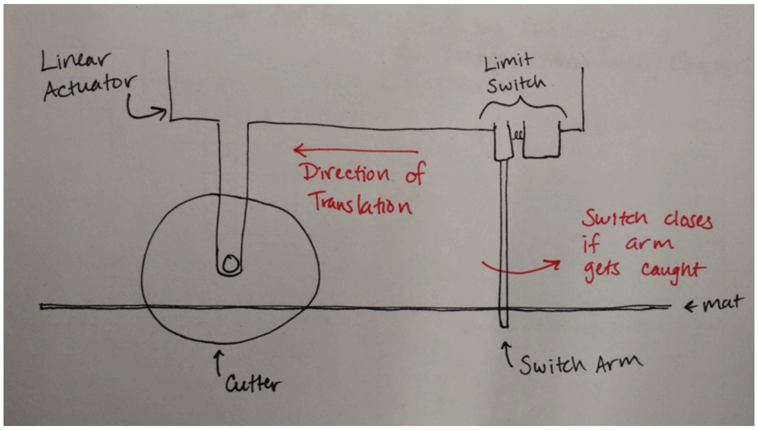

Figure 4-15: Limit Switch Diagram

4.10.3 Capacitive Sensor

Another way to confirm the cut is to make sure there is a path of direct electrical contact between the fiberglass sheets. For example, as seen in Figure 4-16, if the cutting blade makes contact with the table, it would have had to cut all the way through the fiberglass sheets. One method to detect this contact is through capacitive sensing. One issue with this sensor is that, while the electronics will be relatively inexpensive, we will need to redesign the cutting table to include a capacitive sensor. This can make the design too costly and difficult to implement.

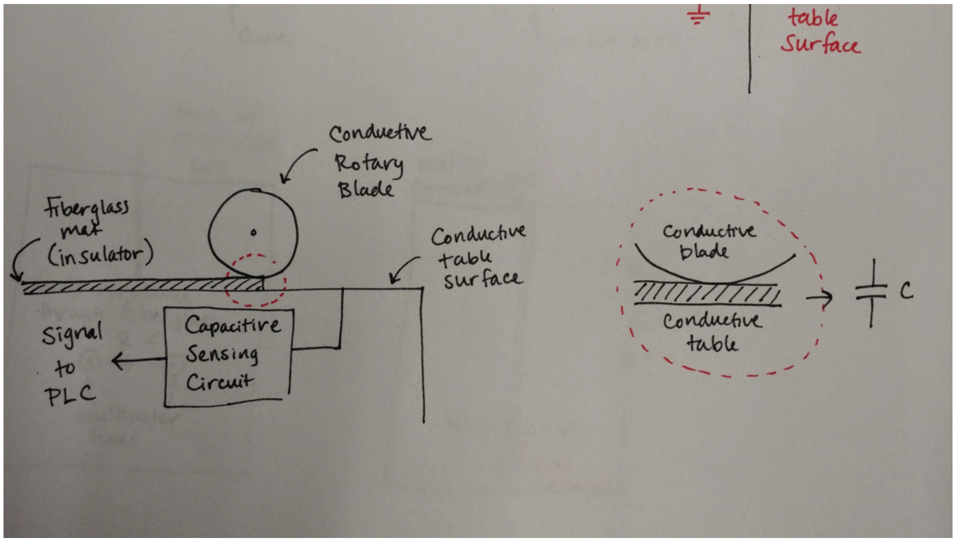

Figure 4-16: Capacitive Sensor Diagram

4.10.4 Light Source + Sensor

Another optical method of cut detection is to shine a light or laser under the cut and detect it above the cut. Similar to the capacitive sensor, this checks for a clear path between the fiberglass sheets.

However, similar to the vision system design, the gap between the sheets may be too small for light to pass through. Additionally, we would also have to redesign the table to include a light source, which adds to cost and hurts compatibility with the current splice table. This design is given in Figure 4-17.

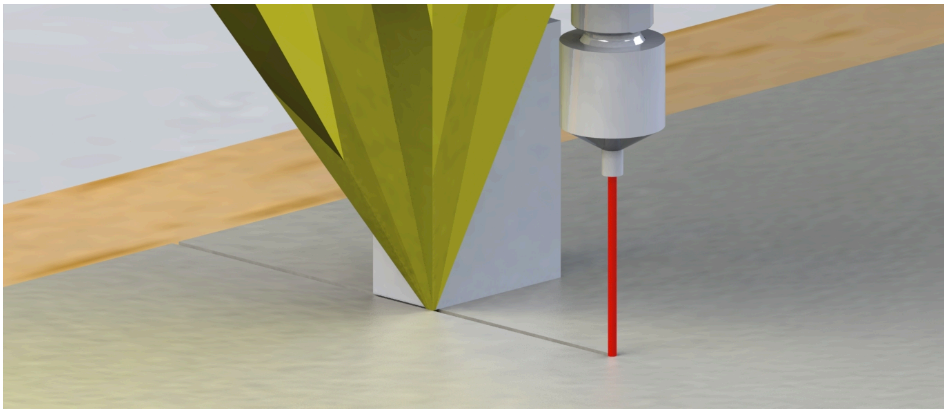

Figure 4-17: Light Detection Design Concept (yellow cone is beam of light from below table)

4.10.5 Fiberglass Impedance Detection

This method, in theory, checks for an impedance discontinuity between the fiberglass sheets. This design will measure the impedance across the cut, where infinite impedance would indicate a gap between the sheets but a finite impedance would mean there is a path through the fiberglass that was not cut, as seen on the right and left of Figure 4-18 respectively. However, since glass is an electrical insulator, measuring the impedance through fiberglass is difficult, which was confirmed through a quick test.

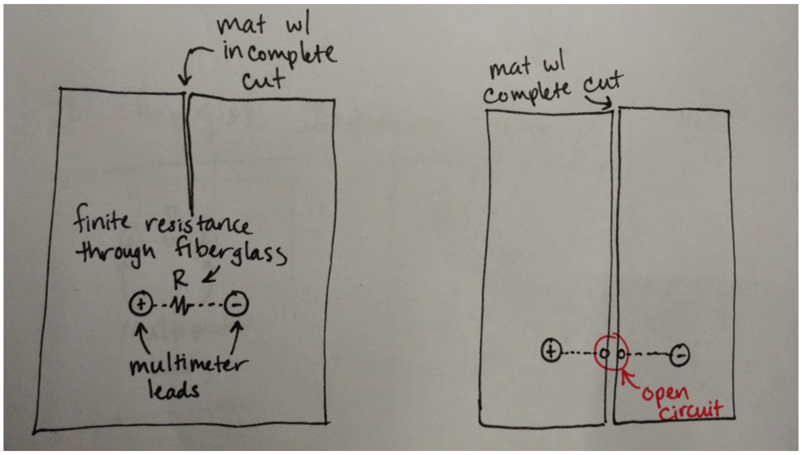

Figure 4-18: Impedance Detection Diagram

4.11 Detection Decision Making

In forming our Pugh matrix, we chose the baseline for comparison to be manual inspection by the operator since this is a new process being implemented with no existing process for comparison. We decided that the vision system, limit switch, and capacitive sensor concepts are the strongest ideas that deserve further consideration. However, since it is not realistic to find a vision system and capacitive sensor setup for quick, preliminary testing, we relied on research to complete the weighted decision matrix. The design criteria included in this decision matrix are identical to those of earlier design evaluations.

While the decision matrix, given in Appendix E, shows the limit switch as the strongest design, the viability of the limit switch is largely dependent on the cutting mechanism used. The limit switch may require a groove beneath the cut for the arm; using the rotary blade as the cutting mechanism may prevent us from including the groove. Therefore, more research into the cutting mechanism and other cut detection methods is still necessary to make a final decision on the best design. Testing will be completed upon the acquisition of the last senior project's assembly from GAF.

4.12 Proposed Assembly and Integration

The final design will incorporate the four above selected components. For the cutting mechanism, we will use a rotary cutter. The rotary cutter assembly will be fixed to the glue gun assembly on the linear actuator. A pneumatic piston will be employed to deploy and retract the cutting blade from the table surface. To confirm that the cutting process is successful, either a limit switch or a vision system will be mounted to the gantry as well. To maintain alignment of the mat, sliding brackets will be attached to either side of the table. Once the parts are fabricated and compiled, given approval from GAF, the entire assembly will be integrated onto the existing table and be used for production. Figure 4-19 gives a representation of the final table assembly.

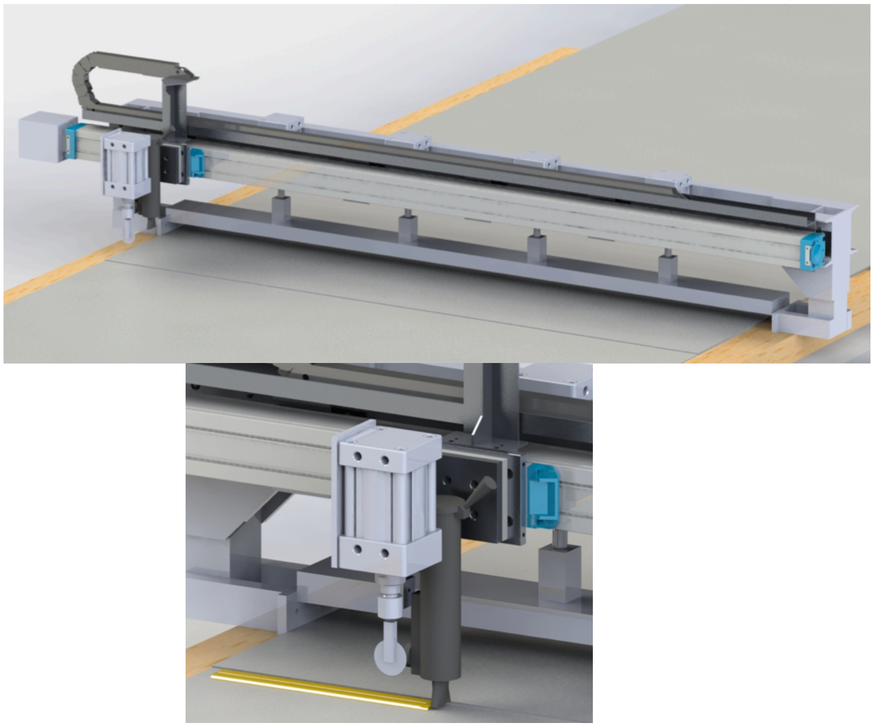

Figure 4-19: Complete Proposed Splice Table Assembly (looking downstream toward the accumulator)

Revisiting the design specifications, the primary goal of the project is to eliminate the need for two operators during the splicing operation. As mentioned in the introduction, the second operator is required because one operator is not capable of reaching over the width of the mat to complete the cutting and gluing operation. The combined assembly of this project and the previous senior project will be capable of performing these individual tasks, thus achieving the design goal of reducing the process to a single operator. As to the other design specifications, the final assembly will have ample safety components designed in to protect the operator from pinch points and the exposed blade. The safety features will be developed further and presented in the Critical Design Review. Furthermore, the inherent consistency associated with the automation of the cutting, gluing, and pressing operations will likely meet the additional goal of decreasing the instance of splice break.

To integrate this proposed assembly, the splicing process will need to be refined. If last year's senior project was implemented on the production line as-is, there would be a collision between the free end of the mat and gluing fixture. See Figure 4-20.

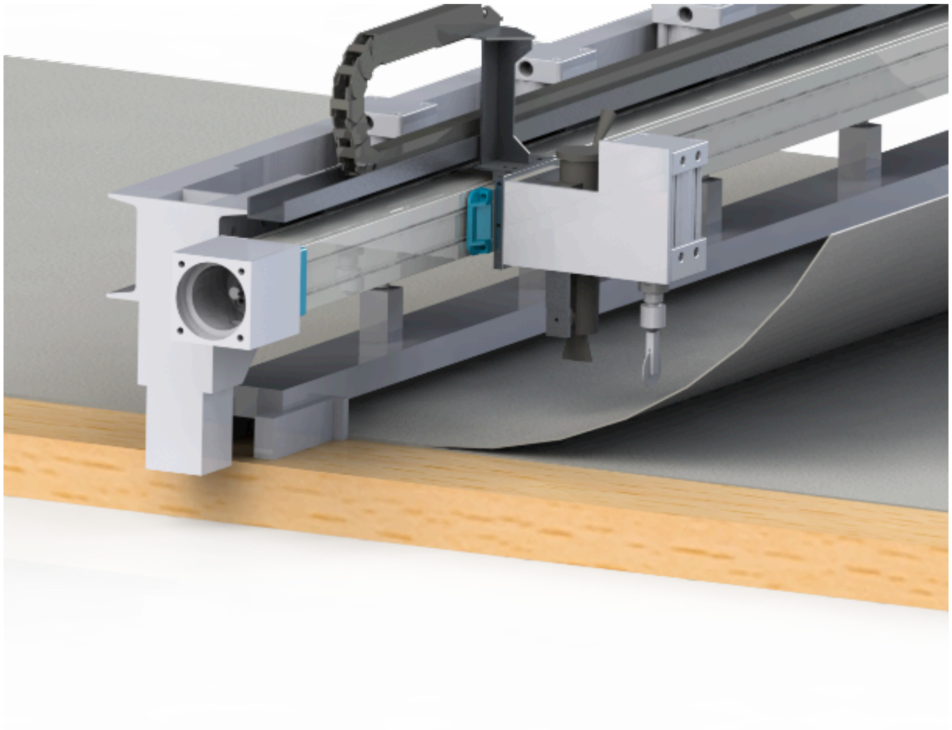

Figure 4-20: Interference conflict of previous senior project

To correct this mistake, the orientation of the splice table will need to be flipped. Currently, the gantry rests upstream of the splice when the operators are cutting the mat. To avoid this interference, the splice location will have to move upstream and the gantry rest location will have to be downstream from the splice. In other words, the operator will lift the upper mat to the right and the gluing fixture will then be able to access the splice from the left. The splice process will change slightly and is discussed below:

1. With the feed still running, the operator will align the new mat to be parallel with the existing mat.
2. After alignment, the brakes will be engaged and the press assembly will be moved into position 1, the cutting position.
3. The operator will trigger the cutting process to begin.
4. After the process is complete, the press assembly will move to the home location and the operator will remove the cut section of the new mat and pull the old mat out from underneath as done in the current process.

5. The operator will then use the alignment fixture again to feed the new mat 4 inches into the overlap position.
6. While the mat is lifted away, the press will move back to position 1 and the operator will trigger the gluing process.
7. The operator will then drop the mat onto the glue and move the press to position 2 for pressing.
8. The operator will trigger the pressing process.
9. The operator will release the brakes thus completing the process.

5 Final Design

The Preliminary Design phase of the project concluded with our Preliminary Design Review presented to the pertinent teams at GAF. Ron K'Miller (point of contact) approved our design concepts and authorized further development of the proposed idea. Upon this approval, the critical design phase of the project began. The critical design phase culminates with a complete design and assembly of the proposed solution. The following sections detail the critical design process as well the management plan for integration if approval is granted.

5.1 Overall Design Description

Per the recommendation of GAF, the following design proposal encompasses two different possible designs: one design encompasses an off-the-shelf cutting mechanism manufactured by Dienes Corporation and the other employees a custom cutting mechanism. Besides the cutting mechanism, and the associated fixtures, the designs are the same. The complete design assemblies are provided in Figure 5-1, Figure 5-2, and Figure 5-3.

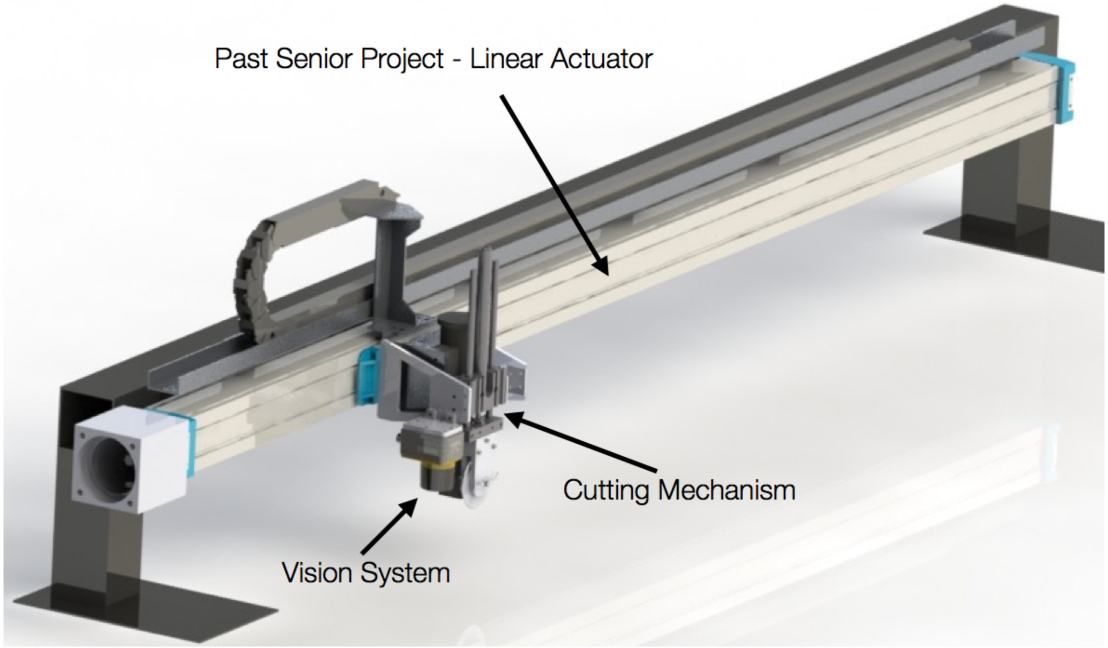

Figure 5-1: Complete Assembly of Proposed Design (featuring Cutting Mechanism Option 1)

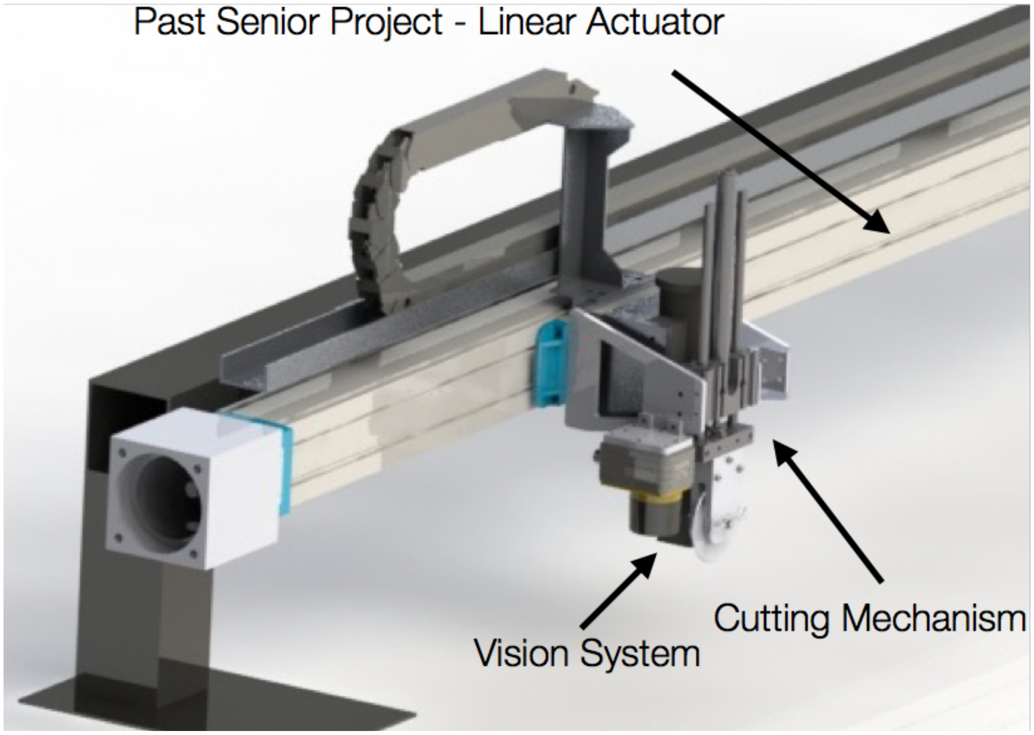

Figure 5-2: Cutting Mechanism Option 1 Assembly

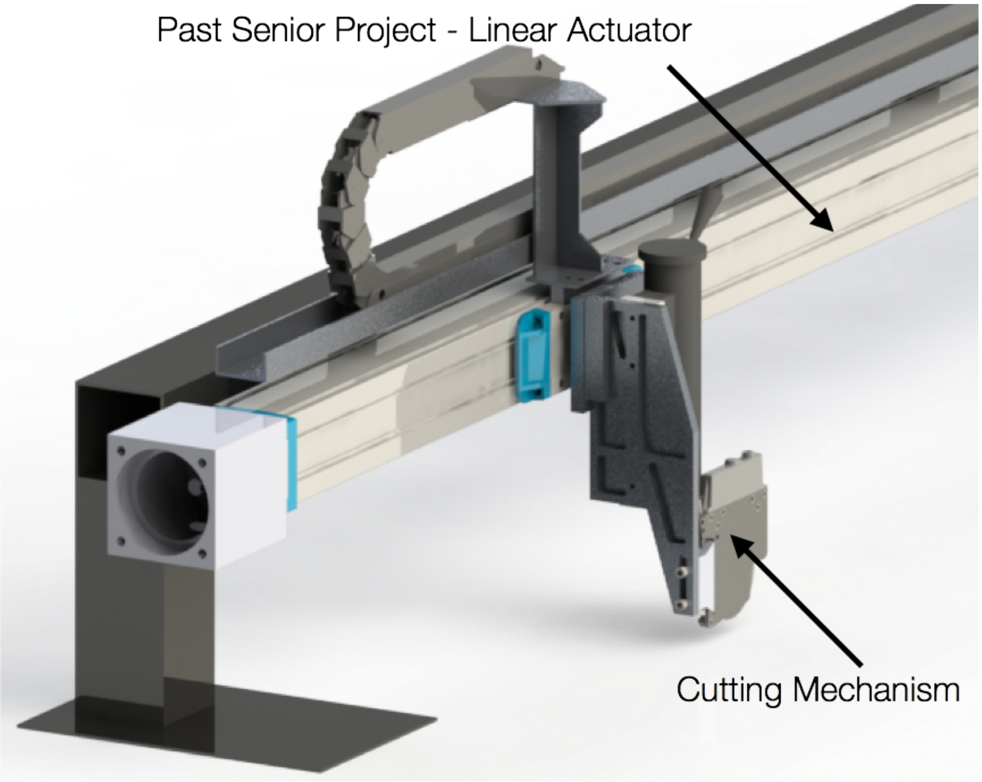

Figure 5-3: Cutting Mechanism Option 2 Assembly

As can be seen in the above figures, our proposed designs are comprised of the following main components.

- Cutting Mechanism
- Vision System
- Past Senior Project
- Alignment Fixture

The design and analysis of these components is discussed in the following sections.

5.2 Detailed Design Description

5.2.1 Cutting Mechanism – Option 1

A company that specializes in crush cutters is Dienes Corporation. Dienes offers a variety of crush cutters assemblies that combine a rotary blade and a deployment mechanism into one module; this is exactly what we proposed as a design solution in our Concept Design Report. Based on the design constraints of minimizing mass and needing 10lbs of actuation force, the Dienes PQAS ½” Holder was selected.

Figure 5-4: Dienes PQAS ½" Holder Source: www.dienesusa.com

The Dienes cutter, seen in Figure 5-4, is comprised of a 3.03" blade with a piston assembly that actuates the blade. The cutter is fixed to a machine through the use of a dovetail interface. The blade actuation has a stroke length of .625" and is able to apply up to 90lbs of force. Due to the high integrity of the design, the manufacturer states that the cutters function well in high particulate environments and are capable of continuously cutting fiberglass mats. This disadvantage of this blade, and the motivation for the second design, is that the stroke length is short. This short stroke length will require the blade assembly to exist, at maximum, .625" away from the table surface. This lack of clearance is alarming as it increases the chances of the blade crashing against the table surface when traversing on the actuator. In other words, it only requires a small object to be left on the table to disrupt the path of the cutter and potentially cause the part to fail.

Moving forward with the design, a custom dovetail part connects the Dienes cutter to a bracket. This assembly is given in Figure 5-5. A setscrew secures the cutter to the dovetail and two ¼-20 screws attach the assembly to the supporting bracket. The dovetail will be machined from aluminum to reduce weight.

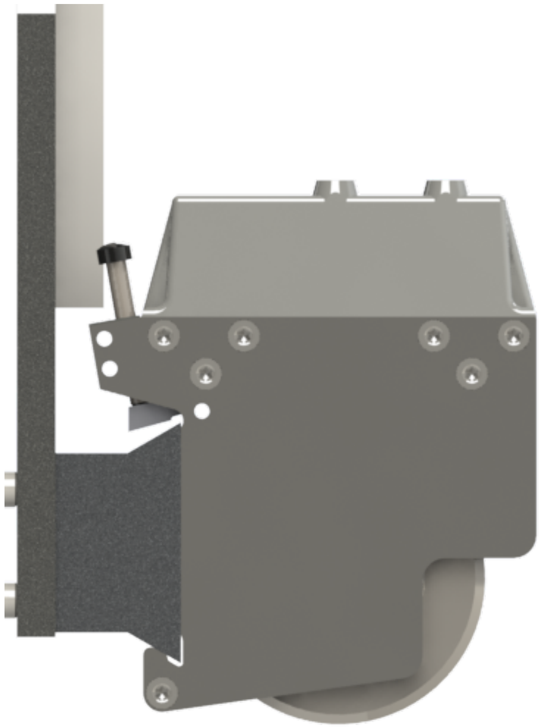

Figure 5-5: Dienes Cutter with dovetail mounting scheme.

The dovetail interface created a challenge when designing the supporting bracket because the interface only extends off of one side. This constraint made it so that there is no simple way of supporting the blade from both sides; two sided supports would eliminate the “cantilevered beam” loading case that can be seen in Figure 5-5. Thus, the bracket that connects the blade assembly to the actuator was designed to be able to withstand the cantilevered loading case. Furthermore, as discussed in section 4.12, to make it so that the press only needs to move to one unique location to complete both the cutting and gluing operation, the support bracket needs to mount the blade assembly two inches away from the center of the gluing nozzle (the glue bead should exist at the center of the specified four inch overlay). The resulting bracket is given in Figure 5-6 below.

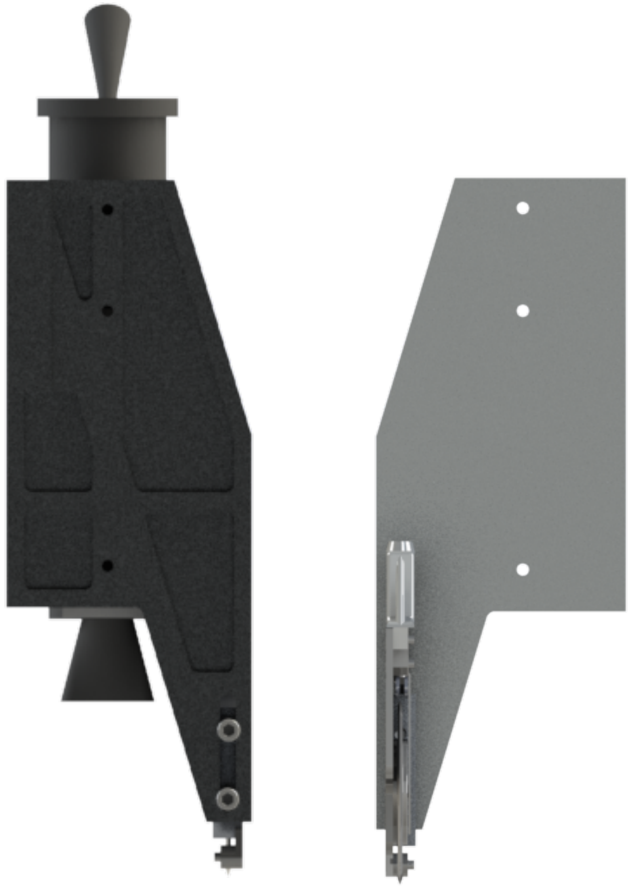

Figure 5-6: Supporting bracket for Dienes blade assembly.

The bracket is made of out aluminum and employs a truss like design to translate the cutting load to the actuator. Pockets are machined out of one side of the bracket to reduce weight while still relying on continuous back plate to transfer the shear load to the mounting holes. This bracket serves a dual purpose as it replaces the existing glue-gun support bracket of the last senior project as well as supports the cutting mechanism. This combination reduces the number of components on the design, thus reducing the overall weight and complexity. The bracket employs the same mounting scheme as the previous senior project's mounting scheme: the bracket is secured to the actuator via two 5/16-24 screws and the glue gun is secured to the bracket using two screws. An isometric view of the total assembly is given in Figure 5-7 below.

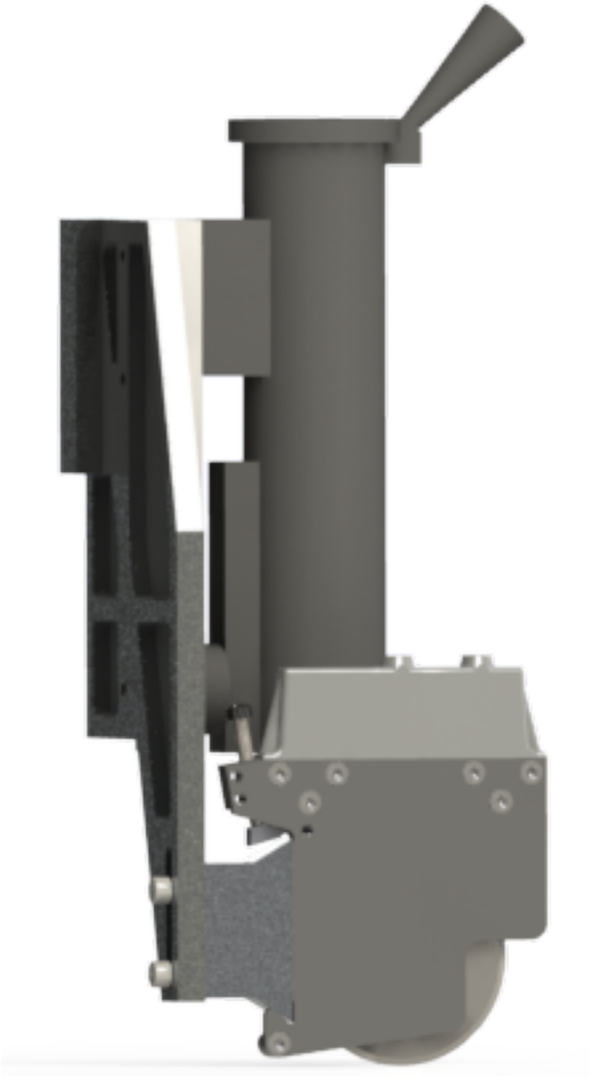

Figure 5-7: Complete Cutter-Glue Assembly

5.2.2 Cutting Mechanism - Option 2

The primary design goal of Cutting Mechanism-Option Two is to increase the clearance between the blade and the table when the blade is not being used. This is accomplished through the use of a custom blade holder, a pneumatic linear guide, and a support bracket to secure the components to the actuator. The assembly is given tin Figure 5-8 below.

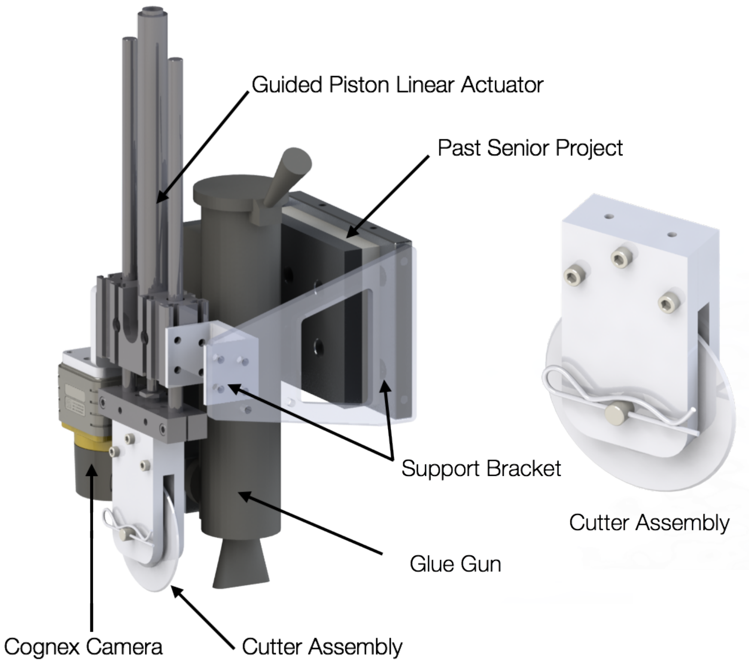

Figure 5-8: Cutter Mechanism Option Two Assembly

The custom "Cutter Assembly" is comprised of a two-part fork, a rotary blade, a bearing, and a dowel pin. The blade for this design is manufactured by Dienes. The blade has a 3.03" outer diameter and a 22mm inner diameter. Dienes offers blades made of a variety of materials. The material of the blade will be selected after wear testing is completed. With that being said, a representative from Dienes has recommended the D2 tool steel blade material as it lasts considerably longer than their standard model when cutting fiberglass. The dimensions of the blade are standard within the company and thus designing for a variety of blades materials is possible. The advantage of selecting a blade from Dienes is that their blades are designed to have a bearing press fit into the inner diameter. The alternative to press fitting a bearing into the blade is rigidly attaching the rotary blade to an axle that is in turn supported by two brackets on each extreme of the axle. This two-bearing alternative increases complexity and the overall size of the fixture and was thus not pursued.

Figure 5-9: Cutter fork assembly.

An exploded view of the fork assembly is given in Figure 5-9 above. It was designed to allow for easy blade maintenance. Removing the three #8 socket head cap screws allows an operator to remove the blade-bearing assembly. The pin will have a slight interference fit with the stationary side of the fork assembly and a close fit with the removable side. The bearing will also be press fit onto the pin. The bearing is a No.608 Double Sealed Metric Steel Ball Bearing for 8mm Shaft Diameter. The bearing is rated to 730lb dynamic load and 30,000rpm max rotational speed; both of these metrics are well beyond the 10lb and about 200rpm expected loading case. Furthermore, the bearing is double sealed to account for the high particulate environment. In conversations with professors on campus, this double seal was considered properly seal the bearings from fiberglass particles. The pin, the cotter pin, and the bearing will be ordered from McMaster Carr.

The two #8-32 threaded holes on the top of the fixture will secure the assembly to the linear guide. The three screws that secure the two parts of the fork together were placed off axis to better withstand any bending moment that might be imparted onto the fork. The part will be made out of aluminum and machined on Cal Poly's campus.

For the sizing of the linear guide, we found that the critical design criteria is being able to apply force onto the table without doing damage to the Thompson linear actuator. This led us to find the maximum amount of force that could be applied at the table. From calculations that will discussed later in the analysis section, the maximum force that can be applied is 17.98lbf. This limited the size of piston that we can use. Because of the technical standard requirements by GAF, all cylinders are required to be Parker pneumatic cylinders. With the selection of Parker brand cylinders, the sizing options were limited as there are not many large stroke, low force actuators. The sizing of the actuator was completed so that weight was minimized.

With all of these selection criteria in mind, the XLT06-06 pneumatic cylinder was used because of its larger width in order to fit inside the mounting brackets. Even with the larger XLT06-06, the force at 80 psi actuation was 31lbf, double the amount allowed. In order to meet this pressure, we will reduce the pressure at a regulator. We will start at a lower pressure and increase the pressure until a consistent extension, cut, and retract can be done. The weight of the system is also 1.83lb, well within our operating parameters. As we were not concerned with the velocity of the guide, the retraction and extension acceleration analysis is not needed.

Two brackets on the side support the linear guide. These brackets are also design to reduce weight by employing a truss system: the thick members of the bracket follow the load line of the part. Unlike the first bracket, these brackets have the middle hollowed out as the use of two brackets prevents any torsional buckling. Lastly, to bridge the gap between the linear guide and the piston, a C-bracket will be machined out of existing C channel or billet.

5.2.3 Camera Assembly

As discussed above, there will likely be another senior project that will follow this project that makes improvements to the splice table with the goal of achieving complete automation. One feature necessary for full automation is error detection. Error detection allows the system to stop and correct itself if it failed to perform the previous step. One design feature we will implement in regard to error detection is cut detection, in which our goal is simply to confirm that the cutting assembly performs a complete cut through the fiberglass mat. The ideation process led to concepts that utilize sensors to work with the existing Allen-Bradley ControlLogix PLC that powers the past senior project. At the conclusion of our preliminary design phase, we were advised to explore two options for cut detection: limit switches and vision systems.

Limit switches are inexpensive and simple mechanisms that use the motion of a lever arm to complete a circuit that sends a signal to a controller. Our design for cut detection would drag a lever arm behind the cutter and through the cutting path; a rough sketch of the concept is available in Figure 4-15. In this application, the arm rotates or deflects if it catches a part of the mat that was not thoroughly cut and sends a signal to the PLC indicating the failed cut. While limit switches are inexpensive and easy to implement, our implementation of dragging the arm through the cut would require a small groove beneath the cutting path for the switch arm to travel through; the alternative design would be relying on a small finger to slip underneath the mat at the start of each cycle.

Vision systems are frequently used in industrial automation systems and can be implemented in a variety of ways. Edge detection is a common implementation and allows our system to look for an edge or gap between fiberglass sheets; the presence of this gap confirms that the mat has been completely severed. Cognex Corporation, a major producer of machine vision products, sells products that give users “unprecedented flexibility to solve vision applications that rely on accurate edge detection.” One main concern with using a vision system for cut detection is finding a camera that can detect the small gap between the sheets after cutting. The rotary blade used for testing had a width of 0.010”, so we estimated this as the width of the gap for the purposes of proof of concept testing. Another complication is the non-uniform texture of the fiberglass mats. This makes the surface visually complex and difficult for the edge to be seen.

We first explored Cognex vision system because of their reputation within industrial applications of vision systems. After consulting with Cognex representatives, we were able to find a product that can locate the 0.010” gap between the fiberglass sheets. Samples of fiberglass sheets were delivered to their facility for testing. The sheets were cut and distanced 0.010” apart. The camera used for this test was the In-Sight 7402 vision system and was placed 22” above the fiberglass sheets. The model is available in Figure 5-10 and the data sheet is available in Appendix J.

Figure 5-10: Cognex In-Sight 7402 Vision System (Source: cognex.com)

The results for this test can be seen in Appendix J. Another important result from this test is the time to take the picture and process the data. The software reported the time to be 0.0 ms, meaning that the system took less than 50 µs to detect the edge. For our purpose, this near-instantaneous feedback will allow us to take immediate action to fix the cut. Given the time constraint of the splicing process, any errors while splicing will need to be resolved as soon as possible. The output of the In-Sight 7402 vision system is a 24V DC signal that is high/low depending on the absence/presence of the edge. The DC input module currently in our PLC, an Allen-Bradley 1756-IB32 ControlLogix DC input module, has a nominal input voltage of 24V, meaning that the camera will be able to communicate with the PLC.

After reviewing our cut detection concept with the GAF team, they recommended looking into sensors from IFM Efector, Inc. Looking into their vision system products, we found a 2D pattern match / contour sensor system that can be used for edge detection. However, after presenting our application to the technical sales representatives, we learned that this sensor would not be able to detect the 0.010” gap with the non-uniform texture, nor do they have a product that will perform this task.

We decided to move forward with the Cognex In-Sight 7402 vision system for our cut detection process. From the tests with fiberglass samples, we are confident that this vision system gives us a reliable method to confirm the fiberglass mat cut and will allow us to quickly reverse the cutting mechanism to complete the cut. We will implement the vision system by mounting the camera on the linear actuator to have it trail the blade as it cuts the fiberglass. This assembly is available in Figure 5-11 below.

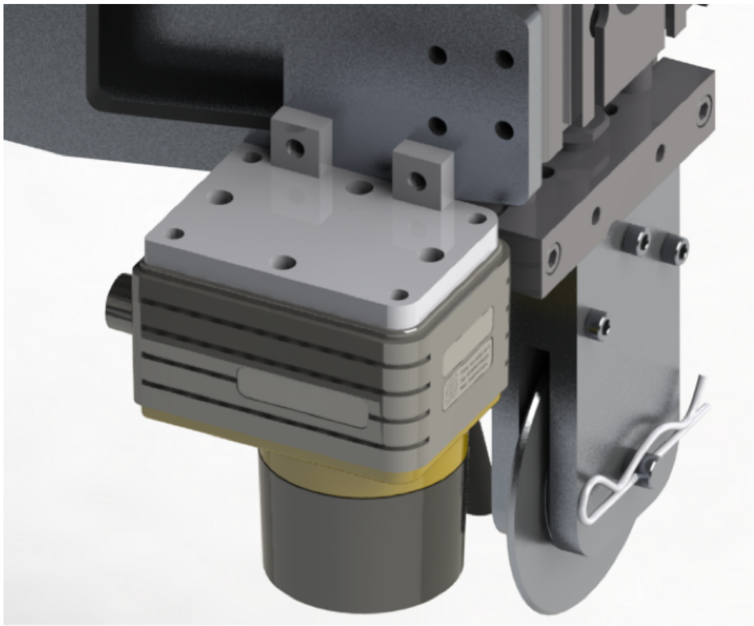

Figure 5-11: Cognex Camera assembly on the custom cutter

The servo used for driving the linear actuator uses an encoder to track its position, which we will utilize to have the camera take a picture at intervals that allow it to analyze the entire length of the cut.

5.2.4 Alignment Mechanism

Initially, the printer alignment was designed to fit onto the press plate and ride with the gantry. This would make the alignment fixture mobile and prevent the alignment sections from interfering with the rest of the splice operation. However, the design would require the alignment fixture to drag across the table. This design relies on the alignment plates making contact with the table surface; if the fixture does not touch the table, the thin sheets of fiberglass mat will slip below the alignment brackets. The current table has an uneven wood surface and even the final splice table will experience scratches and wear from the moving fiberglass mats. The press alignment was replaced with an alignment fixture mounted underneath the table. The proposed printer alignment mechanism is available in Figure 5-12 below.

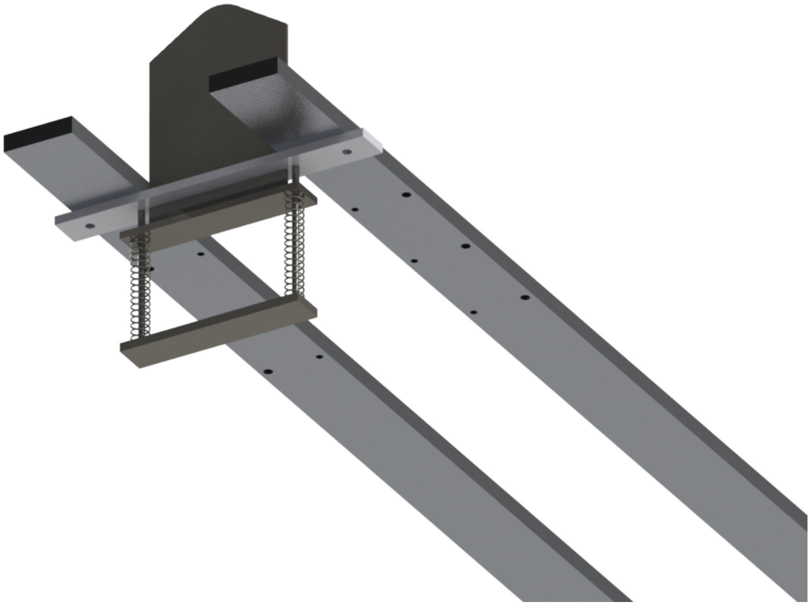

Figure 5-12: Proposed Alignment Mechanism – Bottom View

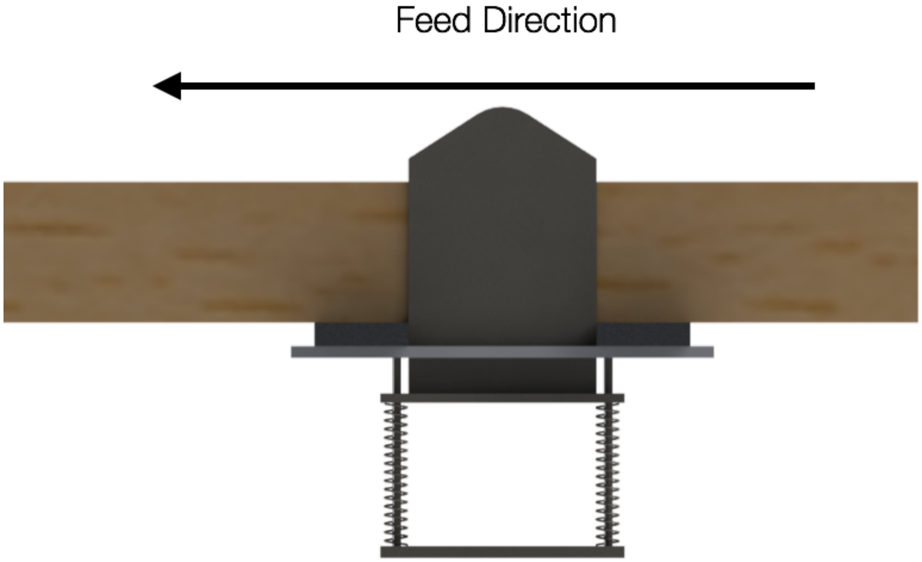

Figure 5-13: Proposed Alignment Mechanism – Side View

The table mounted alignment features two 4” long steel guides protruding from slits underneath the table. The guides are located between the location of the cutting operation and pressing operation.

While the operator's side of the table will have only one slit for mounting the alignment section, the other side of the table will have several slits. Each slit will be located so that the alignment will work for the various widths of fiberglass mats used by GAF.

The guides will be spring mounted under the table so that if the press is accidently deployed over the guides, they can retract beneath the table unharmed. The press will pass over the alignment guides frequently, so the guides will extend 1" above the table and have 0.25" clearance between the top of the guides and bottom of the raised press.

The guides will be constructed out of predominantly steel. The base of the guide will be machined from stock bar that is cut to length. The top of the guide will be made from sheet metal. The two pieces of the guide will be welded together. The weld will be 4" long and simple enough that the senior project team can complete the welds using material from the Hanger located on Cal Poly's campus.

5.3 Analysis Results

To verify to the performance of the proposed assembly, the following analysis was completed based on critical components and functions:

- Bracket Mechanical Failure
- Thermal Sensitivity
- Actuator Loading Limits
- Safety Considerations
- Computer Integration

5.3.1 Bracket Mechanical Failure

The largest component of each of the proposed designs is a support bracket that connects the blade mechanism to the actuator. These brackets were designed to be as light as possible while still being able to withstand the load of the cutting action. As mentioned in section 4.4.1, preliminary concept testing revealed that only about 3lbs is required to cut through two sheets of fiberglass mat. As the bracket should be designed for any impact load that it might see during use, we changed our design criteria to designing a bracket that can withstand a 50lb load parallel to the direction of axis of the actuator. This 50lb load reflects loading cases such as someone bumping into the assembly or the assembly catching on something that is left on the table; the load is likely five times more that what we expect to see during the cutting process.

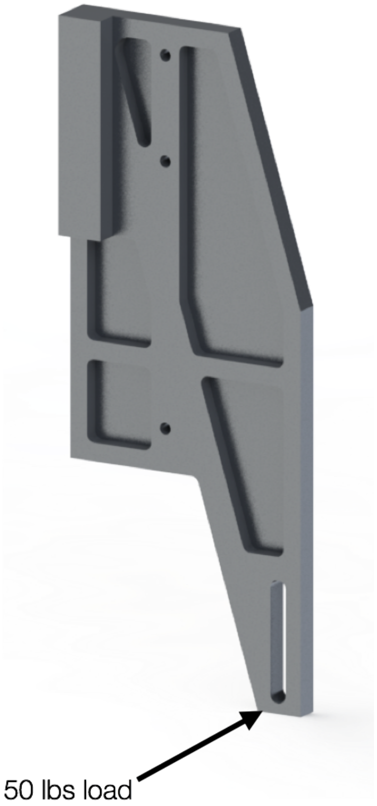

Figure 5-14: Design load for bracket design

Two methods were used to analyze each of the brackets: simplified beam calculations and finite element analysis.

For the Dienes cutter assembly (the bracket in Figure 5-14), the largest variable was the thickness. To determine this, the bracket geometry was simplified down to be a beam that was 11" long and 1" wide with a variable thickness. The maximum stress would be a result of the bending stress at the support location (shear stress was ignored due to its relative insignificance). With this conclusion, the stress can be calculated using the following formula:

$$\sigma_{max} = \frac{F * L * t}{\frac{1}{12} w * t^3}$$

Where F is the design load, t is the thickness of the plate, w is the width, and L is the length. As the bracket will be machined from aluminum, the yield strength to be designed for is 40,000 psi.

Table 5-1: Bending stress for different plate thicknesses for the Dienes Cutter Assembly (the bracket is assumed to be a simple rectangular beam)

Parameters	Plate Thickness					
Thickness (in)	0.5	0.41	0.4	0.3	0.2	0.1
Length (in)	11	11	11	11	11	11
Height (in)	1	1	1	1	1	1
I (in^4)	1.04E-02	5.74E-03	5.33E-03	2.25E-03	6.67E-04	8.33E-05
Max Deflection (in)	0.20	0.37	0.40	0.95	3.20	25.60
Max Bending Stress (psi)	13200	19631	20625	36667	82500	330000
FOS	3.0	2.0	1.9	1.1	0.5	0.1

Using the above equation, the minimum thickness was determined to be 0.41” while maintaining a factor of safety of 2. Since the part will be machined from a stock plate, the thickness was reduced to .4”. This factor of safety was confirmed using the finite element analysis function in solid works. Sample calculations for the numbers in Table 5-1 and the FEA results are available in Appendix G. In sum, for the loading case of 50 lbs, the conservative beam-bending calculations concluded a FOS of 1.9 and FEA predicts a FOS of 2.57; both numbers are adequate in proving the structural rigidity of the bracket.

For the custom cutter assembly, a similar analysis was done. The design moment was applied on two of the brackets. The sectional properties of the two parts were found inside SolidWorks. Using engineering judgment, we found that the weakest point in the structure was along the thinnest cross section points, where material was pocketed out of the part as seen in Figure 5-15. This was then confirmed with FEA analysis. The cross section of this point was then analyzed to ensure that part would be well below yielding.

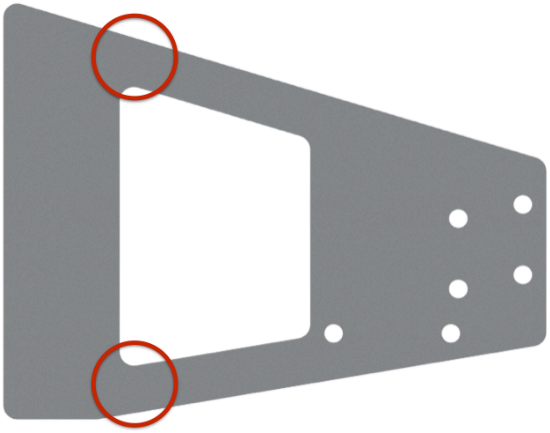

Figure 5-15: Custom cutter bracket critical points

From the FEA and the conservative calculations, the FOS from yield was determined to be 2.5 and 3.1 respectively. Both of these metrics confirm that the fixture will adequately be able to within stand the process loads.

5.3.2 Thermal Sensitivity

To effectively prepare the glue beads for the splicing process, the glue gun must be maintained at around 450°F. This temperature is above the suggested operating temperature of some of the components of the proposed cutting assembly. The past senior project group designed the gun support bracket such that the actuator would not see a bracket temperature of above 100°F; we will use this as our design temperature as well.

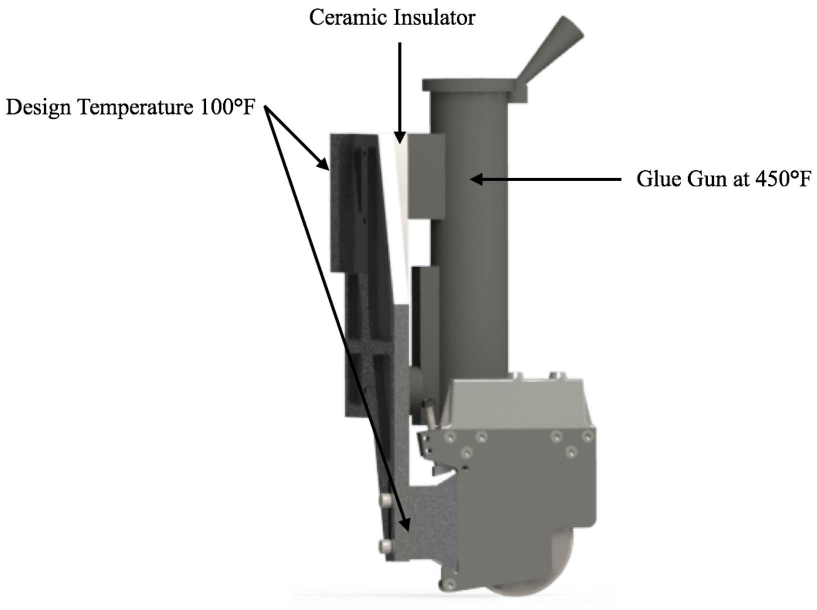

Figure 5-16: Design temperatures for thermal sensitivity analysis

This design temperature is below the specified operating temperatures of 230°F for the ball bearing and the Dienes cutter and 250°F for the linear guide. To determine if the bracket would effectively insulate these components from the gun temperature, a thermal resistance network was assembled. This thermal resistance network and the associated calculations are available in Appendix H. To know the temperature of the bracket with absolution, the power input of the gun must be quantified. As this information was not available, we first looked at the resistance of convective heat loss versus conduction. From the thermal resistance network, it was determined that the thermal resistance of convection is 54x less than that of conduction. This is a result of the extremely insulative ceramic block selected by last senior project's thermal studies (seen in the new assembly in Figure 5-16). Thus, because there is such a large difference in the thermal resistance, it is assumed that the majority of the heat loss will be through natural convection, which will not represent a threat to the actuator or other components.

To confirm this, an additional study was completed with the thermal resistance network. If it is assumed that the gun operates at 450°F and the actuator interface is 100°F, the temperature at the point between the bracket and the ceramic plate can be calculated. Using EES, this intermediate temperature was calculated to be 103°F. Since this intermediate temperature is so low, it confirms that the bracket will not exist at a large temperature differential between the two geometric extremes of the bracket. This proves that the insulating ceramic can contain the large temperature difference necessary to protect the components.

Not considered in this study is radiation. This is because we are assuming that conduction and convection will dominate the heat transfer network. Furthermore, if radiation is an issue, it will be easily fixed by surrounding the heat gun with a thin Mylar blanket. This will be tested once we get the entire assembly together after approval. In sum, the vast majority of the temperature differential will be contained in the ceramic block and thus the bracket and the surrounding components will stay within a safe operating limit.

5.3.3 Weight Considerations

The motor and the linear guide were selected with the intention of actuating the glue gun and all of its components. However, now that the design includes the cutting mechanism, the forces that are applied to the linear guide have increased. The analysis presented in Appendix I shows the spreadsheet that was designed in order to ensure that we are still within the design limits of the actuator purchased from the last senior project.

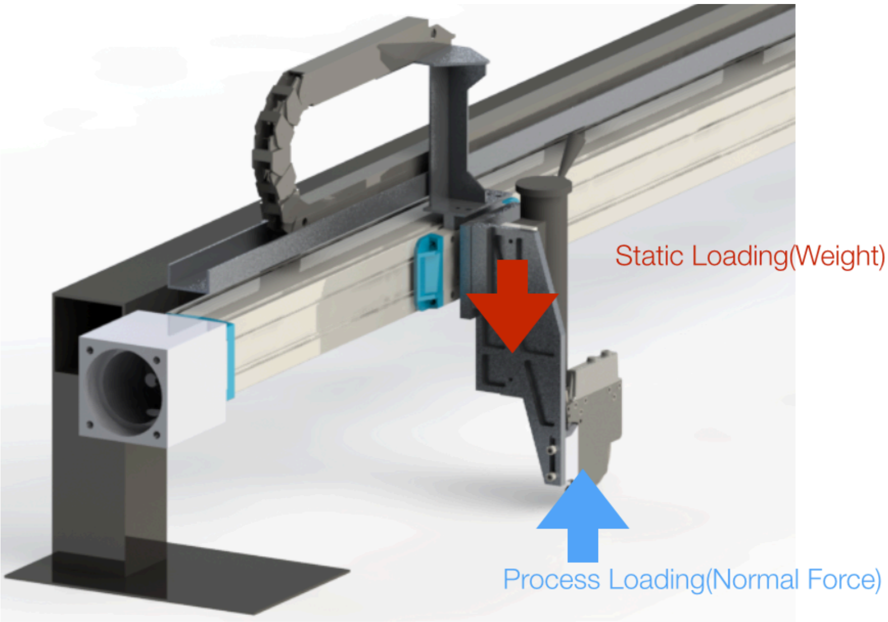

Figure 5-17: 3D free body diagram of loading on actuator drive screw

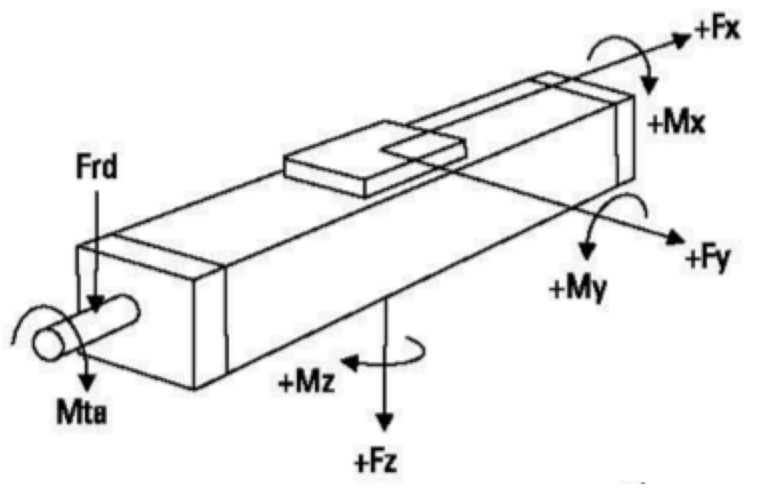

Figure 5-18: Loading Diagram provided by Thomson

Through a free body diagram (Figure 5-17), we determined that the most concerning load would be the moment about the axis of the slide (M_x in Figure 5-18) and the transverse forces to the slide (F_y). Given the performance specifications provided by Thomson (available in Appendix C) we calculated the force and moment couples created for both static loading and process loading cases (air pressure off and air pressure on, respectively).

To determine the moment and forces on the linear actuator, center-of-gravity, distances, and weight measurements were gathered from SolidWorks and added to the Tables in Appendix I. These moments were then summed and compared to the maximum allowable moment provided by Thomson. Furthermore, a remaining weight was calculated. This remaining weight would be the amount of weight that could be added to the linear guide a certain distance away without surpassing the loading limit. All of these calculations were done with a safety factor of 1.5 on top of the manufacturer’s safety factors built in to the published performance specifications.

For the process loading cases, static conditions were still assumed. However, when the cutting force is added to the FBD (normal force in Figure 5-17), more loading is permitted, as the cutting force creates a moment in the opposite direction of the weight. In sum, the driving factor for further design is reducing the moment about the x-axis of the linear guide, as the safety factor for transverse force over 20. With both of the proposed cutting designs, we are able to still exist above our design factor of safety of 1.5. If further components need to be attached to the mechanism, such as a heat shield or a safety guard, these tables will be used to guide the weight and center of gravity of the addition components.

5.3.4 Safety & Maintenance Considerations

A few notes have to be made regarding the safe operation of the proposed assembly. First, the actuator requires 480 V to run. GAF is already familiar with the safety risks associated with 480V as it is in use at many places around the splice table already. With that being said, the computer module has a transformer lock on it; this lock is to be connected with the existing lockout/tagout system already installed at GAF so that no unqualified person is able to turn on power to the machine.

Second, the traversing of a 450°F glue gun can represent a significant risk to operators. Thus, until the time that the system achieves complete automation, the existing thermal personal-protection-equipment should continue to be worn by the technicians on the production line.

Lastly, the inclusion of a blade into the design introduces hazards to the operator. Since, by design, the operator will not be leaning over the table while that operation is being completed, we do not see a need to any large safety mechanism. If GAF requests a safety mechanism, we will use sheet metal to create a box around the blade that pushes potential interferences out of the way while the blade is traversing.

In regard to maintenance, the only component that we foresee degrading during use is the blade. Both of the designs allow for the blade to be easily swapped out so this is not a concern. It is recommended that GAF has two of the blade assemblies on hand at all times so that the modules can be replaced on the production line quickly. In other words, if GAF purchases two Dienes slitter assemblies, it will be very easy for an operator to replace the entire module through the one set screw, thus allowing production to continue.

5.3.5 Computer Integration

To further grasp the code required to detect the cut and the associated corrective action, a flow chart of the code structure was developed. This flow chart is available in Appendix L, alongside the overview schematic of the complete box.

5.4 Cost Analysis

A complete cost analysis is available in Appendix M. The proposed design sums to a total cost of either $3,275 or $3,166 for the design including the custom cutter and the Dienes cutter respectively. The Cognex camera represents the largest expense.

6 Design Verification Plan

The following section details the critical testing that will be completed once the assembly is completed. A complete table of the testing plan is available in Appendix N. Additionally, to ensure safe operation during testing, the Safety checklist, which has been approved by the campus electrician, is available in Appendix Q.

6.1.1 Failure Modes and Effects Analysis

A Failure Modes and Effect Analysis (FMEA) was first completed to allow for the determination of possible failure modes of the assembly and the suggested corrective action. This FMEA table will be revisited once testing begins to look at corrective action for different failure modes.

6.1.2 Blade Traverse Speed and Application Force Testing

Two sets of tests will be completed in order to determine the maximum travel speed of the actuator and the optimal application force of the actuator. Because the accumulator at the production facility only lets feed be paused for 45 seconds, we will design the code to force the actuator to traverse the fiberglass mat as quickly as possible without compromising cut quality. This number will likely be directly connected with the actuation force of the assembly. Thus, a 2^2 testing bracket will be designed to determine the optimal speed and actuation force.

6.1.3 Blade Material Selection

Dienes offers multiple blade materials that can be used in their slitter assemblies. Thus, with the permission of the sponsors at GAF, we plan to order multiple blade materials as test their resistance to wear and how wear effects cut accuracy and consistency. Ideally, there is a blade material that can remain sharp through a month of use. Since the fiberglass is such an abrasive material to cut, this application will likely call for a harder material than usually specified by Dienes. This testing will reveal which blade is best to use.

6.1.4 Program Testing

In order to get the code running properly, Kevin will run trials on testing software that is available. Once the program is running as intended, testing will have to be done to determine the time interval between successive shots of the cut detection system. This will ensure that the entirety of the splice is being checked for cut failures.

7 Manufacturing & Management Plan

Both of the proposed cutter designs and their associated components were designed with the manufacturing processes in mind. Most parts are off the shelf and can be ordered from either McMaster-Carr or Dienes. However, the custom brackets do require in-house manufacturing; the in house machining will be completed by the team members and will not represent an expense of the project. For these parts, the material of choice for all parts is Aluminum 6061-T6 because on its superior machinability, strength to weight ratio, and availability. Although cost can be reduced with sheet metal parts, last year's senior project group designed some components with sheet metal that ultimately were replaced with block aluminum due to concerns expressed by our sponsors at GAF.

Because members on the team have experience with CNC machining, the support brackets, c-channel bracket, and dovetail will be CNC machined on the Industrial and Manufacturing Engineering Department Haas-VF2. These parts have been designed for manufacturing so setup is simple: all proposed designed are single setup machining which means that they can all be machined from one side. Support brackets will be machined on the table of the VF-2 and the remaining parts will be able to be fitted on a vice. Only simple drills and end mills will be used, therefore no special tooling will be required. All parts ran on the CNC will be programmed in either HSMWorks or Mastercam. For the manual parts, again, no special setup is required. All parts can be mounted inside a vice. The schedule for the process is available in Appendix P.

In order to successfully execute a solution to the given design requirements, each member of the team has been assigned specific roles. These roles are summarized in Table 7-1 below. While each member will be the point person for their described role, all team members will contribute to all aspects of the project where qualified. Following the project roles, Table 7-2 gives timetable of events that will involve the sponsor. In addition to these events, we will continue to meet with GAF on a regular basis to keep all parties updated on the manufacturing process.

Furthermore, an updated Gantt chart is available in Appendix P. This Gantt chart has enabled the team to more accurately plan and structure the development of the project. In addition to the project deliverable due dates, the Gantt chart lists the tasks that remain, as well as an estimation of their timeline. As the project progresses, we will update the Gantt chart as necessary and notify GAF of any changes.

Table 7-1: Project Responsibilities

Name	Role/Responsibility
Grant Haug	Communications: Main point of contact with GAF and responsible for scheduling and facilitating meetings
	Testing Design: Establish and benchmark testing plans for new concepts and designs
Michael Mooney	Treasurer: Oversee all expenditures for travel, materials, and supplies
	Solid Modeling: Compile and Manage all 3D models
	Controls and Automation
Ronald Lam	Recording weekly progress for the project
	Manufacturing: Oversee realization and fabrication of all prototypes
Kevin Lansang	Documentation: Organize project files, documents, and sources of information; Record meeting minutes
	Controls and Automation + Electrical Interface

Table 7-2: Project Timeline

Deliverable/Activity	Due Date
Project Proposal	2/2
Concept Design Report Due to Sponsor	3/5
Concept Design Review	By 3/13
Critical Design Report Due to Sponsor	5/1
Critical Design Review	By 5/8
Prototype and Test Plan Review	5/29 (tentative)
Progress Report	6/5
Design Expo	11/20
Final Design Report	12/1

8 Product Realization

8.1 Critical Design Review Updated

The above detailed designs were presented to GAF at the end of Spring Quarter 2015 in a critical design review. During this review, it was determined that the assembly that utilizes the Dienes Cutter, "Option 2," is the best design. This design was selected for its simplicity and modularity. In conjunction with the critical design review, conversation with Cognex continued regarding the functionality of the camera vision system within this application. Due to a lack of significant evidence that the vision system can actually detect a failed cut, it was decided that the vision system represented too much of a risk for how expensive it was. As cut detection is still a critical portion of the design, this group transitioned to a design that uses a limit switch to detect a failed cut. Due to the extremely narrow width of the cut, it was concluded that a mechanical switch is the best approach for this application. Thus, the final manufactured design is presented in Figure 8-1 and Figure 8-2 below.

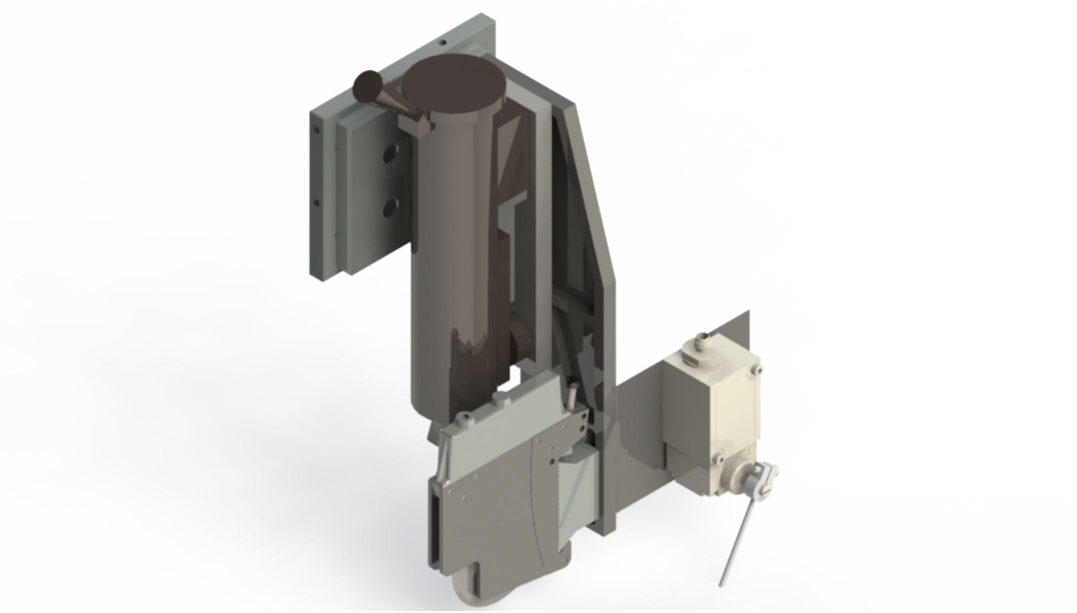

Figure 8-1: Final design including limit switch and reversed geometry

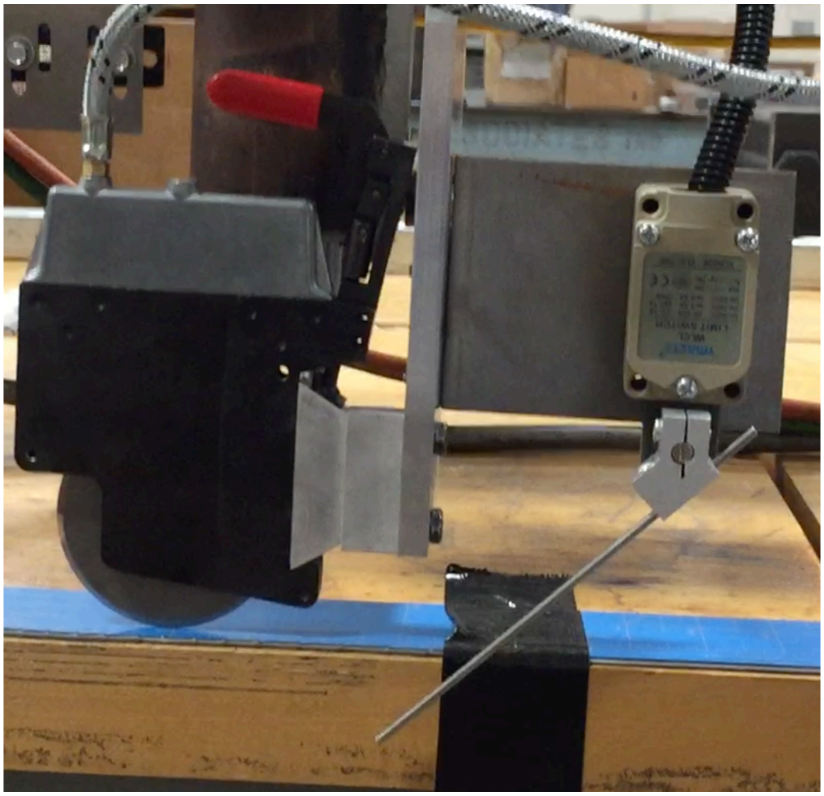

Figure 8-2: Final assembly including limit switch and geometry reversal

Lastly, during the critical design review meeting, it was determined that the alignment mechanism proposed would not work in this application. All ideated alignment mechanisms relied on the assumption that a physical barrier can make contact with the mat while the mat is being fed into the production line. However, this group learned in the critical design review meeting that it is not possible to touch the mat when it is moving. While this group attempted to redesign the alignment mechanism to meet the criteria that it cannot touch the mat, the conclusion was reached that an alignment mechanism would require the ability to pick up and move the mat to the correct location. To complete this requires the ability to move along the length of the table, which the actuator does not provide. Thus, the alignment mechanism will have to be incorporated into the next senior project whose main goal is to automate the movement process of the splice operation. As alignment is currently done visually by the operator, the lacking of an alignment mechanism does not disallow the implementation of the current design.

8.2 Manufacturing Methods

While we prioritized the use of stock parts for the final design, some elements of the fixture needed to be machined from 6061-T6 Aluminum and sheet steel. The major bracket, shim block and dove tail were made from the stock aluminum and the L-bracket was made from sheet steel.

8.2.1 Main Structural Bracket

The main structural bracket was machined on the CNC Mill in the IME advanced machining lab. In order to produce an effective part, the bracket needed all datums to be located properly. Furthermore, due to the long dimensions of the part, the fixturing needed to be stiff in order to avoid a situation where the entire plate would flex. This flexure could become drastic because of the large 11-inch dimension and the uneven pocketing throughout the part.

Figure 8-3: CNC Machining of the main structural Bracket in the IME Lab on a Haas CNC

If the part were to be machined without any consideration for its flatness, the part would easily flex from the internal stresses within the part. In order to combat this flexure in the CNC milling process, low stress machining practices were used. The part was flipped multiple times in order to ensure that part would be able to relax after machining. Also, the part needed to be supported more than usual in order to reduce the stresses in the part. As seen in Figure 8-4, a 3 jaw setup was used in order to ensure that the center would not flex. These practices, along with using good machining practices, allowed the bracket to be used as a locating component for the blade and limit switch.

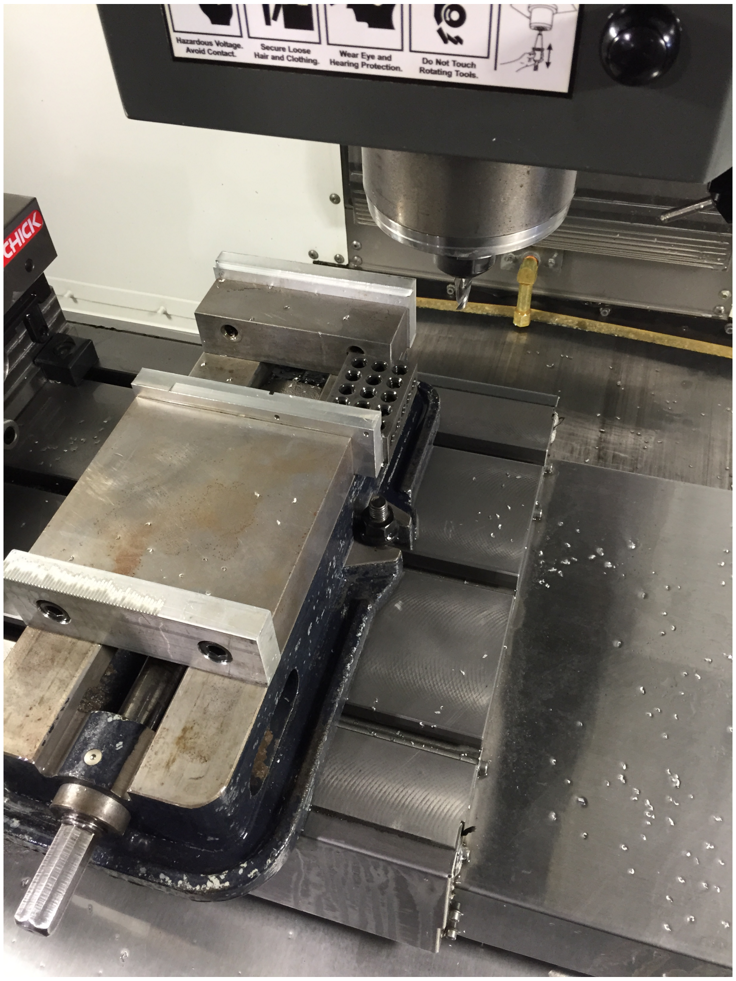

Figure 8-4: Three jaw support fixturing of the main structural bracket

8.2.2 Dove Tail and Shim Block

A simple manual mill was used to produce the final shim block and dove tail. For early an prototype made for cut testing, the shim block was made from wood and dove tail machined from aluminum. To produce the final shim block, a few facing operations were completed to get the stock part to the correct dimensions, and then the through holes were drilled. Flatness on this part was critical, so extra care was taken to ensure that the fixturing did not allow for any slop.

The dove tail was manufactured similarly to the shim block. The initial rectangular shape of the dove tail was created though a few facing operations on a mill. The through holes are drilled and tapped on the mill as well. After the holes were completed, the angled sides of the dove tail were made using a grinder. The proper angle was achieved by frequently running fit checks with the dines cutter. We found that the grinding method produced a better fit than machining the dove tail at an angle, as two parts were made with these methods.

8.2.3 Limit Switch L Bracket

The sheet metal L bracket used to secure the limit switch to the main bracket went through a few iterations. The iterations were motivated by material changes and changes in the desired mounting location of the limit switch. All iterations of the bracket were made using the IME metal working lab in building 192. The final part was made from 16-gauge steel. This steel was both thick enough to provide enough stiffness, as well as thin enough to be manufacturing using the available tools. The part was first cut to shape using a powered shear. The holes were then manufacturing using a hole punch (Figure 8-5) by first using a 1:1 drawing to properly locate the holes with a center punch. A corner shear was then used to add clearance for the near by screws. The part was then completed using the banding press.

Figure 8-5: Hole punch aviaable in the IME metal working lab used to create the limit switch l-bracket

8.2.4 Recommendations for Future Manufacturing

For future iterations of the project, a coating should be applied to the steel L bracket to prevent any potential corrosion. It is also recommend that the main structural bracket be anodized to provide an additional layer of protection. To improve the accuracy of the limit switch bracket, the holes can be drilled on a mill prior to bending. With that being said, the location of the limit switch, within reason, is not critical, and the current bracket will adequately serve the function.

9 Design Verification

The previous senior project assembly was delivered to Cal Poly at the end of spring quarter. Due to the utilization of 480V, many safety checks had to be completed to ensure that the machine was safe for use. Thus, design verification testing began in Fall Quarter.

As mentioned above, the testing plan incorporates tests that would allow the team to determine the optimal piston piston pressure, travel speed, and cutting material. Thus a full factorial with three replications was designed for use in this optimization. Table 9-1 details the design of experiment.

Table 9-1: Design of experiment Main effect levels for cutting surface, blade pressure, and travel speed

Parameter	Settings
Blade Actuation Pressure	15, 25, 35 psi
Travel Speed	10, 15, 20 ft/s
Cutting Surface	Cutting Mat, Steel Plate
Total Number of Trials	54

Due to the lengthy process of the machining phase for the main support bracket, a prototype bracket was employed to locate the blade in the correct position. To make this bracket, holes were drilled into a 12” x 9” aluminum plate in the same locations, relative to the mounting holes, as the main support bracket. A views of this bracket and the testing setup are available in Figure 9-1 and Figure 9-2. In order to accurately compare each trial, a scoring system was developed for the success of the cut. The possible options for the test score were 0, .25, .5, .75, .9, and 1. A 0 was awarded if no evidence of a cut attempt was noticed. A .25 was awarded if the top sheet was partially cut but not severed. A .5 was awarded if the top sheet was completely severed but the bottom sheet was unaffected. A .75 was awarded if the top sheet was completed severed and the bottom sheet was partially cut. A .9 was awarded if almost everything but a few strands of fiberglass were severed. Lastly, a 1 was awarded for a successful cut. The data table for this testing is available in Appendix R.

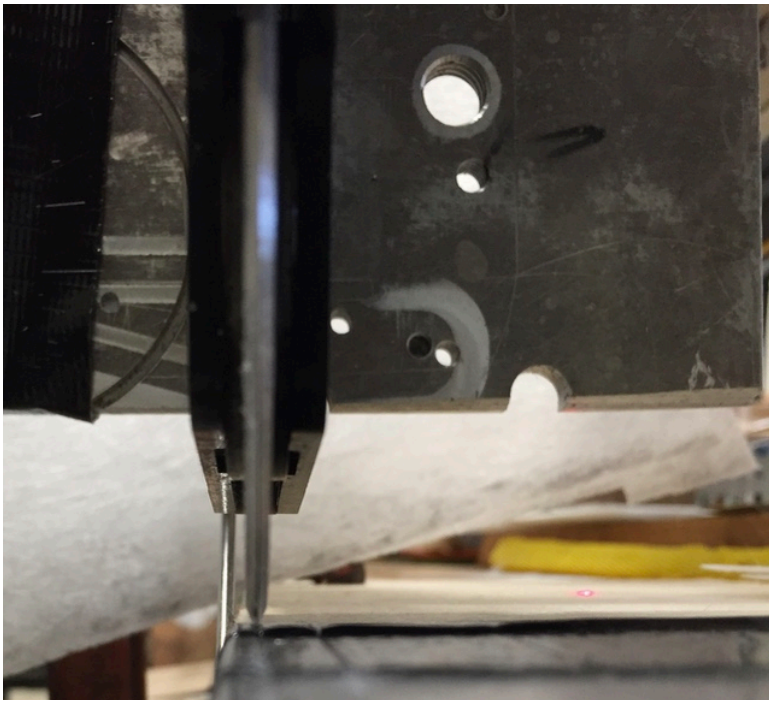

Figure 9-1: A view of the testing bracket setup looking in the direction of the axis of drive screw.

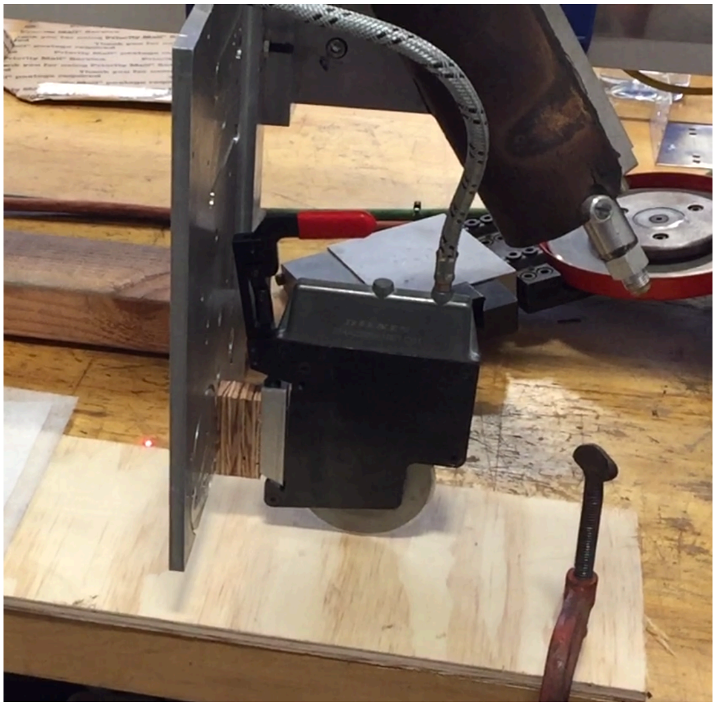

Figure 9-2: Testing bracket prototype for design validation testing

9.1 Testing Results

To analyze the results of the test, an ANOVA test was completed using Minitab. From this test, it was determined that the only significant factors in the test were cut pressure and an interaction between speed and cut surface material. An interaction plot was generated to see if there were any visual interactions between the main effects. The interaction plot is available in Figure 9-3.

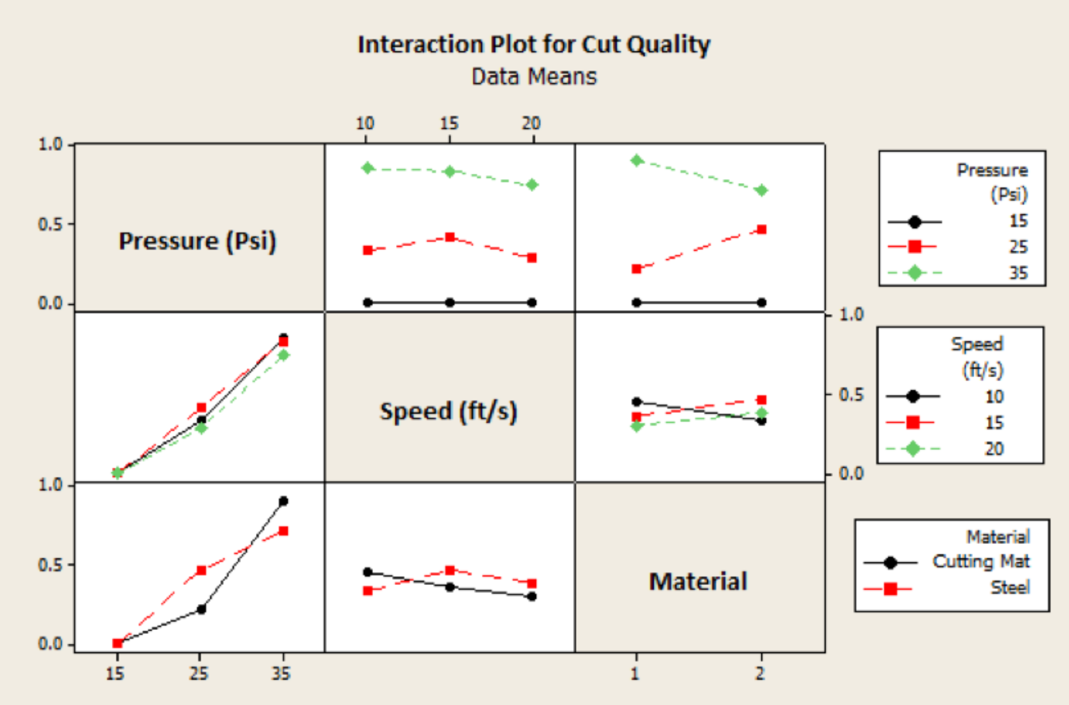

Figure 9-3: Interaction plot of the main effects of the design verification testing

From this testing, it was determined that speed had no significant effect on the cut performance. As a result, it was concluded that utilization of the maximum tested cutting speed of 20ft/s is the best option. As to pressure, to repeatedly cut the mat, 35 psi pressure is recommended. Lastly, because the cutting mat showed better performance at high pressures, it was selected as the best option for the cut surface. Since cutting mat is made out of an ultra high molecular weight polyethylene, a relatively soft material, the selection of this material eliminated the accelerating wearing concern of the blade. Over the course of nearly 150 cutting trials, no noticeable wear or degradation in cut quality was noticed. Thus, in summary, recommended cutting parameters are available in Table 9-2.

Table 9-2: Recommended parameter levels based on testing results

Parameter	Recommended Setting
Blade Actuation Pressure	35 psi
Travel Speed	20 ft/s
Cutting Surface	Cutting mat (UHMW PE)

In conjunction with this testing, the code was configured to properly perform the necessary actions. In order to integrate the new components for the cut cycle and cut detection, the programmable logic controller (PLC) required modifications to the software and hardware wiring. As previously discussed, the 2014 GAF Senior Project team utilized an Allen-Bradley ControlLogix system to control a linear actuator with software that executed the automated glue cycle. This team built upon this existing software and implemented a cut cycle before the glue is applied. The cut cycle begins once the operator initiates the splicing process by pressing a button. When all the initialization conditions are met, the controller will then activate the blade solenoid to deploy the cutter. Before the blade is driven across the fiberglass mats, there is a one second delay to ensure the blade is fully deployed. While the cut is in progress, the controller actively looks for a DC input from the limit switch, which happens in the event of a failed cut. At the detection of a failed cut, the servo will stop the blade, reverse 8", then proceed forward to rerun over the cut area that failed. After backtracking, the controller will continue until the end of the mat or until another failed cut is detected. Once the blade completes the cut, the controller will continue with the glue cycle as the system travels back to its home position. To accommodate the new blade solenoid and limit switch input, new connections were established in software and hardware. The new software tells the controller to look for the failed cut input signal at a specific port in the DC input card. The electrical connections between the limit switch and the controller are shown in Figure 9-4. Likewise, a port in the AC output card is now designated to control the blade solenoid.

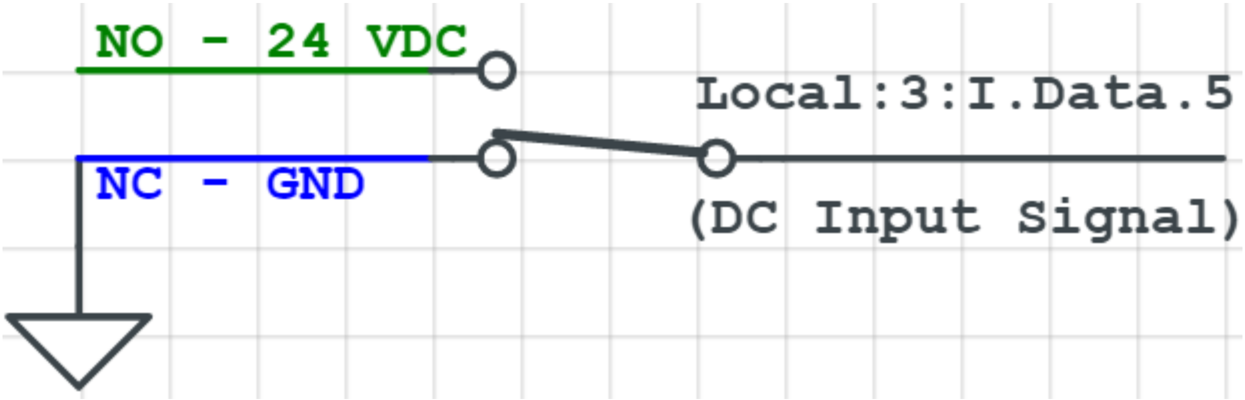

Figure 9-4: Limit Switch Wiring Diagram

Once this cut detection section was added to the code, no cuts were observed to fail and not be corrected by the machine.

In summary, via parameter optimization and many programming trials, the assembly is ready for use by GAF. GAF should use the parameters noted in Table 9-2 once the machine is implemented onto the production line. A completed design validation plan is available in Appendix N.

10 Conclusions and Recommendations

This project was a continuation of a past senior project. The project scope for this iteration of the project was to seek to increase the automation of the splice table by removing the need for operators in the cutting step of the splice process. This was achieved by attaching a rotary cutter to the previous senior project's assembly via a redesigned main structural bracket. Additionally, to ensure the process did not fail, a cut detection element was added so that the computer is able to reattempt the cut in the event of a failure.

Additionally, the project team recommends that GAF continues to work with Cal Poly students on a further iteration of the project that seeks to automate the movement of the press. Once this is achieved, there will no longer be a need for an operator at the splice table. Through a considerable amount of design work, student-completed manufacturing, and testing trials, all functions of the project were proved to be successful. Thus, the assembly is ready to be implemented for use on the GAF production line.

Acknowledgments:

The Shafter Engineering staff was critical to the success of this project. Through their guidance and expertise, this project was able to achieve the point at which it can be implemented on the production line. This project team would like to extend a special thanks to Jeff Munoz, Reuben Cavazos, Ron K'Miller, and Nigel Abraham for their continual commitment to the project.

Appendix A: Bibliography

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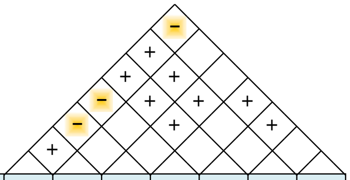
Appendix B: QFD House of Quality

Correlations	
Positive	+
Negative	−
No Correlation	

Relationships	
Strong	●
Moderate	○
Weak	▽

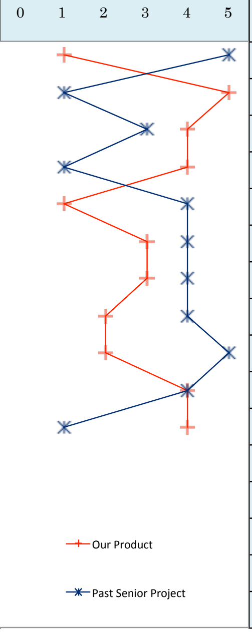
Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼



WHO: Customers

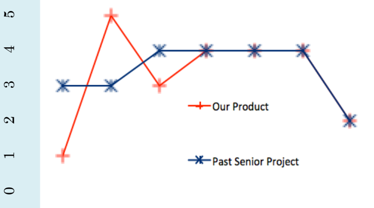
NOW: Current Product Assessment

Row #	Weight Chart	Relative Weight	Production Management	Line Operator			Maximum Relationship	WHAT: Customer Requirements (explicit & implicit) / HOW: Engineering Specifications	Reliance on Operator	Cycle Time	Splice Break Strength	Splice Fixture Size	Mat Placement Location & Tolerance	Splice Cut Quality	Stress on Operator	Current Process	Past Senior Project	Row #
								Column #	1	2	3	4	5	6	7			
								Direction of Improvement	▼	▼	▲	▼	▲	▲	▼			
1		8%	10	3			9	Single Operator	●	▽		○			●	1	5	1
2		11%	8	9			9	Completes Splicing Operation	●	○	●	○		●	○	5	1	2
3		8%	9	4			3	Integration With Past Project	○			○				4	3	3
4		10%	7	9			9	Completes Positioning Operation	●	○	○	○	●		○	4	1	4
5		11%	9	9			9	Process Automation	●	●	○	○	○	○	●	1	4	5
6		8%	9	4			9	Reliable	○		●		○	○		3	4	6
7		12%	10	10			3	Safe Operation				▽			○	3	4	7
8		8%	8	5			9	Splice Break Frequency Reduction			●		○	○		2	4	8
9		9%	6	8			9	Ease of Operation	○	▽					●	2	5	9
10		5%	6	3			3	Ease of Maintenance	▽			○				4	4	10
11		11%	8	9			9	Completes Pressing Operation	●	▽	○				▽	4	1	11
12		0%																12
13		0%																13
14		0%																14
15		0%																15
16		0%																16



	1	2	3	4	5	6	7
HOW MUCH: Target	Yes or No Criteria	Not To Exceed Current Process	Equal To Or Greater than Current Process	Not To Impede Operator Accesibility	Meets Current Tolerance	Visual Inspection Given in SOP	Not To Exceed Current
Max Relationship	9	9	9	3	9	9	9
Technical Importance Rating	528.7	189.5	331.4	170.1	170.8	175.8	358.1
Relative Weight	27%	10%	17%	9%	9%	9%	19%
Weight Chart							
Current Process	1	5	3	4	4	4	2
Past Senior Project	3	3	4	4	4	4	2

Current Product Assessment - Engineering Specifications



Column #	1	2	3	4	5	6	7

Template Revision: 0.9 Date: 4/23/2010
Christopher Battles

Appendix C: Thomson Linear M75 Actuator Specification Sheet

THOMSON
Linear Motion. Optimized.

M75

Ball Screw Drive, Ball Guide

» Ordering key - see page 194
» Accessories - see page 135
» Additional data - see page 182

General Specifications

Parameter	M75
Profile size (w × h) [mm]	86 × 75
Type of screw	ball screw with single nut
Carriage sealing system	self-adjusting steel cover band
Screw supports	number of screw supports to be specified by customer at order
Lubrication	lubrication of ball screw
Included accessories	none

Performance Specifications

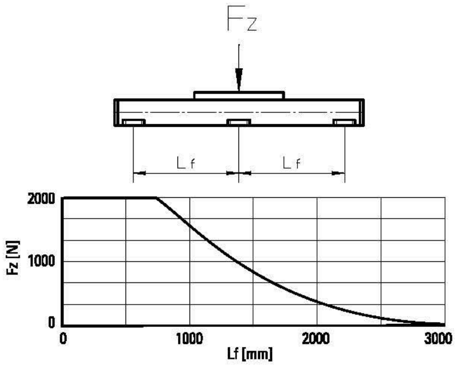
Parameter		M75
Stroke length (Smax), maximum	[mm]	4000
Linear speed, maximum	[m/s]	1,0
Acceleration, maximum	[m/s^2]	8
Repeatability	[± mm]	0,05
Input speed, maximum	[rpm]	3000
Operation temperature limits	[°C]	-20 – 70
Dynamic load (Fx), maximum	[N]	2500
Dynamic load (Fy), maximum	[N]	2000
Dynamic load (Fz), maximum	[N]	2000
Dynamic load torque (Mx), maximum	[Nm]	18
Dynamic load torque (My), maximum	[Nm]	130
Dynamic load torque (Mz), maximum	[Nm]	130
Drive shaft force (Frd), maximum	[N]	600
Drive shaft torque (Mta), maximum	[Nm]	30
Screw diameter (d0)	[mm]	20
Screw lead (p)	[mm]	5, 12,7, 20
Weight of unit with zero stroke of every 100 mm of stroke of carriage of option single screw support of option double screw supports	[kg]	 6,90 1,05 2,50 1,70 3,58

Carriage Idle Torque (M idle) [Nm]

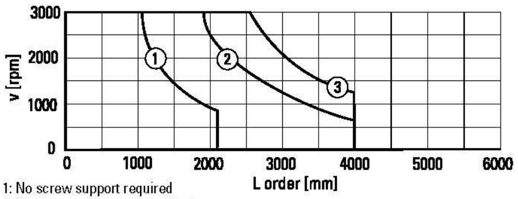
Input speed [rpm]	Screw lead [mm]		
	p = 5	p = 12,7	p = 20
500 - no screw supports	0,04	0,1	0,16
500 - with screw supports	0,06	0,12	0,2

M idle = the input torque needed to move the carriage with no load on it.

Deflection of the Profile

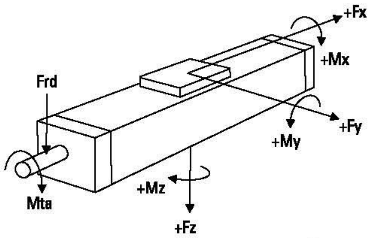


Critical Speed



1: No screw support required
2: Single screw support required
3: Double screw supports required

Definition of Forces



Appendix D: Pugh Matrices

Table D-1: Pugh Matrix - Cutting Mechanism

		Cutting Mechanisms					
		Laser	Pizza Cutter	Hook Knife	Guillotine	Dremel	Hot Knife
Criteria	Cycle Time	+	+	s	+	+	s
	Reliability	-	s	s	+	+	-
	Maintenance	-	s	s	-	-	-
	Safety	+	+	s	-	-	-
	Cost	-	s	s	-	-	-
	Edge Condition	+	+	s	+	+	s
	Cut Quality	+	s	s	-	-	-
	Force Needed	+	-	s	+	+	+
	Integration	+	+	+	-	s	s
	Σ(+)	6	4	1	4	4	1
	Σ(-)	3	1	0	5	4	5
	Σ(s)	0	4	8	0	1	3
	Total	3	3	1	-1	0	-4

Table D-2: Cutter Actuation Pugh Matrix

		Blade Actuation Methods										
		Long Arm				Moving Tool						
		4 Bar Linkage	Gullitine	Cam lever	Wheel	Solenoid	Pinion Gear	4 Bar Linkage or Piston	Belt Drive	Pnematics	Guide Wire	Gravity
Criteria	Cycle Time	+	+	+	+	+	+	s	s	+	-	+
	Reliability	+	+	+	+	+	+	+	-	s	s	-
	Fixture Weight	-	-	+	+	s	-	s	-	+	+	+
	Safety	-	-	-	s	s	s	-	s	+	+	+
	Cost	-	-	-	-	-	-	s	-	s	+	
	Achievable Force	-	+	+	s	s	+	+	-	+	-	-
	Integration	-	-	-	-	+	-	-	-	+	s	+
Σ(+)		2	3	4	3	3	3	2	0	5	3	4
Σ(-)		5	4	3	2	1	3	2	5	0	2	2
Σ(s)		0	0	0	2	3	1	3	2	2	2	0
Total		-3	-1	1	1	2	0	0	-5	5	1	2

Table D-3: Alignment Concept Pugh Matrix

		Alignment Methods					
		Printer	Trough	Pierce	Vibrate	Gravity	Center Alignment
Criteria	Stress on Operator	s	s	+	+	-	s
	Cycle Time	s	s	+	-	-	-
	Safety	s	s	-	-	-	-
	Accuracy	+	+	+	-	+	+
	Cost	s	-	-	-	-	-
	Integration	+	-	-	-	-	-
	Adjustability	+	-	-	+	-	-
Σ(+)		3	1	3	2	1	1
Σ(-)		0	3	4	5	6	5
Σ(s)		4	3	0	0	0	1
Total		3	-2	-1	-3	-5	-4

Table D-4: Cut Detection Pugh Matrix

		Cut Detection Methods					
		Vision System	Light Source + Sensor	imit Switch	Capacitive Sensor	Fiberglass Impedance Detection	Visual Inspection
Criteria	Cycle Time	s	s		s	s	s
	Reliability	-	-		+	-	s
	Maintenance	-	-		-	-	s
	Cost	-	-		-	-	s
	Integration	-	-		-	-	s
	Single Operator	-	+		+	+	s
Σ(+)		2	1		2	1	0
Σ(-)		3	4		3	4	0
Σ(s)			1		1	1	6
Total		-1	-3	1	-1	-3	0

Appendix E: Decision Matrices

Table E-1: Cutting Mechanism Decision Matrix

Cutting Mechanism											
		Laser		Pizza Cutter		Hook Knife		Guillotine		Dremel	
	Weight	Unweighted Score	Weighted Score	Unweighted Score	Weighted Score	Unweighted Score	Weighted Score	Unweighted Score	Weighted Score	Unweighted Score	Weighted Score
Cycle Time	0.2	90	18	90	18	75	15	100	20	90	18
Reliability	0.3	100	30	75	22.5	75	22.5	75	22.5	90	27
Maintenance	0.05	25	1.25	75	3.75	80	4	60	3	80	4
Safety	0.15	50	7.5	90	13.5	80	12	50	7.5	50	7.5
Cost	0.1	25	2.5	90	9	90	9	75	7.5	50	5
Integration	0.1	25	2.5	90	9	70	7	20	2	70	7
Start Edge Condition	0.1	100	10	90	9	25	2.5	100	10	100	10
Total Score		71.75		84.75		72		72.5		78.5	

Table E-2: Deployment Method Decision Matrix

Moving Tool									
		Drive Screw		Pneumatics		Crank Slider		Gravity	
	Weight	Unweighted Score	Weighted Score	Unweighted Score	Weighted Score	Unweighted Score	Weighted Score	Unweighted Score	Weighted Score
Cycle Time	0.2	70	14	90	18	80	16	70	14
Reliability	0.2	90	18	90	18	70	14	70	14
Weight	0.2	50	10	80	16	70	14	50	10
Safety	0.05	70	3.5	80	4	70	3.5	90	4.5
Cost	0.05	70	3.5	85	4.25	75	3.75	90	4.5
Force Adjustability	0.1	80	8	100	10	50	5	100	10
Force	0.1	90	9	80	8	90	9	90	9
Integration	0.1	65	6.5	80	8	70	7	80	8
Total Score		72.5		86.25		72.25		74	

Table E-3: Cut Detection Decision Matrix

Cut Detection							
Weight		Vision System (Edge Detection)		Limit Switch		Capacitive Sensor	
Cycle Time	0.1	70	7	70	7	70	7
Reliability	0.4	80	32	90	36	70	28
Maintenance	0.05	25	1.25	75	3.75	80	4
Cost	0.25	25	6.25	90	22.5	70	17.5
Integration	0.2	75	15	90	18	40	8
Total Score		61.5		87.25		64.5	

Table E-4: Alignment Mechanism Decision Matrix

Alignment Methods											
		Printer		Trough		Pierce		Gravity		Vibrate	
	Weight	Unweighted Score	Weighted Score	Unweighted Score	Weighted Score	Unweighted Score	Weighted Score	Unweighted Score	Weighted Score	Unweighted Score	Weighted Score
Single Operator/	0.1	100	10	100	10	100	10	100	10	100	10
Cycle Time	0.1	90	9	90	9	50	5	50	5	50	5
Safety	0.1	80	8	80	8	80	8	90	9	50	5
Accuracy	0.1	80	8	100	10	80	8	25	2.5	25	2.5
Cost	0.1	75	7.5	75	7.5	40	4	30	3	30	3
Integration	0.3	100	30	90	27	70	21	0	0	50	15
Adjustablity	0.2	100	20	0	0	100	20	0	0	50	10
Total Score		92.5		71.5		76		29.5		50.5	

Appendix F: Preliminary Concept Testing Design and Results

Cutter Screening DOE					
DOE#	Variables		Response		
Pattern	Blade Type	Cut Speed (Low,High)	Mat Tension Required (None, Low, High)	Cut Quality (A-F)	Force Required (None,Low, Medium,High)
11	Laser	Low	None	A	None
12	Laser	High	None	A	None
21	Hook	Low	Low	B	Medium
22	Hook	High	High	B	High
31	Rotary	Low	Low	B	Low
32	Rotary	High	Low	B	Low
41	Long Blade	Low	High	D	High
42	Long Blade	High	High	C	High
51	Dremel	Low	None	C	None
52	Dremel	High	None	C	None

Appendix G: Bracket Mechanical Analysis

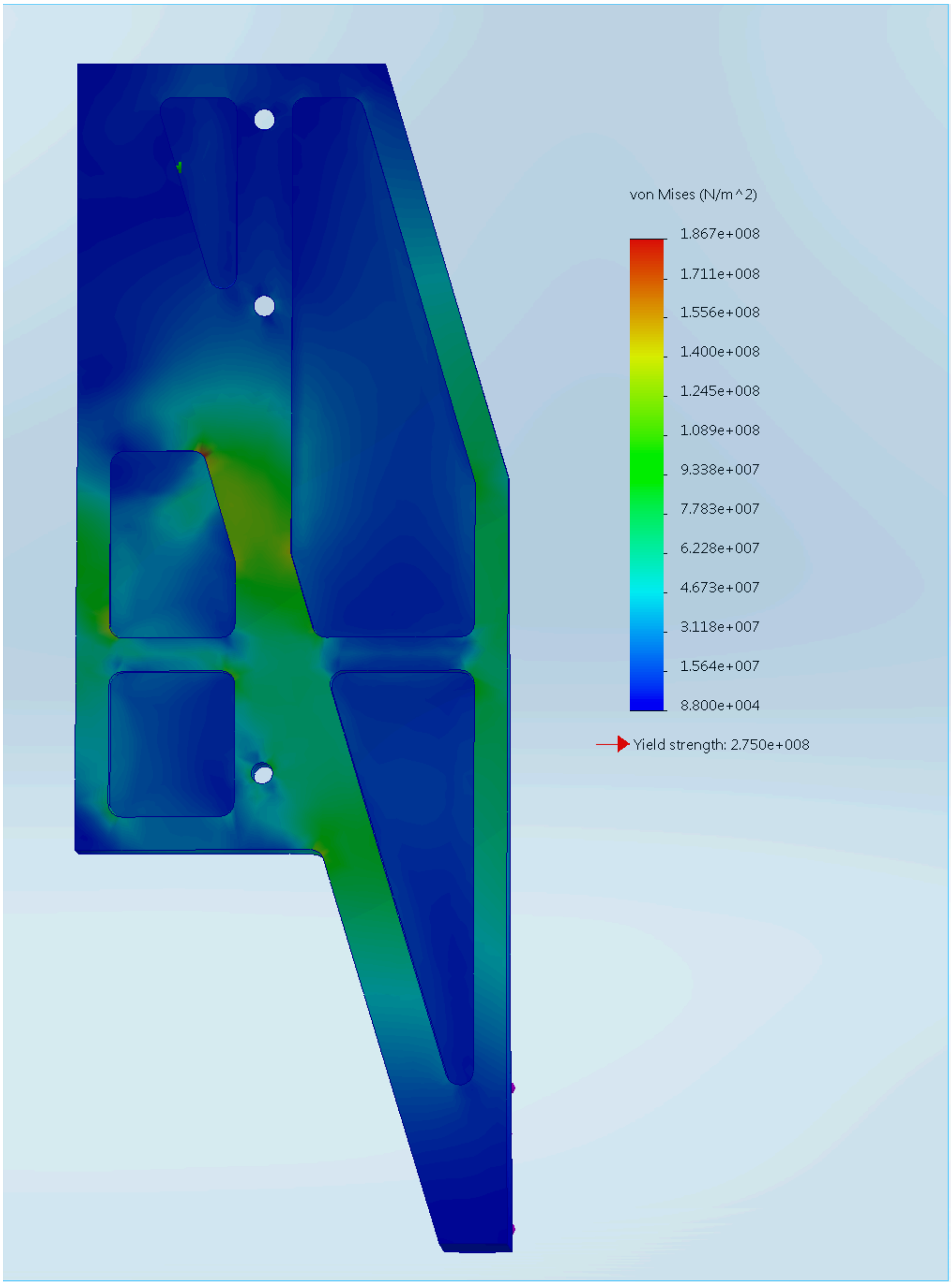
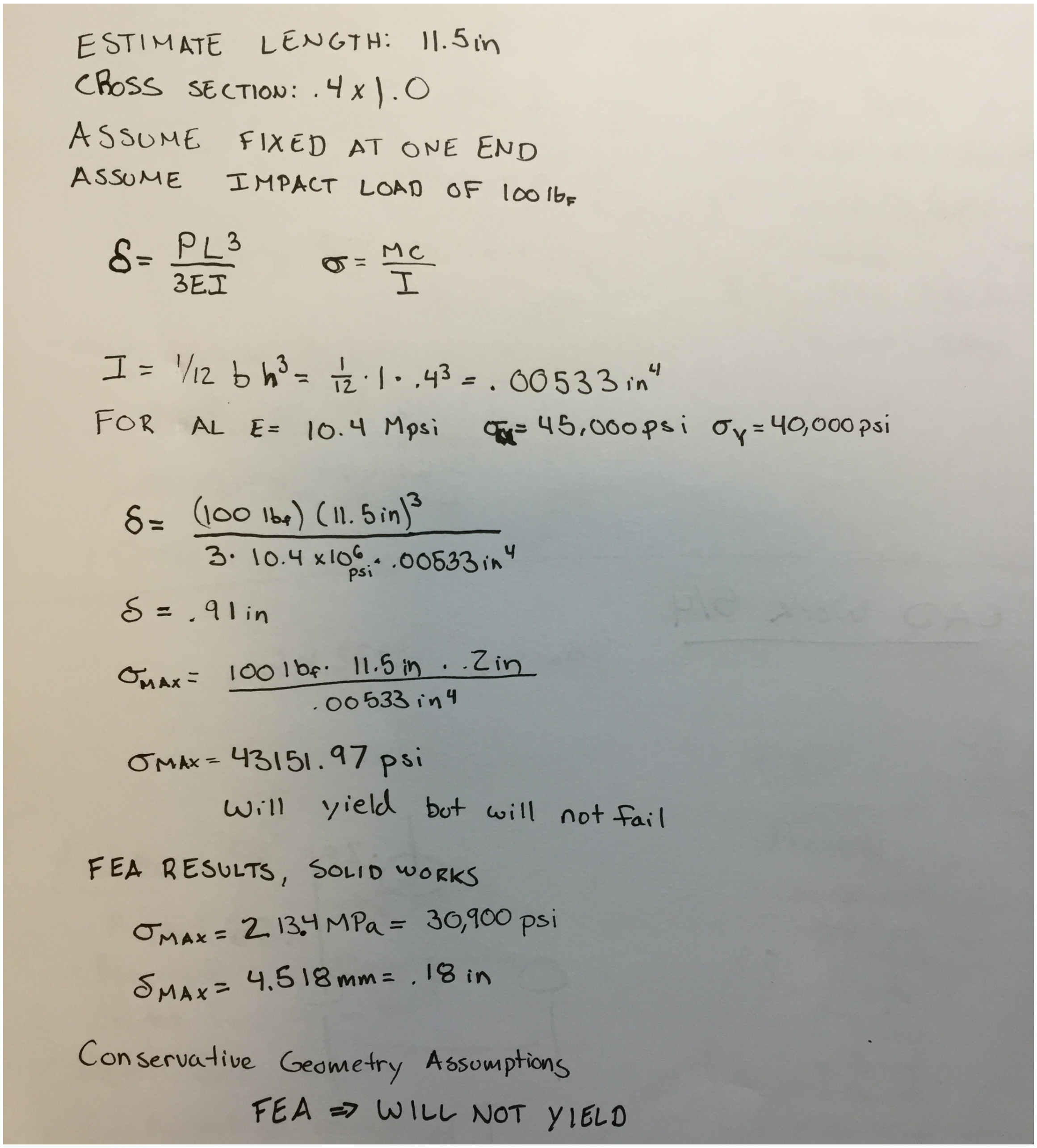


Figure G-10-1: FEA results for the Diesnes cutter. Note that the force concentration happens at the thinnest member closest to the mounting points as expected. The FOS for this loading case is 2.57.



ESTIMATE LENGTH: 11.5in
CROSS SECTION: .4 x 1.0
ASSUME FIXED AT ONE END
ASSUME IMPACT LOAD OF 100 lb_F

$$\delta = \frac{PL^3}{3EI} \qquad \sigma = \frac{Mc}{I}$$

$$I = 1/12\, b h^3 = \frac{1}{12} \cdot 1 \cdot .4^3 = .00533 \text{ in}^4$$

FOR AL $E = 10.4$ Mpsi $\sigma_{u} = 45{,}000$ psi $\sigma_Y = 40{,}000$ psi

$$\delta = \frac{(100 \text{ lb}_f)(11.5 \text{ in})^3}{3 \cdot 10.4 \times 10^6_{\text{psi}} \cdot .00533 \text{ in}^4}$$

$$\delta = .91 \text{ in}$$

$$\sigma_{MAX} = \frac{100 \text{ lb}_f \cdot 11.5 \text{ in} \cdot .2 \text{ in}}{.00533 \text{ in}^4}$$

$$\sigma_{MAX} = 43151.97 \text{ psi}$$

Will yield but will not fail

FEA RESULTS, SOLID WORKS

$$\sigma_{MAX} = 213.4 \text{ MPa} = 30{,}900 \text{ psi}$$

$$\delta_{MAX} = 4.518 \text{ mm} = .18 \text{ in}$$

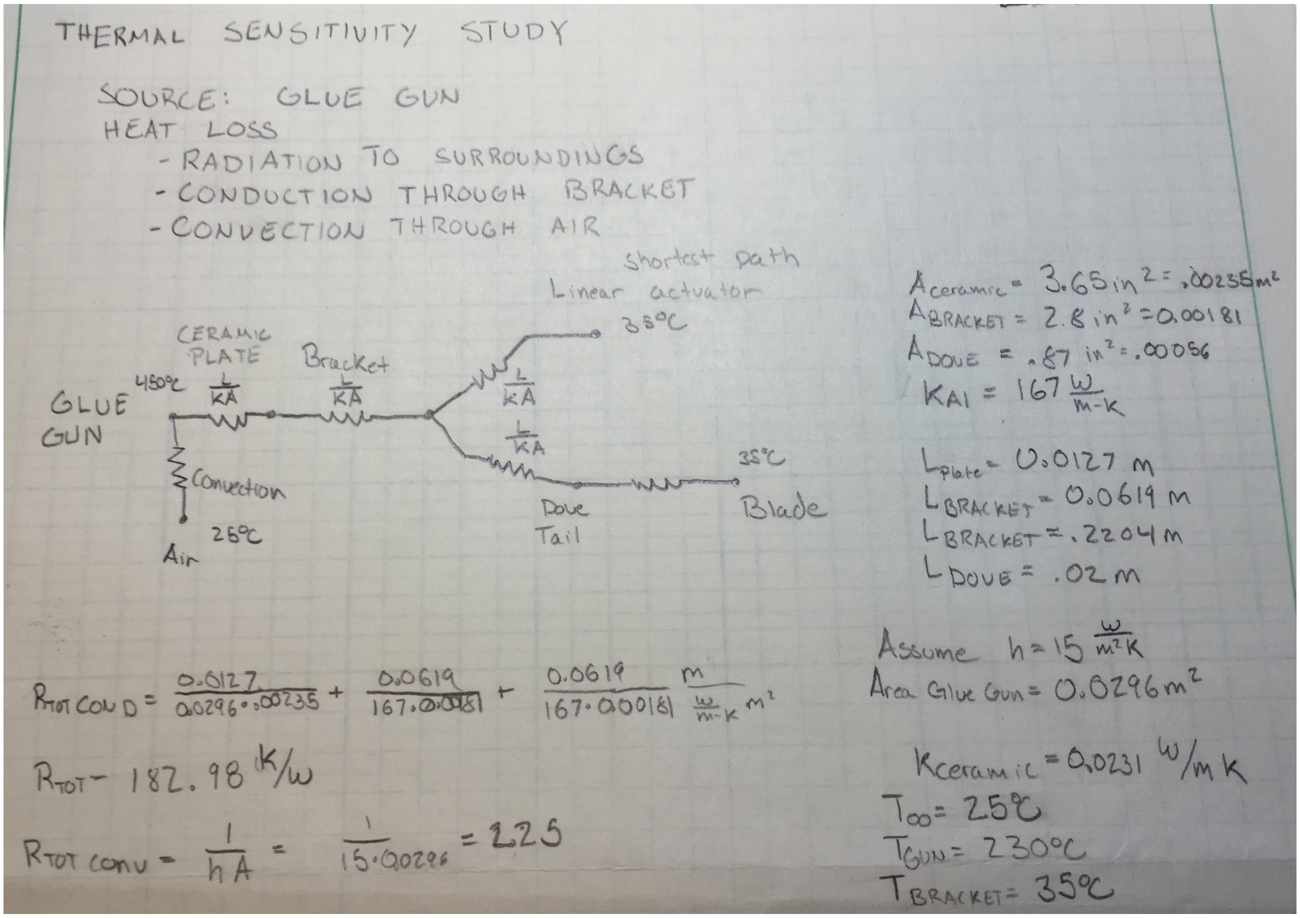
Conservative Geometry Assumptions

FEA ⇒ WILL NOT YIELD

Figure G-10-2: Sample calculation to support the calculations provided in Table 5-1. Note that the force in the calculation was doubled. The true FOS is 1.9.

Appendix H: Thermal Sensitivity Study

The following thermal analysis is comprised of a resistance network that follows the heat loss through convection through the brackets and convection through the air. Key takeaways are the thermal resistances provided at the bottom and the difference between the total resistance the resistance due to convection.



THERMAL SENSITIVITY STUDY

SOURCE: GLUE GUN
HEAT LOSS
- RADIATION TO SURROUNDINGS
- CONDUCTION THROUGH BRACKET
- CONVECTION THROUGH AIR

$A_{ceramic} = 3.65\,in^2 = .00235\,m^2$
$A_{BRACKET} = 2.8\,in^2 = 0.00181$
$A_{DOVE} = .87\,in^2 = .00056$
$K_{Al} = 167\,\frac{W}{m\text{-}K}$

$L_{plate} = 0.0127\,m$
$L_{BRACKET} = 0.0619\,m$
$L_{BRACKET} = .2204\,m$
$L_{DOVE} = .02\,m$

Assume $h = 15\,\frac{W}{m^2K}$
Area Glue Gun $= 0.0296\,m^2$

$K_{ceramic} = 0.0231\,W/mK$
$T_\infty = 25°C$
$T_{GUN} = 230°C$
$T_{BRACKET} = 35°C$

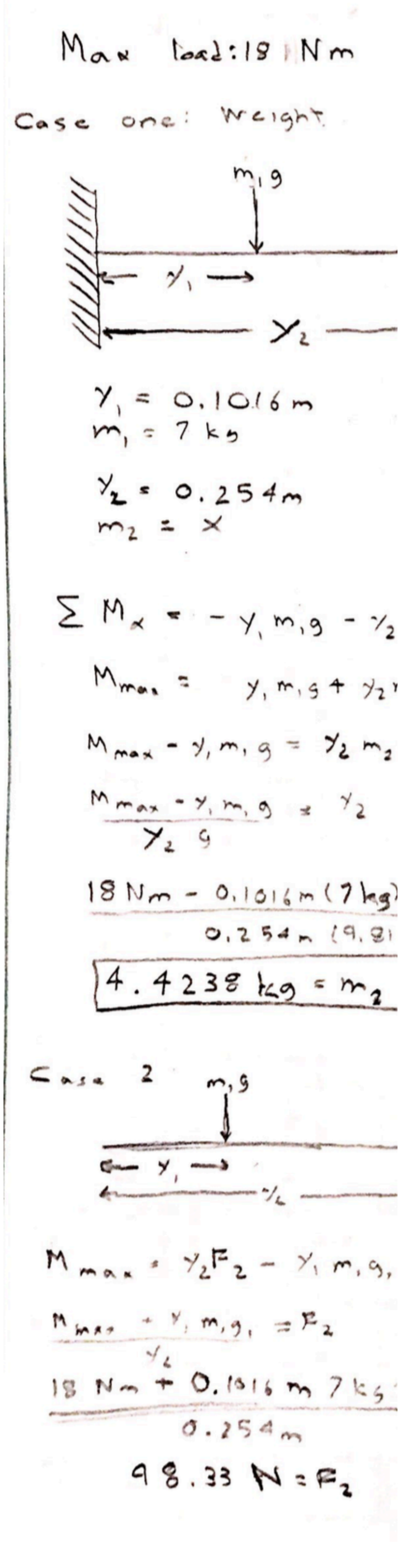
$$R_{TOT\,COND} = \frac{0.0127}{0.0296 \cdot .00235} + \frac{0.0619}{167 \cdot 0.00181} + \frac{0.0619}{167 \cdot 0.00181} \quad \frac{m}{\frac{W}{m\text{-}K}\,m^2}$$

$R_{TOT} - 182.98\,K/W$

$$R_{TOT\,conv} - \frac{1}{hA} = \frac{1}{15 \cdot 0.0296} = 2.25$$

Appendix I: Linear Actuator Loading Limits

Sample Calculation



Max load: 18 Nm

Case one: Weight

$m_1 g$

y_1

Y_2

$Y_1 = 0.1016\,m$
$m_1 = 7\,kg$

$Y_2 = 0.254\,m$
$m_2 = X$

$\sum M_x = -Y_1 m_1 g - Y_2$

$M_{max} = Y_1 m_1 g + Y_2$

$M_{max} - Y_1 m_1 g = Y_2 m_2$

$\frac{M_{max} - Y_1 m_1 g}{Y_2 \, g} = Y_2$

$\frac{18\,Nm - 0.1016\,m\,(7\,kg)}{0.254\,m\,(9.81}$

$\boxed{4.4238\,kg = m_2}$

Case 2

$m_1 g$

Y_1

Y_2

$M_{max} = Y_2 F_2 - Y_1 m_1 g_1$

$\frac{M_{max} + Y_1 m_1 g_1}{Y_2} = F_2$

$\frac{18\,Nm + 0.1016\,m\;7\,kg}{0.254\,m}$

$98.33\,N = F_2$

Table I-1: Loading Calculations on the actuator for the Custom Cutter Assembly

Part	Mass (kg)	Weight (N)	Distance (mm)	Moment (Nmm)
Cable Chain Bracket 2a	.04	.39	4.44	1.74
Cable Chain Bracket 2b	.10	.98	-19.01	-18.65
Cable Chain Bracket 2c	.04	.39	-1.65	-.65
Cable Chain Bracket 2d	.10	.98	-48.01	-47.10
Rectangular support	.05	.50	11.15	5.58
Mount Plate	.51	5.04	23.32	117.59
Glue gun mount A	.30	2.94	73.15	215.29
Glue gun mount B	.37	3.63	49.25	178.76
Gun	2.72	26.68	98.46	2627.23
Support Bracket x2	.30	2.96	138.18	409.36
Linear Guide	1.83	17.95	120.90	2170.43
C-channel	.05	.51	105.68	53.91
Camera mount	.06	.58	106.68	61.75
Cognex Camera	.22	2.16	146.03	315.16
Cutter Assembly	.24	2.32	125.73	291.09
Totals	6.93	68.02		6381.49

Static Loading			Process Loading	
Safety Factor(Moment)	1.50		Safety Factor	1.50
Allowed Mx (Nmm)	18000.00		Allowed Mx (Nmm)	18000.00
Distance (mm)	203.20		Allowed Force (N)	79.99
Remaining Weight (Kg)	2.82		Allowed Force (lbf)	17.98
Remaining Weight (lbf)	6.21		Safety Factor(Force)	29.40
Allowed Mx (Nmm)	18000.00		Allowed Fy(N)	2000.00

Table I-2: Loading Calculations on the actuator for the Dienes Cutter Assembly

Part	Mass (kg)	Weight (N)	Distance (mm)	Moment (Nmm)
Cable Chain Bracket 2a	.04	.39	4.44	1.74
Cable Chain Bracket 2b	.10	.98	-19.01	-18.65
Cable Chain Bracket 2c	.04	.39	-1.65	-.65
Cable Chain Bracket 2d	.10	.98	-48.01	-47.10
Rectangular support	.05	.50	11.15	5.58
Mount Plate	.51	5.04	23.32	117.59
Glue gun mount A	.43	4.21	73.15	307.86
Glue gun mount B	.37	3.63	49.25	178.76
Gun	2.72	26.68	98.46	2627.23
Dienes Cutter	1.30	12.75	125.73	1603.43
Dovetail Assembly	.05	.51	125.73	64.14
Totals	5.72	56.07		4839.94

Static Loading			Process Loading	
Safety Factor(Moment)	1.50		Safety Factor	1.50
Allowed Mx (Nmm)	18000.00		Allowed Mx (Nmm)	18000.00
Distance (mm)	203.20		Allowed Force (N)	74.93
Remaining Weight (Kg)	3.59		Allowed Force (lbf)	16.85
Remaining Weight (lbf)	7.92		Safety Factor(Force)	35.67
Allowed Mx (Nmm)	18000.00		Allowed Fy(N)	2000.00

Appendix J: Technical Specifications of Cognex Camera

Specifications

The following sections list general specifications for the In-Sight vision system.

Vision System Specifications

Table 1-1: Vision System Specifications

Specifications	In-Sight 7010/7020/7050/7200/ 7210/7230/7400/7410/7430	In-Sight 7010C/7200C/7400C	In-Sight 7402/7412/7432	In-Sight 7402C
Minimum Firmware Requirement	In-Sight Version 4.7.1/4.7.3[1]	In-Sight Version 4.8.0	In-Sight Version 4.7.1/4.7.3[1]	In-Sight Version 4.8.0
Job/Program Memory	512MB non-volatile flash memory; unlimited storage via remote network device.			
Image Processing Memory	256MB SDRAM			
Sensor Type	1/1.8-inch CMOS			
Sensor Properties	5.3mm diagonal, 5.3 x 5.3µm sq. pixels		8.7mm diagonal, 5.3 x 5.3µm sq. pixels	
Resolution (pixels)	800 x 600		1280 x 1024	
Electronic Shutter Speed	16µs to 950ms			
Acquisition	Rapid reset, progressive scan, full-frame integration.			
Bit Depth	256 grey levels (8 bits/pixel).	24-bit color.	256 grey levels (8 bits/pixel).	24-bit color.
Image Gain/Offset	Controlled by software.			
Frames Per Second[2]	102 full frames per second.	50 full frames per second.	60 full frames per second.	30 full frames per second.
Lens Type	M12 or C-Mount.			
Image Sensor Alignment Variability[3]	±0.127mm (0.005in), (both x and y) from lens C-Mount axis to center of imager.			
Trigger	1 opto-isolated, acquisition trigger input. Remote software commands via Ethernet and RS-232C.			
Discrete Inputs	3 general-purpose inputs when connected to the Power and I/O Breakout cable. (Eight additional inputs available when using the optional CIO-MICRO or CIO-MICRO-CC I/O module.)			
Discrete Outputs	4 high-speed outputs when connected to the Power and I/O Breakout cable. (Eight additional outputs available when using the optional CIO-MICRO or CIO-MICRO-CC I/O module.)			
Status LEDs	Network link and activity, power and 2 user-configurable.			
Internal LED Ring Light	Red, Green, Blue, White, IR (M12 lens configuration only).			
Network Communication	Ethernet port, 10/100 BaseT with auto MDI/MDIX. IEEE 802.3 TCP/IP protocol. Supports DHCP (factory default), static and link-local IP address configuration.			
Serial Communication	RS-232C: 4800 to 115,200 baud rates.			

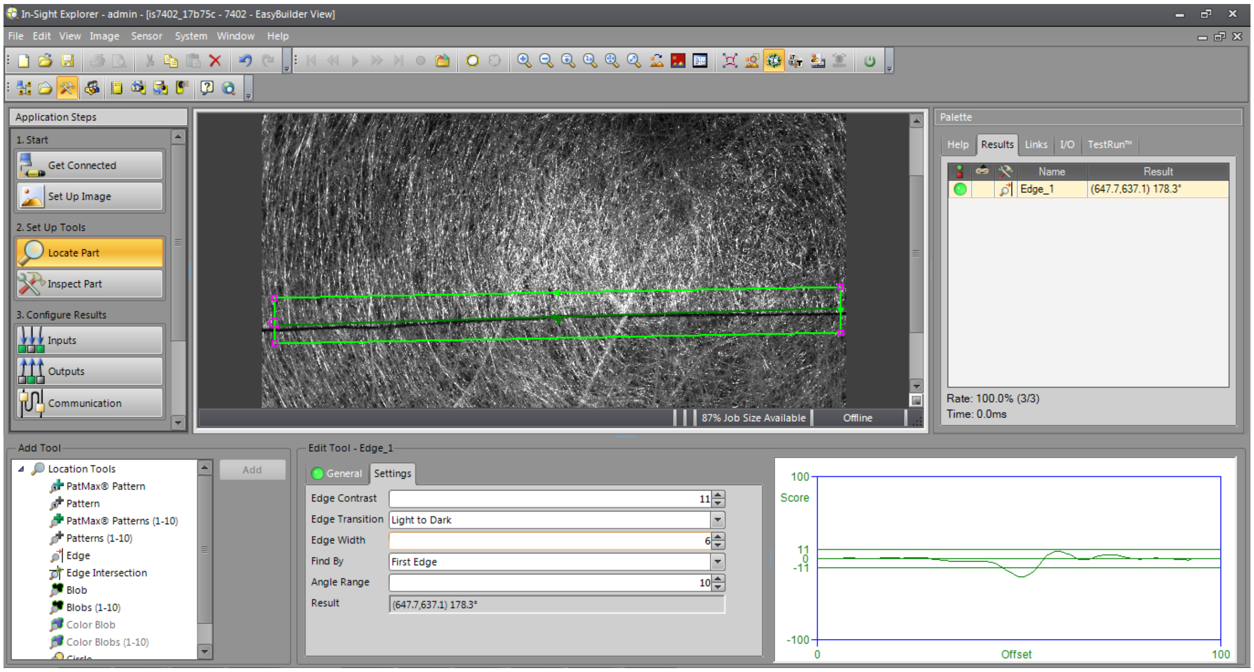
---

[1] Firmware version 4.7.1 is the minimum firmware requirement for models with the C-Mount Lens configuration. Firmware version 4.7.3 is the minimum firmware requirement for models with the M12 Lens configuration.

[2] Maximum frames per second is job-dependent, based on the minimum exposure for a full image frame capture using the dedicated acquisition trigger, and assumes there is no user interface connection to the vision system.

[3] Expected variability in the physical position of the image sensor, from vision system-to-vision system. This equates to ~ ±24 pixels on a 800 x 600 resolution CMOS and a 1280 x 1024 resolution CMOS.

Appendix K: Cognex Camera Output



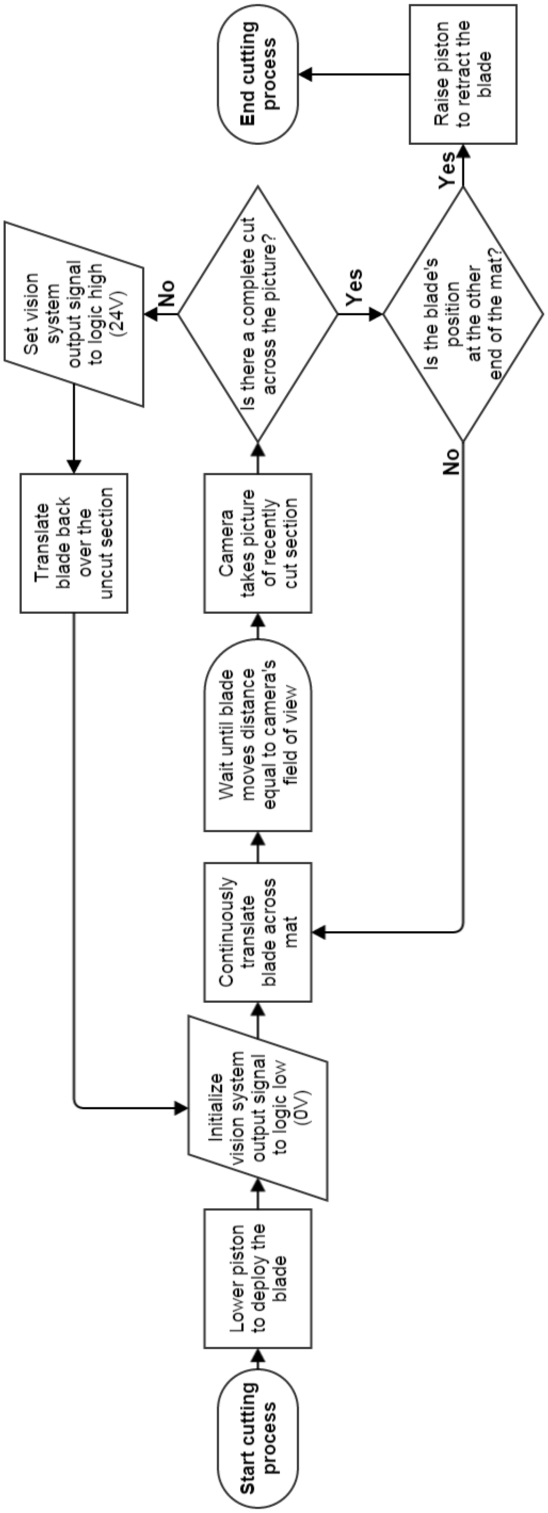
Name	Result
Edge_1	(647.7,637.1) 178.3°

Rate: 100.0% (3/3)
Time: 0.0ms

Edge Contrast: 11
Edge Transition: Light to Dark
Edge Width: 6
Find By: First Edge
Angle Range: 10
Result: (647.7,637.1) 178.3°

Figure K1: Testing results provided by Cognex

Appendix L: Computer Integration



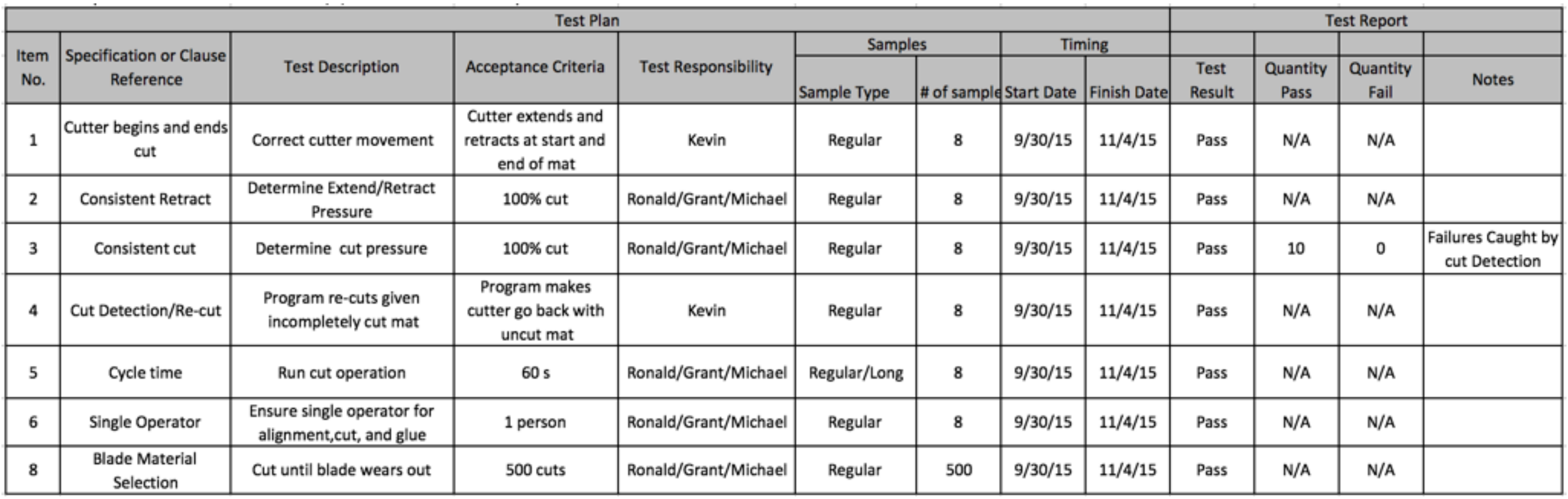
Software Flow Diagram: Cutting Process

Appendix M: Cost Analysis

Cost Analysis

Part	Manufacture	Part Number	Notes	Material	Qty	Price Per	Total Price
PQAS 1/2" Holder with Quick-Clamp	Dienes	22300		-	1	$137.39	$137.39
Multipurpose 6061 Aluminum Bar, 3/4" x 12",	McMaster	8975K149	For Support Bracket	6061 Al	1	$39.72	$39.72
Multipurpose 6061 Aluminum Bar, 2" x 2", 1/2'	McMaster	9008K53	I-Beam and Camera Bracket	6061 Al	1	$16.09	$16.09
						Cutter Option 1 Total	**$193.20**
Double Shielded Ball Bearing No.608	McMaster	5972K501	For 8mm Shaft Diameter	Steel	1	$4.68	$4.68
Crush/Score Cut Blade	Dienes	2347	3.030 x .866 x .244	D2	1	$20.00	$20.00
Multipurpose 6061 Aluminum Bar, 3/4" x 12",	McMaster	8975K149	For Support Bracket	6061 Al	2	$39.72	$79.44
Multipurpose 6061 Aluminum Bar, 2" x 2", 1/2'	McMaster	9008K53	I-Beam and Camera Bracket	6061 Al	2	$16.09	$32.18
Hairpin Cotter Pin, 2mm Diameter	McMaster	98350A910	Box of 10	Zinc Plated	1	$2.70	$2.70
Metric 8mm Clevis Pin	McMaster	93131A370	-	Zinc Plated	1	$6.68	$6.68
1/4"-20 x 1-5/8" Socket Head Cap Screw	McMaster	92185A507	Box of 10	316 SS	1	$7.07	$7.07
Pneumatic Guided Cylinder Piston	Parker	XLT-06-06-	Estimated Cost - Waiting on	Aluminum	1	$150.00	$150.00
						Cutter Option 2 Total	**$302.75**
In-sight 7402 Vision System	Cognex	Custom	-	-	1	$2,390.00	$2,390.00
Vision System Industry M12 Cable	Cognex	Custom	-	-	1	$240.00	$240.00
Low-Carbon Steel Rectangular Bar, 1/2" Thick, 1"	Mcmaster	8910K698	For Alignment Bracket	Carbon Steel	1	$19.59	$19.59
Steel Compression Spring 3”x.48 OD .045 Wire	McMaster	9657K428	Box of 6	Music Wire	1	$6.10	$6.10
Mac Valve 6300 Solenoid	-	-	Provided by GAF	-	1	$-	$-
#8-32 x 5/8" Socket Head Cap Screw	McMaster	92185A196	Box of 25	316 SS	1	$3.55	$3.55
Additional Miscellaneous Fasteners and Cabling	Various	-	-	-	1	$50.00	$50.00
Prototyping Costs	Various	-	Blade Types	-	1	$72.00	$72.00
Travel Expenses	-	-	Trips to Shafter	-	4	$48	$192
						Other Components	**$2,973.24**
						Total - 1	**$3275.99**
						Total - 2	**$3166.44**
						Past Senior Project	**$6,222.36**

Appendix N: Design Validation Testing



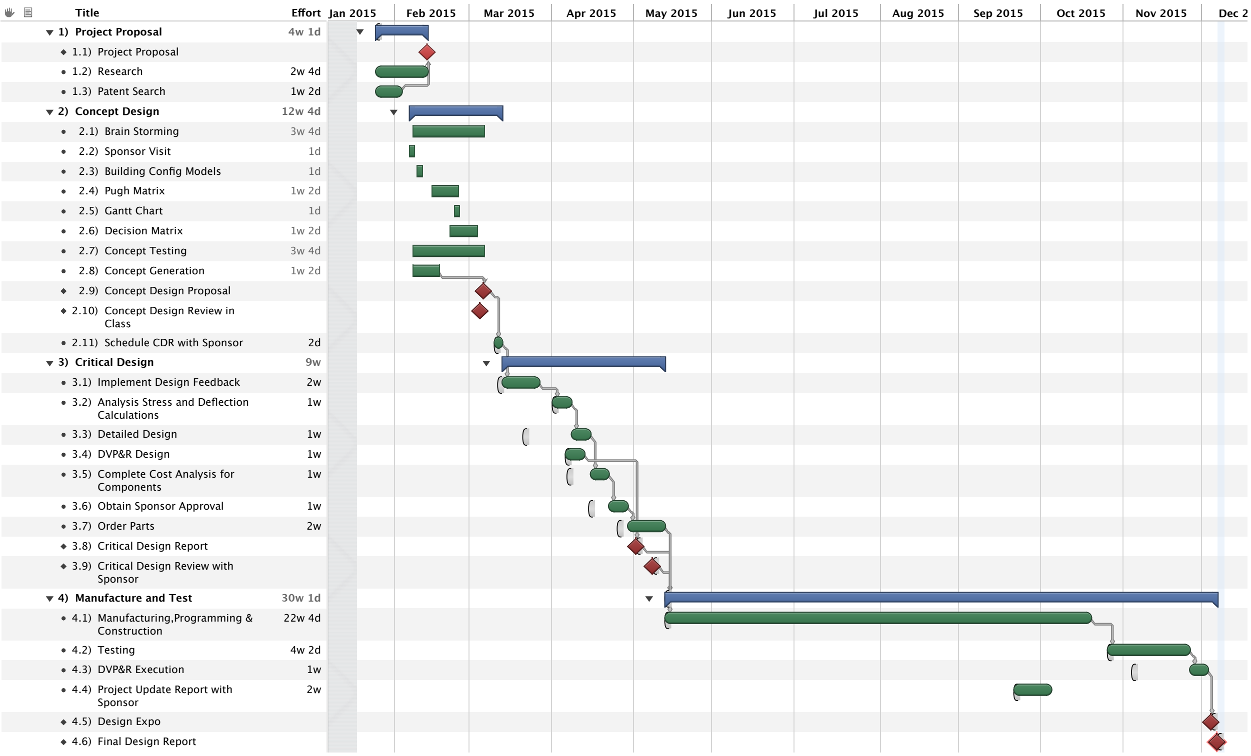
Test Plan									Test Report			
					Samples		Timing					
Item No.	Specification or Clause Reference	Test Description	Acceptance Criteria	Test Responsibility	Sample Type	# of sample	Start Date	Finish Date	Test Result	Quantity Pass	Quantity Fail	Notes
1	Cutter begins and ends cut	Correct cutter movement	Cutter extends and retracts at start and end of mat	Kevin	Regular	8	9/30/15	11/4/15	Pass	N/A	N/A	
2	Consistent Retract	Determine Extend/Retract Pressure	100% cut	Ronald/Grant/Michael	Regular	8	9/30/15	11/4/15	Pass	N/A	N/A	
3	Consistent cut	Determine cut pressure	100% cut	Ronald/Grant/Michael	Regular	8	9/30/15	11/4/15	Pass	10	0	Failures Caught by cut Detection
4	Cut Detection/Re-cut	Program re-cuts given incompletely cut mat	Program makes cutter go back with uncut mat	Kevin	Regular	8	9/30/15	11/4/15	Pass	N/A	N/A	
5	Cycle time	Run cut operation	60 s	Ronald/Grant/Michael	Regular/Long	8	9/30/15	11/4/15	Pass	N/A	N/A	
6	Single Operator	Ensure single operator for alignment,cut, and glue	1 person	Ronald/Grant/Michael	Regular	8	9/30/15	11/4/15	Pass	N/A	N/A	
8	Blade Material Selection	Cut until blade wears out	500 cuts	Ronald/Grant/Michael	Regular	500	9/30/15	11/4/15	Pass	N/A	N/A	

Appendix O: Failure Mode And Effects Analysis

									Action Results			
Item / Function	Potential Failure Mode	Potential Effect(s) of Failure	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occur	Crit	Recommended Action(s)	Responsibility & Target Completion Date	Actions Taken	Sev	Occur	Crit
Deployment Mechanism	Deployment at wrong time	Incomplete cut	4	PLC software failure	1	4	Cut detection feature, fail safe software loop	Kevin Lansang				
			4	Electrical wiring/hardware	3	12	Electrical hardware protection	Kevin Lansang				
	Failure to retract	Blade failure due to interference	7	Air valve failure	3	21	Allow for manual completion of cut					
			7	PLC software failure	1	7	Fail safe software loop	Kevin Lansang				
			7	Electrical wiring/hardware	3	21	Electrical hardware protection	Kevin Lansang				
	Failure to deploy	No cut initiation	8	Air valve failure	3	24	Allow for manual completion of cut					
			8	PLC software failure	1	8	Fail safe software loop	Kevin Lansang				
			8	Electrical wiring/hardware	3	24	Electrical hardware protection	Kevin Lansang				
	Incorrect application force	Premature blade failure - table damage	6	Air valve failure	3	18	Inspect blade after splice is complete and replace as necessary					
		Incomplete cut	4	Cylinder Failure	1	4	Cut detection feature	Kevin Lansang				
Rotary Blade	Wavering of blade	Uneven cut	6	Interference with table	6	36	Ensure correct blade application pressure					
		Table damage	5	Blade failure	1	5	Adjust cutting location on table during production, repair table after production stops					
			5	Fixture failure	1	5						
	Premature wear failure	Incomplete cut	4	Too much application pressure	1	4	Replace blade between splicing operations					
			4	Interference with	1	4						
	Partial cut	Improper splice	8	Too little or inconsistent		0	Cut detection feature					
	Blade warpage	Wavering of blade	5	Blade crash		0	Replace blade between splicing operations					
		Incomplete cut	8	Too much application pressure		0	Cut Detection					
	Mat snags on blade	Misalignment	6	Blade not spinning		0	Cut Detection, second pass					
				Dull blade		0	Replace blade between splicing operations					
	Blade not revolving	Table damage	5	Bearing failure		0	If bearing cannot be replaced, switch to mannual operation					
	Fixture failure	Unsafe conditions	10	Machine crash		0	Stop line if worker safety is in question					
Cut Detection	Doesn't detect cut - false negative	Failed cut and stopped production line	8	Camera software failure	6	48	Allow manual completion of cut					
	Incorrectly detects cut - false positive	Delayed splice operation	4	Camera software failure	6	24	Implement manual override of cut	Kevin Lansang				
	Failed program start	Cut detection program fails to run	6	PLC software failure	1	6	Fail safe software loop	Kevin Lansang				
			6	Electrical wiring/hardware	3	18	Electical hardware protection	Kevin Lansang				

Appendix P: Gantt Chart

Provided below is an Updated Gantt chart depicting progress and expected completion dates.



Title	Effort
1) Project Proposal	4w 1d
◆ 1.1) Project Proposal	
• 1.2) Research	2w 4d
• 1.3) Patent Search	1w 2d
2) Concept Design	12w 4d
• 2.1) Brain Storming	3w 4d
• 2.2) Sponsor Visit	1d
• 2.3) Building Config Models	1d
• 2.4) Pugh Matrix	1w 2d
• 2.5) Gantt Chart	1d
• 2.6) Decision Matrix	1w 2d
• 2.7) Concept Testing	3w 4d
• 2.8) Concept Generation	1w 2d
◆ 2.9) Concept Design Proposal	
◆ 2.10) Concept Design Review in Class	
• 2.11) Schedule CDR with Sponsor	2d
3) Critical Design	9w
• 3.1) Implement Design Feedback	2w
• 3.2) Analysis Stress and Deflection Calculations	1w
• 3.3) Detailed Design	1w
• 3.4) DVP&R Design	1w
• 3.5) Complete Cost Analysis for Components	1w
• 3.6) Obtain Sponsor Approval	1w
• 3.7) Order Parts	2w
◆ 3.8) Critical Design Report	
◆ 3.9) Critical Design Review with Sponsor	
4) Manufacture and Test	30w 1d
• 4.1) Manufacturing,Programming & Construction	22w 4d
• 4.2) Testing	4w 2d
• 4.3) DVP&R Execution	1w
• 4.4) Project Update Report with Sponsor	2w
◆ 4.5) Design Expo	
◆ 4.6) Final Design Report	

Table P-1: Manufacturing plan for parts that will be machined on campus

Manufacturing Plan								
Dienes Cutter								
Component	Material	Op 1	Op2	Resource 1	Resource 2	Estimated Time	DRI	Completion Date
Support Bracket	6061-T6	CNC Mill	-	IME Haas VF2	-	4 Hours	Ronald/Grant	5/24/15
Camera Bracket	6061-T6	CNC Mill	-	IME Haas VF2	-	3 Hours	Ronald/Grant	6/10/15
Dovetail	6061-T6	CNC Mill	-	IME Haas VF2	-	2 hours	Ronald/Grant	5/24/15
Custom Cutter								
Component	Material	Op 1	Op2	Resource 1	Resource 2	Estimated Time	DRI	Completion Date
Support Bracket(x2)	6061-T6	CNC Mill	-	IME Haas VF2	-	5 hours	Ronald/Grant	5/24/15
Camera Bracket	6061-T6	CNC Mill	-	IME Haas VF2	-	3 hours	Ronald/Grant	6/10/15
C-channel bracket	6061-T6	CNC Mill	-	IME Haas VF2	-	2 hours	Ronald/Grant	5/24/15
Custom Cutter Mount	6061-T6	Manual Mill	-	AeroHangar	-	3 hours	Ronald/Grant	5/24/15
Alignment Fixture								
Component	Material	Op 1	Op2	Resource 1	Resource 2	Estimated Time	DRI	Completion Date
Alignment Posts	4130	Sheet Metal Shear	Weld	AeroHangar	AeroHangar	4 hours	Michael	6/10/15

Appendix Q: Safety Checklist

- Eye Protection is required at all times
- Safety gloves are required when handling the glue gun and fiber glass
- Long pants and closed toed shoes are required at all times.
- Never work with electrical components unless the 480 volt power is unplugged and locked in the off position
- Keep the electrical control cabinet locked while 480 volt power is plugged in

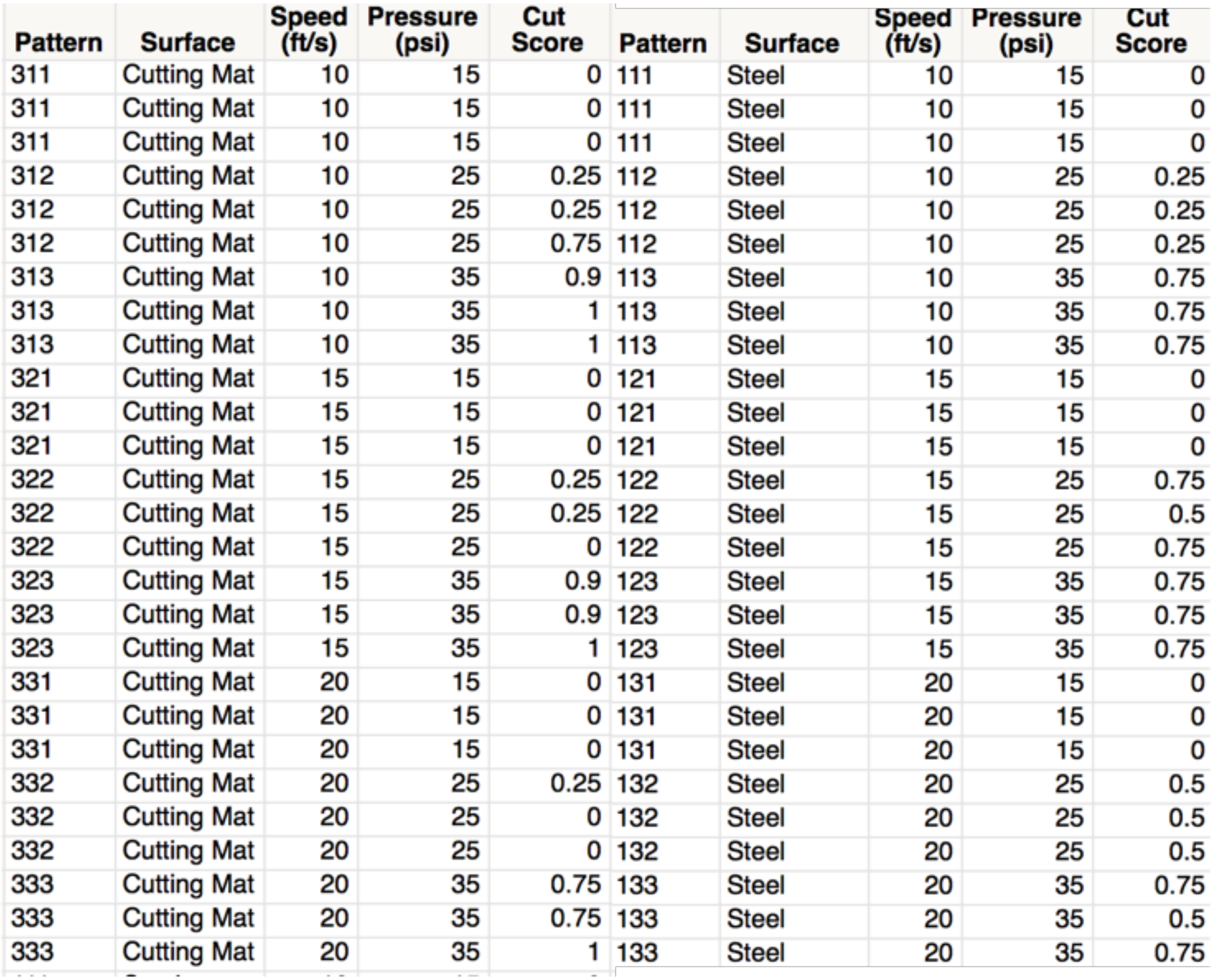
Testing procedure:

- Check all insulated cables to ensure they are not damaged
- Ensure that the gantry has at least two feet of clearance with surrounding objects
- Ensure that emergency stop buttons are in place
- Connect the 120 volt
- Open the electrical control cabinet and turn on the circuit breaker for the stratix system
- Close and lock the control cabinet
- Plug in the 480 volt cable
- Turn on the 480 volt breaker on the wall, then unlock and turn on the 480 volt fuse disconnect on the control cabinet
- Position the fiberglass mat
- If using the glue gun, wait 15 minutes for gun to reach a temperature of 500 degrees F
- Clear all persons from gantry workspace
- Run cutting and gluing operations
- Wait for operation to complete before touching or altering the glue gun system
- Wait 5 minutes before handling dispensed glue
- Repeat steps 11 through 14 as needed

Shutdown

- Purge remaining glue from gun into cache
- Turn off the 480 v breaker on the wall and then the 480 V fuse disconnect on the control box
- Disconnect the 120 v power supply
- Make sure that all systems are properly locked before leaving

Appendix R: Design Validation Testing Results

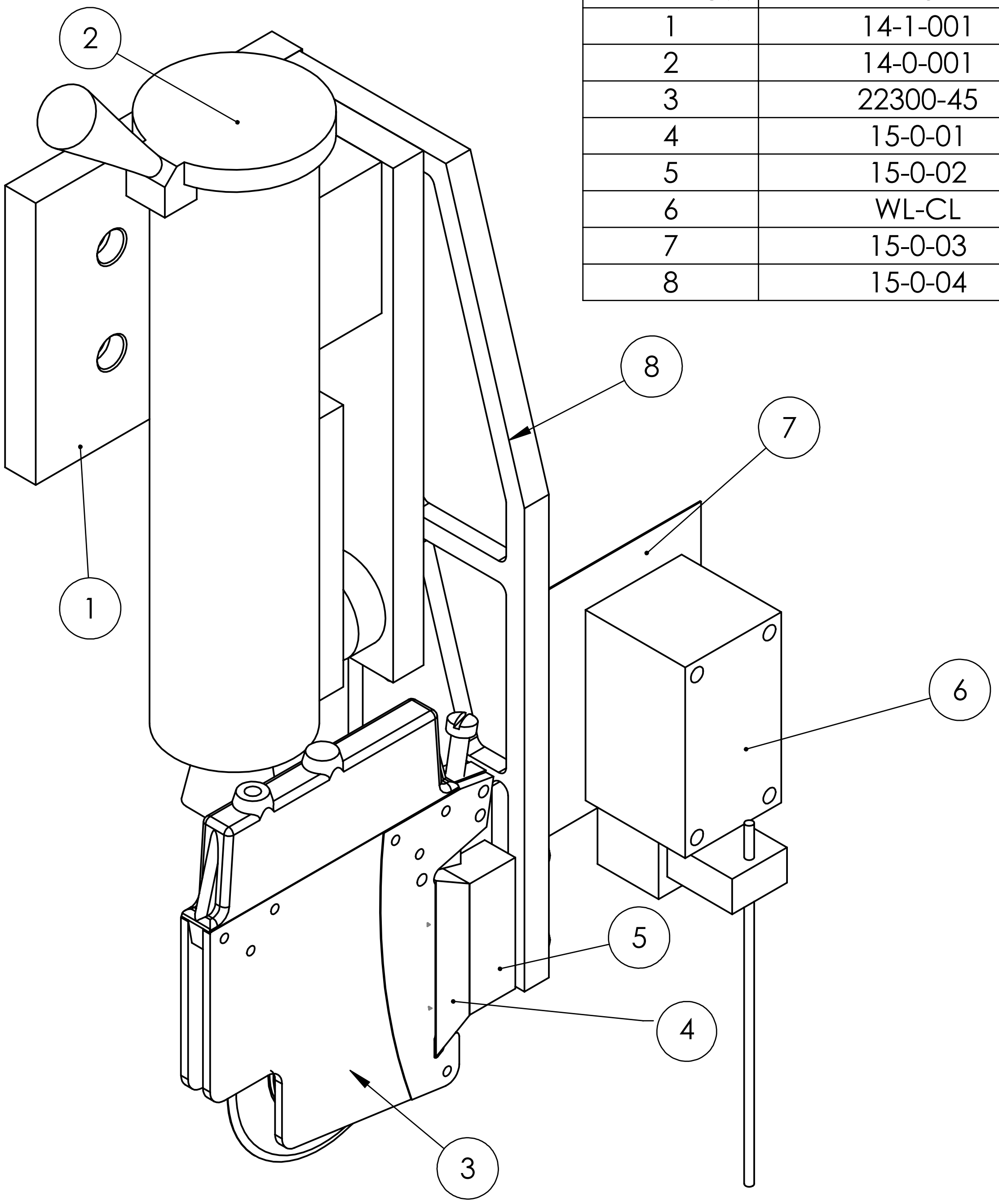


Pattern	Surface	Speed (ft/s)	Pressure (psi)	Cut Score	Pattern	Surface	Speed (ft/s)	Pressure (psi)	Cut Score
311	Cutting Mat	10	15	0	111	Steel	10	15	0
311	Cutting Mat	10	15	0	111	Steel	10	15	0
311	Cutting Mat	10	15	0	111	Steel	10	15	0
312	Cutting Mat	10	25	0.25	112	Steel	10	25	0.25
312	Cutting Mat	10	25	0.25	112	Steel	10	25	0.25
312	Cutting Mat	10	25	0.75	112	Steel	10	25	0.25
313	Cutting Mat	10	35	0.9	113	Steel	10	35	0.75
313	Cutting Mat	10	35	1	113	Steel	10	35	0.75
313	Cutting Mat	10	35	1	113	Steel	10	35	0.75
321	Cutting Mat	15	15	0	121	Steel	15	15	0
321	Cutting Mat	15	15	0	121	Steel	15	15	0
321	Cutting Mat	15	15	0	121	Steel	15	15	0
322	Cutting Mat	15	25	0.25	122	Steel	15	25	0.75
322	Cutting Mat	15	25	0.25	122	Steel	15	25	0.5
322	Cutting Mat	15	25	0	122	Steel	15	25	0.75
323	Cutting Mat	15	35	0.9	123	Steel	15	35	0.75
323	Cutting Mat	15	35	0.9	123	Steel	15	35	0.75
323	Cutting Mat	15	35	1	123	Steel	15	35	0.75
331	Cutting Mat	20	15	0	131	Steel	20	15	0
331	Cutting Mat	20	15	0	131	Steel	20	15	0
331	Cutting Mat	20	15	0	131	Steel	20	15	0
332	Cutting Mat	20	25	0.25	132	Steel	20	25	0.5
332	Cutting Mat	20	25	0	132	Steel	20	25	0.5
332	Cutting Mat	20	25	0	132	Steel	20	25	0.5
333	Cutting Mat	20	35	0.75	133	Steel	20	35	0.75
333	Cutting Mat	20	35	0.75	133	Steel	20	35	0.5
333	Cutting Mat	20	35	1	133	Steel	20	35	0.75

Appendix S: Drawing Package

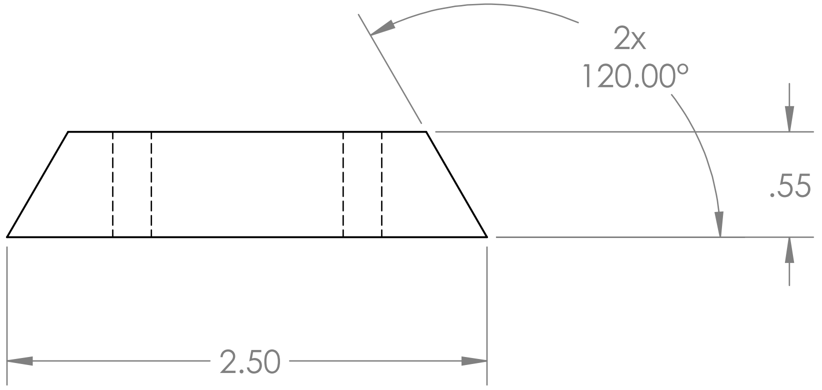
The Following pages are design drawings for the final design given to GAF.

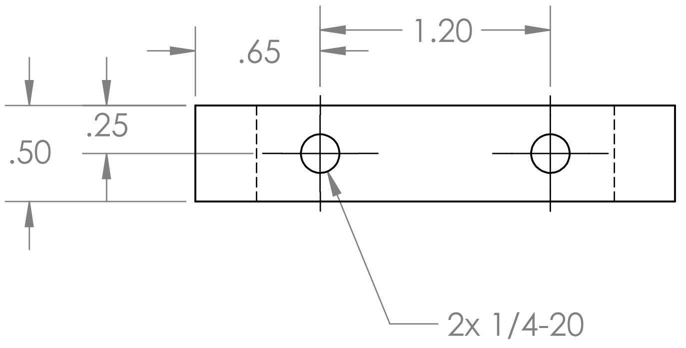
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	14-1-001	2014 SENIOR PROJECT ASSY	1
2	14-0-001	GLUE GUN	1
3	22300-45	DEINES 1/2" PQAS CRUSH CUTTER	1
4	15-0-01	DOVE TAIL	1
5	15-0-02	EXTENDER BLOCK	1
6	WL-CL	TMAZTZ LIMIT SWICH	1
7	15-0-03	LIMIT SWITCHL-BRACKET	1
8	15-0-04	MAIN BRACKET	1



Cal Poly Mechanical Engineering
GAF Automated Cutter
Dwg. #:15-1-001
Title:COMPLETE ASSY
Date: 12/8/2015
Scale: 1:4
Drwn. By: MICHAEL MOONEY
Chkd. By: RON LAM

NOTES:
1. MATERIAL: AL 6061-T6

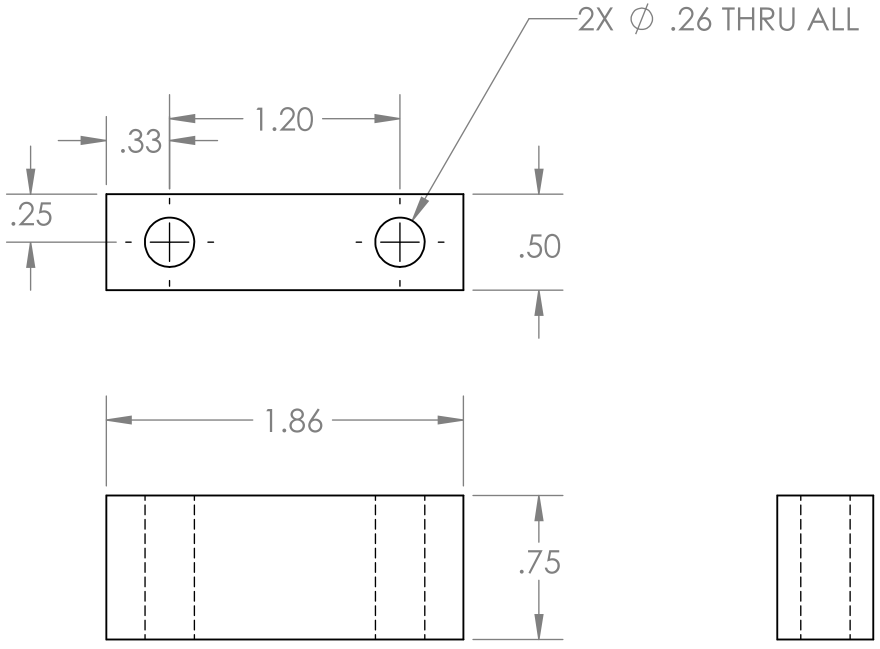




Cal Poly Mechanical Engineering
GAF Automated Cutter

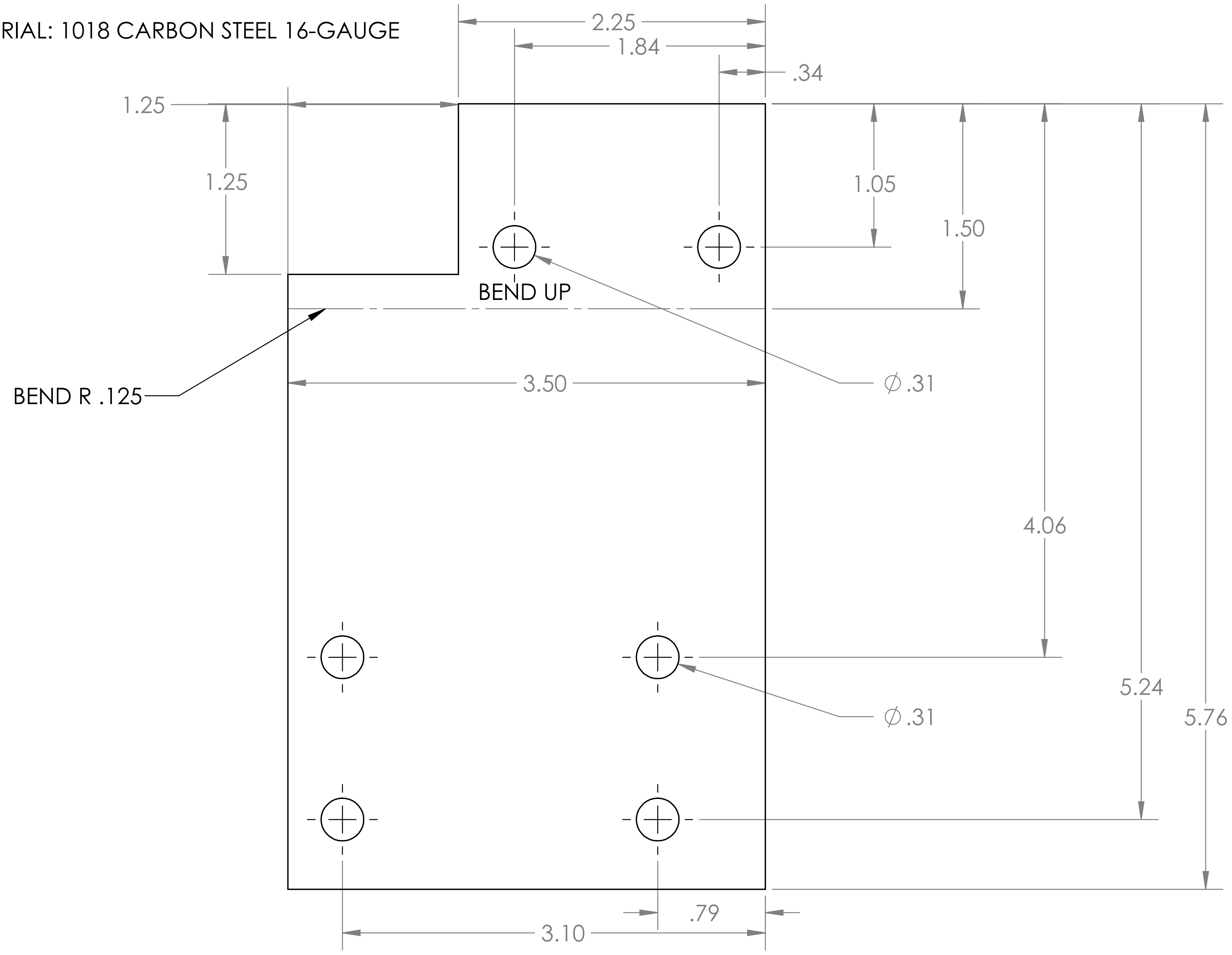
		Title: DOVE TAIL		Drwn. By: MICHAEL MOONEY
Dwg. #: 15-0-01	Nxt Asb: 15-1-01	Date: 12/8/2015	Scale: 1:1	Chkd. By: RON LAM

NOTES:
1. MATERIAL: AL 6061 T6



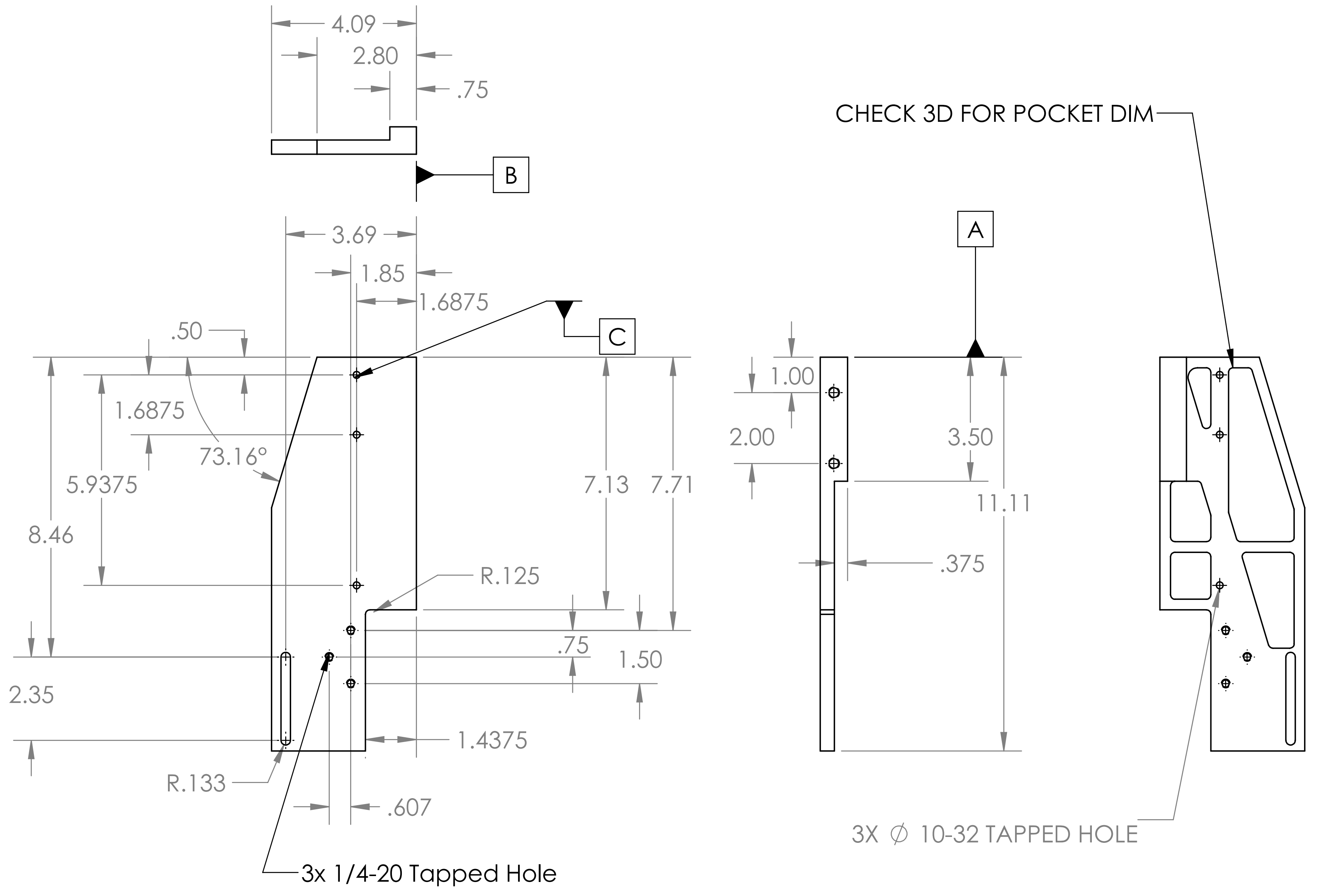
Cal Poly Mechanical Engineering
GAF Automated Cutter
Dwg. #:15-0-02
Nxt Asb: 15-1-01
Title: DOVE TAIL EXTENSION
Date: 12/8/2015
Scale: 1:1
Drwn. By: MICHAEL MOONEY
Chkd. By: RON LAM

NOTES:
1. MATERIAL: 1018 CARBON STEEL 16-GAUGE



Cal Poly Mechanical Engineering GAF Automaed Cutter			Title: LIMIT SWITCH L BRACKET	Drwn. by: MICAHEL MOONEY
	Dwg. #: 15-0-03	Nxt Asb: 15-1-01	DATE: 12/8/2015 Scale: 1:1	Chkd. By: RON LAM

NOTES:
1. MATERIAL: AL 6061 T6



Cal Poly Mechanical Engineering GAF Automated Cutter			Title: MAIN BRACKET	Drwn. By: MICHAEL MOONEY
	Dwg. #: 15-0-04	Nxt Asb: 15-1-01	Date: 12/8/2015 Scale: 1:4	Chkd. By: RON LAM