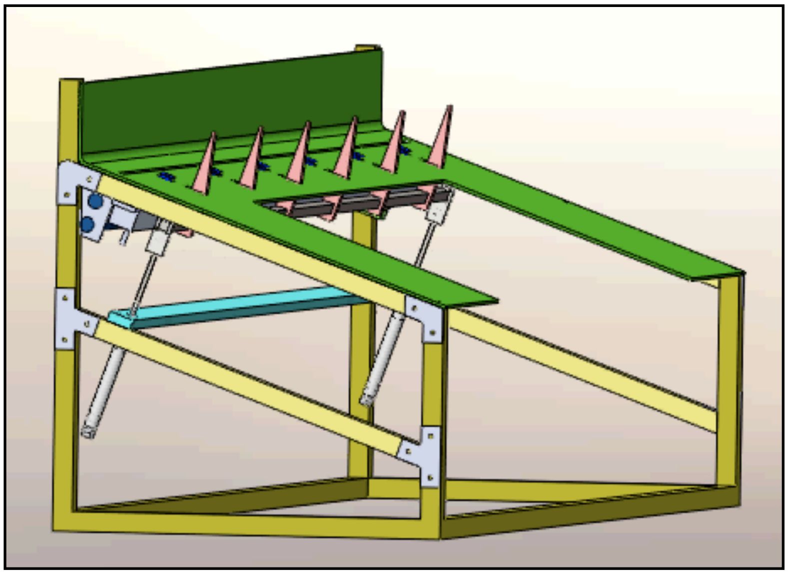
Formax Meat Casing Removal

Final Design Report



AMCaR:
Automatic Meat Casing Remover

Noah Pentelovitch
George Randolph
Sean Wood
Krystian Zimowski

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McCormick
Northwestern Engineering

NORTHWESTERN UNIVERSITY
QUAECUMQUE SUNT VERA
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Executive Summary

Provisur Technologies, a design company that specializes in food processing equipment, was faced with the challenge of designing a robotic end effector to remove the casing from cooked products, such as meat logs. This project was undertaken as a means to design a meat casing removal system in order to increase the throughput while maintaining hygienic standards.

After consulting with the client and performing extensive background research, it was found that there are currently two competitive products currently on the market that remove the casing off of meat logs, but neither are adequate. A virtual archaeology dissection was performed on one of the products in order to give a better idea of a typical flow process the design will encompass and examine and eliminate the current competitor product's flaws. The existing meat casing removal machines have a complicated flow process with many unnecessary steps that hinder the throughput of the meat logs and significantly increase the assembly line footprint. Critical design criteria include effective use of space, quick throughput (4-6 logs/minute), cleanliness, and minimal damage to product. Therefore, the design goal was modified to be: design an device to effectively remove the casing from meat logs while maximizing the throughput, minimizing the assembly line footprint and maintaining hygienic standards.

Next, ideas that would address all of the issues mentioned above were brainstormed. After more than 20 ideas were gathered, the top five most feasible and elegant designs were chosen and processed through concept selection matrices. In the end, two of these designs were built as mock ups and presented to the client for the final screening process.

The simplest and most appropriate idea was the Slice, Suck, and Roll. In this design, the meat log is loaded into a trough-shaped machine laterally, and a knife is driven across to cut the casing. Pneumatic pumps then release stoppers that are holding the meat log in place, the meat log rolls off into the next step of the assembly line while vacuum powered suction cups at the bottom of the trough maintain a grip on the casing and dispose of it.

This design has so far achieved the goal and fixed all the problems Provisur specifically addressed. Detailed models and drawings of the prototype were made for the purpose of manufacturing the prototype, and stress analysis was performed to address the validity of the design. The prototype scope is to manually place the meat log in the trough with the ends already truncated, manually move the knife fixture to cut the casing, pneumatically release the stoppers while turning on the vacuum, and letting the meat log roll out with the casing disposed of behind it. This scope will prove that the prototype successfully and efficiently removes the casing off of meat logs (4-6 logs/minute), minimizes the assembly line footprint by effectively using space, adheres to hygienic standards, and minimizes product damage and waste.

1.0 Product Description

1.1 Project Background

Provisur is a global leader in the meat forming and slicing markets. They currently have no efficient method to automatically remove the cellulose casing from meat products. Instead this is a completely man-powered process, resulting in throughput inconsistencies and the threat of possible injury. A worker first shears the ends of the sausage off and then manually removes the casing and any metal clips. Provisur approached Northwestern for potential concept ideas for automating the meat casing removal process.

Several benefits to automating this process exist

- significant labor savings
- increased worker safety
- increased and consistent throughput
- maximizes production yield
- increased environment hygiene (improves shelf life by reducing human contact with product)

1.2 Project Specifications/ Requirements

Currently, the maximum throughput Provisur can achieve falls in the range of 4-6 logs/minute. One aspect of the design is to at the very least meet this requirement, if not surpass it. The initial design scope was to design an end effector to remove casing which should be attachable to a robotic arm. After the initial conference with the client, it was determined that the it was not required to design an end effector, but because the typical removal processes included tearing/ rotating and cutting/pulling, designing an end effector could prove to be the most viable solution.

The design must efficiently and reliably remove the cellulose casing from standard size meat products. The dimensions that the design should handle are:

- 1 meter long meat product
- 100 mm diameter

These specifications are standard in the meat and food industries, although the design may need to be modified to accommodate less common geometries such as rectangular rod shaped meat product.

Some meat product includes metal clips at either end to help attach the casing. A picture of these clips can be seen below.

Figure 1: Sausage End Clips

The design needs to be versatile enough to handle both the presence of metal clips and their absence.

The available methods of power for the design are as follows

- Pneumatic
- Vacuum
- 24 VDC
- 120 V/ 240V AC

All aspects of the design must comply with FDA cleaning and wash down standards. Because every factory is different and thus every wash down method is different, the design must be able to withstand various cleansing procedures. Some of these procedures include

- Full hot water immersion
- UV exposure
- Chemical wash down

These wash down procedures may occur hourly or daily depending on the factory. As such, areas prone to water damage (*e.g.* electrical cabinets) should be properly sealed and insulated. Also, since the machine will be subject to wash down procedures, small nooks and crannies in the design should be avoided, as these areas will prove difficult to clean. As an example, if two plates are joined together, they should be sealed, to prevent any product residue from seeping between adjoining faces. When this occurs, bacteria can form and the risk of assembly line shut down arises. If pieces must be joined, they should be easily and safely accessible for removal during cleansing procedures. Refer to Appendix A for the complete version of the product design specifications.

1.3 Background Research

Competitor Product

The background research consisted mostly of a virtual dissection of a competitor product. Weber is a company that has the only other meat casing removal machine out on the market, and product archaeology was performed in order to get a better understanding of the entire casing removal process. The layout of the Webber's product, the Webber CCP can be seen below in Figure 2.

Figure 2: Webber CCP Industrial Meat Log Peeler

First, the meat log is loaded into the machine axially, driven into an end clip removal machine, and then moved laterally onto another belt. The meat log is aligned, an initial cut is made, and the meat log is driven through while robotic fingers grip the casing and pull it up and over the log across a roller. Next, another roller engages with the first and removes the rest of the casing while the meat log is driven axially out of the machine. The Weber CCP is a very bulky, drawn-out and complicated machine. Fifteen steps were counted in the entire process. This can be greatly simplified in terms of complexity and bulkiness. The complexity can be reduced by eliminating unnecessary steps, and the bulkiness can be decreased by minimizing assembly line footprint and effective use of space.

Blades

The blade industry is an art form within itself, therefore finding the ideal blade for this application was crucial. Formax specializes in making blades, but external literary research was also performed.

There are many different types of blades, used in many different applications. Depending on the shape of the blade, it can be used for shearing, piercing, or slicing. For the meat casing removal machine, a type of blade with the best initial penetration and repeatable depth of cut was needed.

The first type of blade that was explored was a *normal blade*. A *normal blade* has a curved, sharpened edge and a dull portion on top. This type of blade is best used for thrusting and slicing, as the curved edge slices whatever it passes through, allowing for the rest of the blade to easily slide in. It's the best form of a single-edged knife, but it's not really the type of blade that is needed.

Normal Blade

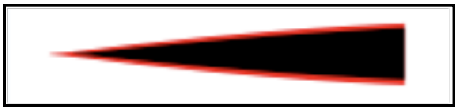
The second type of blade was a *sheepsfoot blade*. This type of blade is the opposite of the normal blade and has the sharpened edge on the flat side instead of the curved side. It gives the most control as well as prevents accidental penetration because of the shape of the tip. This type was not desirable because piercing was not a strong feature and repeatability of a same cut was low.

Sheepsfoot Blade

The third type of blade that was explored was a *spear-point blade*. These types of blades are obviously used for piercing and thrusting, as they are double-edged and can quickly and effectively pierce through material. This is best blade researched so far, but optimizations could be made.

Spear-point Blade

The final type of blade that was researched was a *needlepoint blade*. This is much like a spear-point blade except that it is much more highly tapered, which increases piercing ability and is therefore an optimal version of the spear-point blade. This was the blade that was most desirable, as the most important feature of the design is initial penetration and repeatability.



Needlepoint Blade

From external literary background research, it was found that the *needlepoint blade* was the most suitable for application of effectively cutting the meat log casings at the same required depth every time.

Vacuum Pump Technology

Vacuum pumps can be of three different general types: positive displacement, momentum transfer, or entrapment. The most common vacuum pumps today for small scale vacuums are a type of momentum transfer vacuum pump which are compressed air-driven. These vacuums utilize Bernoulli's Principle) in which a low pressure area is formed in a chamber adjacent to a flow of fluid.

When compressed air (1) passes through the nozzles (2), air is pulled through with the stream of compressed air. “Suction” is thus created at the opening of each stage (3), resulting in low pressure, vacuum (4).

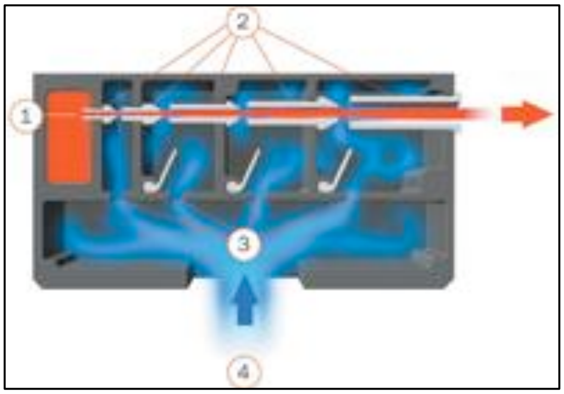


Figure 3: Vacuum Diagram

Suction Cups

A suction cup adheres to a surface when the surrounding pressure (atmospheric pressure) is higher than the pressure between the suction cup and the surface of the object. To create the low pressure in the suction cup it is connected to a vacuum source. The lower the pressure, the higher the vacuum in the suction cup — resulting in increased lifting force.

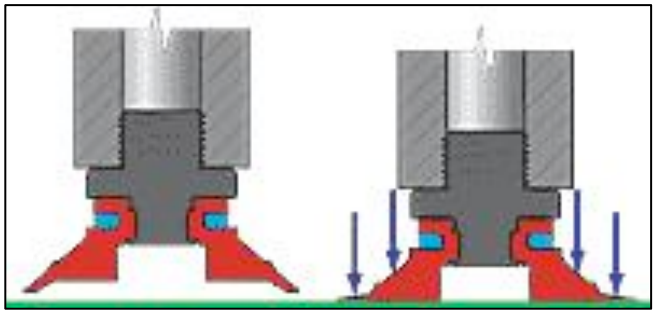


Figure 4: Suction Cup Diagram

Suction cups should not be exposed to unnecessarily high vacuum levels. Too high vacuum levels will cause unnecessary wear and require more energy. With an increase of the vacuum level from 18 -inHg to 27 -inHg the lifting force increases by 20–40% while the energy requirements are increased by a factor of 10.

Since the lifting force is directly proportional to the area of the suction cup, it is better to maintain a lower vacuum level and increase the area of the suction cup when more lifting force is required.

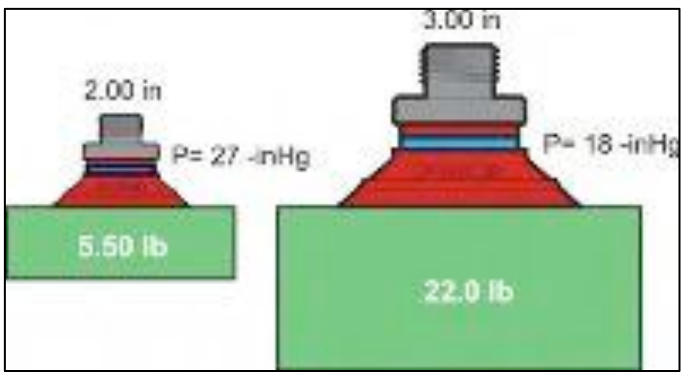


Figure 5: Suction Cup Lifting Force

The lifting force can be perpendicular or parallel to the surface to be handled. The values are based on sample data for a dry steel plate. When sizing a suction cup, the weight of the object to be handled should be multiplied by a minimum factor of 2 for increased safety.

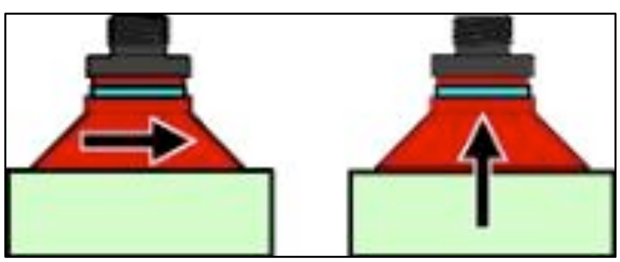


Figure 6: Vertical And Lateral Suction Force

Applications

Vacuum grippers (a combination of suction cup and vacuum pump) can be used to grab or lift a variety of materials, including:

- Corrugated boxes/containers
- Sheet metal
- Glass
- Wood
- Plastic

In addition to these materials, vacuum grippers are capable of gripping both convex and concave surfaces, depending on the type of material and its rigidity.

2.0 Design Concepts

During the brainstorming phase of the project, many different concepts were generated for casing cutting, casing/meat log separation, and casing disposal. In a team evaluation of these ideas, three concept combinations of cutting, separation, and removal were selected for further research and mock-ups: the Drive, Slice, Separate; the Slice, Suck, Roll; and the Slice, Suck, Roll Hot-Wire adaptation.

2.1 Concept Layout

One component of the PDS states that the design should easily integrate with the assembly line. Proposing a design that is cumbersome to install is both unproductive and inefficient. Companies do not want a solution that involves changing the factory floorplan. Thus the type of layout for each idea was constantly considered. The figures below illustrate the two ways the design could integrate with the assembly line.

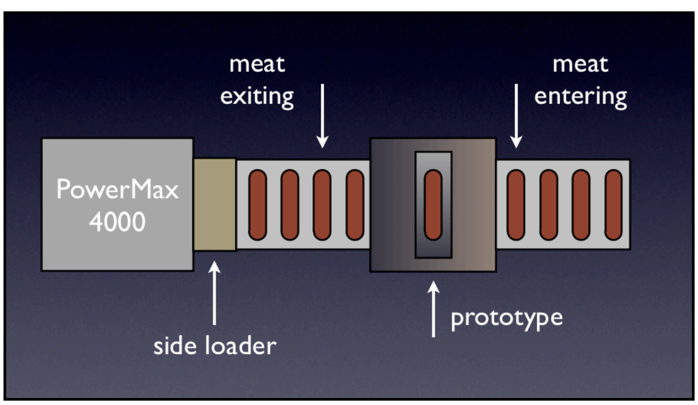


Figure 7: Transverse Concept Layout

A transverse loading method is one of the two preferred loading techniques. Compared to the Webber CCP, this layout reduces the overall size of the machine, as it only needs to be as long as one meat log (in this case, one meter). (Note that the PowerMax 4000 is the industrial packaging machine that the product enters, once the casing has been removed).

Axial loading is the other type of loading that is preferred. Figure 8 below illustrates this concept.

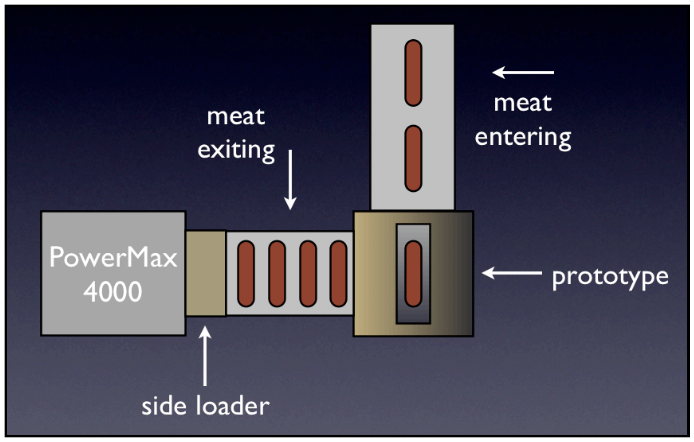


Figure 8: Axial Concept Layout

As with the transverse layout, the axial layout also reduces the footprint of the machine. However, both the width and the length need to be one meter long, imposing an additional constraint on one of the dimensions. But compared to the Webber CCP, this layout is in fact smaller.

Knowing that the design needed to fit into either of these layouts, more feasible concepts could be determined. The following subsections describe the two highest scoring concepts.

2.2 DSS - Drive, Slice, Separate

In the DDS concept (Drive, Slice, Separate) the meat log is loaded axially into the system. An initial drive mechanism then engages the meat log, driving it forward into a set of spring loaded knife arms which cut the front and sides of the casing. While the product is still being sliced down the sides, the front is engaged by a pair of jaws whose purpose is to separate the two halves of the casing from the meat log. As the now partially bare meat log moves through the separating jaws it is then engaged by a second drive mechanism which pulls the bare meat product out of the machine. The single piece of casing (split in half) is then pulled down and out of the machine through a hole from below the bottom separation jaw.

Due to the mechanical complexity of the concept, the mockup was just a simple visualization of how the system would work. The drive mechanisms are represented by square white pads of foam core at the entry and exit of the system. The knife arms are also represented by foam core, but are actually capable of moving when a bar of PVC (which represents the meat product) is driven into them. The separating jaws are fixed in the position they would be in after having already engaged and begun separating the casing from the meat product.

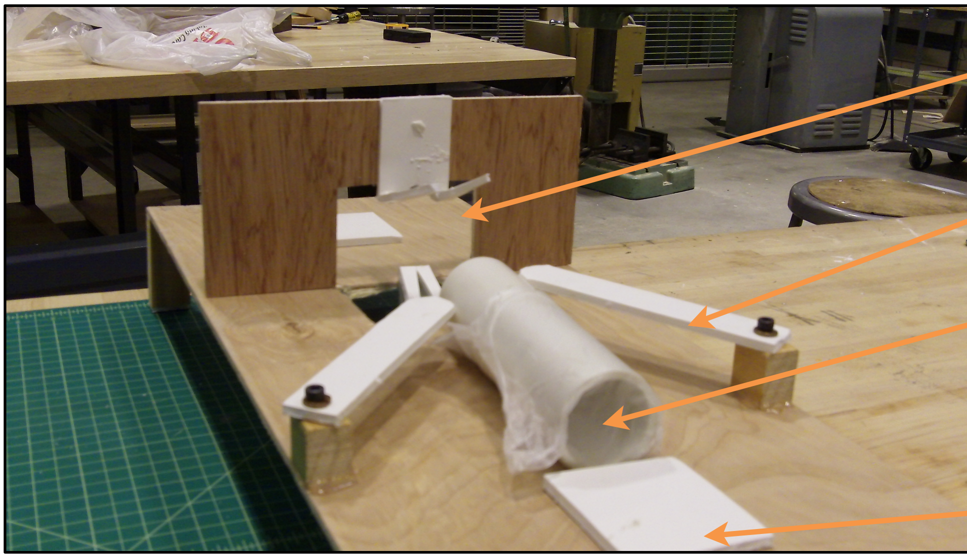


Figure 9: DSS Mock Up

2.3 SSR - Slice, Suck, Roll

In the SSR concept (Slice, Suck, Roll) the meat log is loaded laterally into the system. While it is being loaded, two shear mechanisms remove the ends of the meat log, like scissors. This results in a cylindrical meat log, covered in cellulose casing, save for the ends. The truncated meat product then falls into a "V" shaped trough. While in the trough, a knife runs down the length of the meat product, making one long cut from end to end. A series of vacuum grippers then grip onto one end of the newly cut casing. Then, one end of the trough moves into a declined position, allowing the meat log to roll out, while the vacuum grippers still hold the casing. Once the meat log has evacuated the area, the vacuum grippers disengage and the casing falls into a disposal chamber.

This was another mechanically complex concept and as such, the mock up was a "looks like" rather than a "functions like." The only moving part of the mockup was the trough, which was capable of falling to a declined position with the removal of a pin. The vacuum grippers were represented by holes drilled in the stationary half of the trough, and the knife was represented by a small blade placed adjacent to the vacuum grippers.

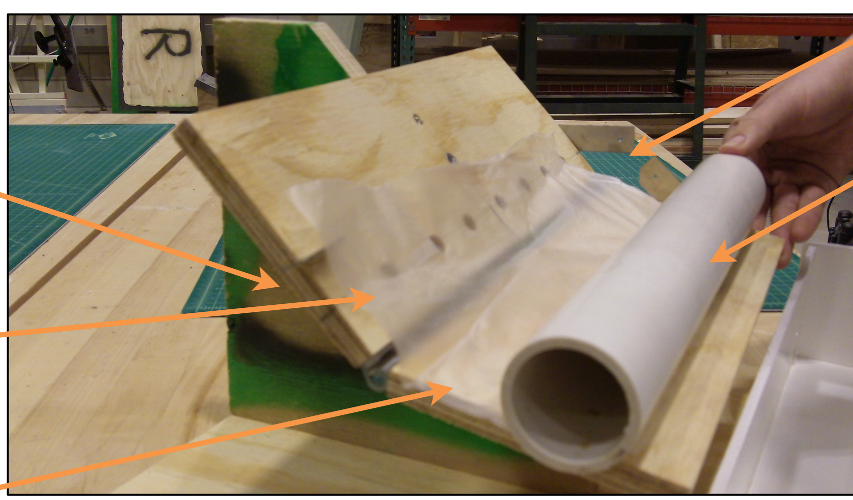


Figure 10: SSR Mock Up

2.4 SSR - Hot Wire

In the Hot-Wire adaptation of the SSR concept the meat log is still loaded laterally, and the casing gripping mechanism is still vacuum grippers, but that is where the similarities end. In this concept the meat log is in continuous motion. As it rolls down, the meat log casing is cut length-wise by the top center section of the hot-wire. As it continues to roll, the vacuum grippers adjacent to the top section of hot-wire contact the meat log casing. Simultaneously, the ends of the casing are cut around the circumference of the meat log, allowing the meat log to roll out of the casing. When the meat log has rolled out and all that remains is the unrolled casing, it is pulled down into the disposal hole in the center by redirected vacuum force, previously used to power the vacuum grippers.

As this idea was a later adaptation of the SSR concept, it was not mocked-up. The image below shows the different aspects of the concept, including: Meat log, hot-wire, vacuum grippers, disposal hole, and decline.

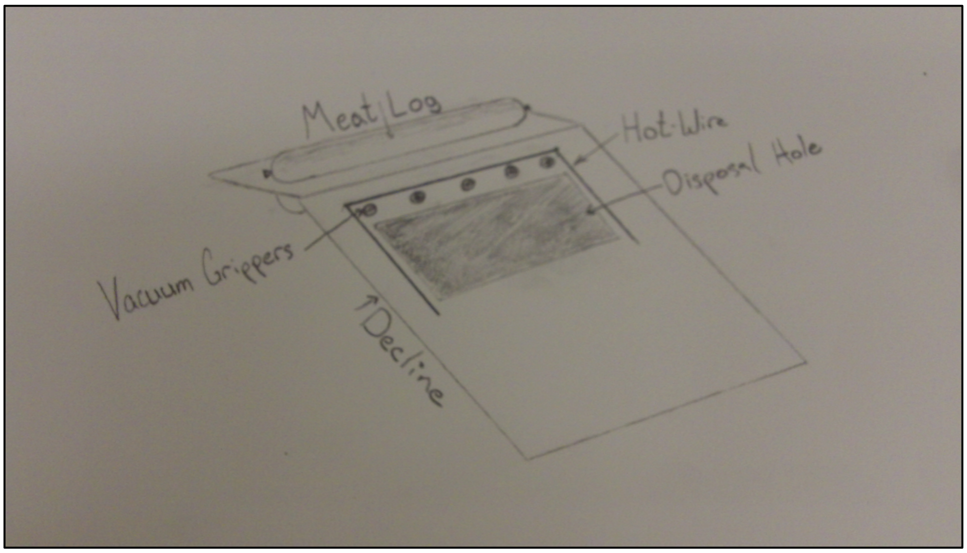


Figure 11: SSR Hot Wire Possible Mock Up

2.5 Concept Selection

After brainstorming a list of several dozen concepts, including combinations of many different methods of cutting, separating, and disposing of meat product casing, the top five ideas were selected: DSS, SSR, SSR-Hot Wire, Laser Vacuum, and Helical Slice. The two concepts that were not described in the previous sections were the Laser Vacuum and the Helical Slice. The benefits of the Laser Vacuum idea were virtually no damage to product, effective repeatability and cleanliness; the detriments were large assembly line footprint, cost, and size. The benefits of the Helical Slice idea were process speed, small footprint and small damage product; the detriments were poor repeatability, and maintenance/cleanliness issues.

The design of the one major competitor, the Webber CCP, was also extensively researched and studied. This was used as a reference to with which to base the quality of the concepts. Based off of the Product Design Specifications, a list of Selection Criteria was created. Each concept was graded according to how well the met these selection criteria. They included:

- Process Speed
- Damage To Product
- Safety
- Maintenance
- Cost
- Reliability
- Ability To Be Easily Implemented Into Assembly Line

A concept screening matrix was generated to make initial comparisons to the Webber CCP, the reference. In doing so, each concept was given a score of either a +, 0, or - as compared to the reference. For example, it was believed a particular concept would perform better in one selection criterion, the score was a +. If a concept would theoretically perform as well as the reference, it was scored with a 0. This was done for all the concepts and the results can be seen below in Table 1.

After all the evaluation was complete, each concept's score was totaled. Based on the results, all of the concepts performed as well or better than the Webber CCP. Thus, each idea was competitive enough to pursue further development, with the SSR and the DSS having the highest probability of success.

	Webber CCP	**SSR**	**DSS**	**Laser Vacuum**	**Robotic Grab and Slice**	**Helical Slice**
Selection Criteria						
Process Speed	0	+	+	0	0	+
Damage to Product	0	-	+	+	+	+
Ability to Integrate into Line	0	+	+	-	+	+
Assembly Footprint	0	+	+	-	+	+
Safety	0	0	0	+	0	0
Maintenance	0	+	0	+	-	-
Cost/Complexity	0	+	+	-	0	+
Reliability	0	+	0	+	0	-
Sum +'s	0	6	5	4	3	5
Sum 0's	8	1	3	1	4	1
Sum -'s	0	1	0	3	1	2
Net Score	0	5	5	1	2	3
Rank		1	1	5	4	3
Continue?		YES	YES	NO	NO	NO

Table 1: Concept Screening Matrix

2.6 Concept Scoring

The only useful information the concept selection provided was wether or not an idea was worth pursuing past its initial brainstorm phase. To narrow down the pool of ideas to ones worth researching, a concept scoring matrix was used. The theory behind concept scoring is simple: each criterion is given a weight, proportional to its importance in the scope of the design and its role in the PDS. The rank of criteria for this project are as follows:

1. Process Speed (35%):

   This criterion describes how quickly the concept would theoretically remove the casing. Because one of the main requirements in the PDS was to provide a throughput of at least 4-6 logs/ minute, this criterion was weighted the heaviest. It also makes sense when considering an assembly line environment: when a machine breaks down, the whole factory may come to a stop. Concepts with a high risk of downtime should not be considered for this project.
2. Assembly Footprint (20%)

   This criterion describes what kind of presence the concept would have in the assembly line. For example, if the concept required a lot of power or lots of air hose connections, it would have a relatively high assembly line footprint. Rearranging components in an assembly line environment is cumbersome and thus the concept should be as simple as possible. A high assembly line footprint would be counterproductive to the scope of the project and thus this criterion was assigned a high weight.
3. Reliability (15%)

   This criterion was weighted third. Again, because the design will be used in an assembly line setting, if it is not reliable, it can prove costly to the company. Frequent maintenance results in more downtime which means less profit for the company. The design should be as robust an reliable as possible.
4. Damage To Product (10%)

   The design cannot damage the product because, after all, the product is being prepared for commercial packaging. If increased damage to product is sacrificed for increased throughput, then the design specifications were not met. Note that Formax currently shears the ends of the meat log off and this does not constitute as damage to produce. Slicing several millimeters into the product to remove casing, thereby leaving a visible mark does constitute as damage to product.
5. Maintenance (7.5%)

   Machines in the meat packing industry are subject to frequent wash down procedures. Thus the design should be relatively easy to fix should problems arise. If small components are used, then access to them should not be restricted.
6. Integration Into Assembly Line (7.5%)

   The design should fit nicely into the assembly line. If several additional hoses and or connections need to be brought to the machine, then its likelihood of being incorporated into factories will be low. Ideally, the design should be small enough, so that it can be installed in any assembly line environment with little effort. Additional problems concerning installation should not arise
7. Safety (3%)

   The main objective of the project is to automate the casing removal process. Thus, the machine will have little human contact and as such, safety should not be an issue. Of course necessary protection will be implemented (*i.e.* guards on blades to prevent accidental puncture) but overall, safety should not be a huge concern. Thus its weight is relatively low.

Each criterion was given a score (1-10) based on its performance to the reference. If a concept performed much better than the reference in a particular criterion it would be given a score of 9 or 10. If it performed equally to the Webber CCP then it would be given a score of 5. If it performed worse than the Webber CCP, then it was given a score of 1 or 2. The weight of each criterion is multiplied by its rank, yielding a weighted score. These weighted scores were totaled and the results can be seen in Table 2.

As with the concept selection, the two highest scoring ideas were the DSS and the SSR. This information further verified that these concepts should be further pursed. Note that the Hot Wire SSR concept was not included in this stage because it had not yet been conceived.

3.0 Initial Experimentation

A variety of tests were conducted to prove concept feasibility. These included experiments with vacuum suction force, force measuring experiments and hot wire tests. These experiments will all be discussed in detail in the following sections. Mathematical analysis was also done to verify concept performance. The results of all this work aided in determining the appropriate material for the final prototype.

3.1 Vacuum Test

The goal of the first test was to prove the feasibility of the vacuum casing removal concept. Using vacuums to grip the casing is a critical component of the Slice, Suck and Roll concept and thus it's success needed to be

		Webber CCP (reference)		SSR		DSS		Laser Vacuum		Robotic Grab and Slice		Helical Slice	
Selection Criteria	Weight	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Process Speed	0.35	5	1.75	8	2.8	8	2.8	7	2.45	6	2.1	8	2.8
Damage to Product	0.1	5	0.5	3	0.3	6	0.6	10	1	6	0.6	6	0.6
Ability to Integrate into Line	0.075	5	0.375	10	0.75	7	0.525	4	0.3	8	0.6	7	0.525
Assembly Footprint	0.2	5	1	9	1.8	7	1.4	4	0.8	8	1.6	7	1.4
Safety	0.03	5	0.15	5	0.15	5	0.15	7	0.21	5	0.15	5	0.15
Maintenance	0.075	5	0.375	7	0.525	6	0.45	7	0.525	4	0.3	4	0.3
Cost/Complexity	0.02	5	0.1	8	0.16	7	0.14	3	0.06	5	0.1	7	0.14
Reliability	0.15	5	0.75	7	1.05	4	0.6	8	1.2	4	0.6	4	0.6
Total Score		5		7.535		6.665		6.545		6.05		6.515	
Rank				1		2		3		5		4	
Continue?				YES		YES		NO		NO		NO	

Table 2: Concept Scoring Matrix

verified. A square piece of aluminum tubing was used to simulate the trough. Twelve 1/8" diameter holes were drilled down one side to simulate the vacuum grippers. The end was sealed by hot-gluing a piece of aluminum across the cross section of the bar. The other end of the bar was attached to a 6.5 HP shop-vac via rubber tubing and the connection was sealed with duct tape. This provided a relatively strong air-tight seal between the tube and the hose. The entire apparatus can be seen below in Figure 12.


Figure 12: Vacuum Testing Apparatus

Actual meat product was tested with the apparatus. A 6" long sample was used in the experiments by slitting the casing axially. When the shop-vac was engaged, a vacuum sucking force was generated in the hollow metal tube. The casing was applied to the bar and when the log was slowly unrolled, the casing remained in contact with the bar. This can be seen in Figure 13 below.

This test verified that holding on to the casing with a vacuum force is a viable option. The test was also successful under non ideal conditions. The shop-vac provided very minimal vacuum force and if the concept were to be incorporated in an industrial setting, the force provided by air-compressors would probably be upwards of 5 times greater. Indeed it is promising that the concept worked with the minimal force provided by a shop-vac.

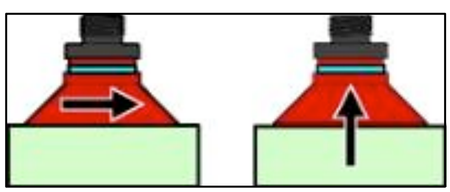


Figure 13: Suction Cups Gripping Casing

3.2 Casing Removal Test

Knowledge that vacuum suction would be a viable method of casing removal, the next step was to determine the amount of force required to remove the casing. A Shimpo FGV-50XY Force Gauge was used to determine this information and was attached at the top of the bracket. A metal bracket was used to attach the meat log to the testing apparatus. This was done by bending a fork and puncturing either ends of the meat log. A picture of the testing apparatus can be seen in Figure 14 below.

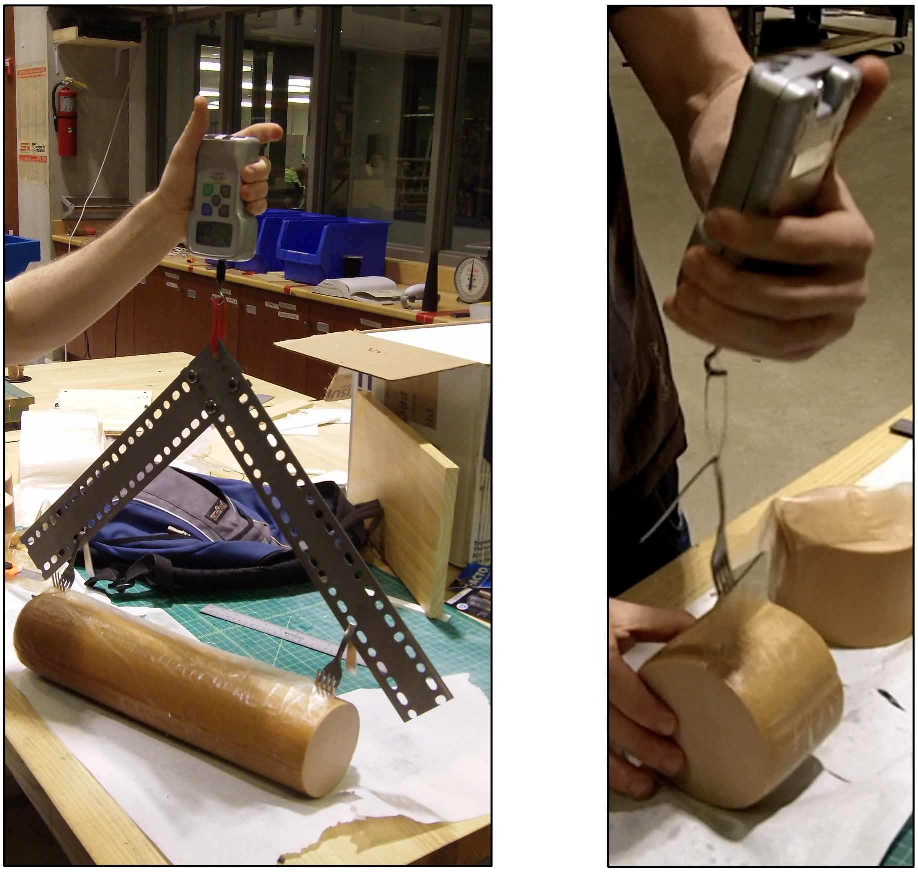


Figure 14: Casing Removal Test Fixture

The tests were scaled appropriately, as it was not practical to conduct tests with full length meat logs. Also, the amount of meat product available for testing was limited, and thus had to be conserved. Also, tests of this nature are unrepeatable and thus precautions had to be taken as to not compromise the results. These included

- Portions of 3" long and 18" long meat logs were used during the experiments. Using smaller portions of product allowed for more tests. Conducting tests with the larger log allowed for proportional comparison, further verifying that the results made sense
- The bracket included lots of holes, allowing for possible adjustments. The fork could be repositioned in order to get the best results
- The bracket was also constructed out of industrial-grade aluminum, which was found in the Northwestern machine shop. This material was ~1/8" thick and would not deflect at all under the load of the meat log.

A slit was made down the length of the log. When the bracket was pulled upwards, the force required to peel the casing was transferred to the dynamometer. The simple testing procedure allowed for several experiments to be conducted. The results of the tests can be seen below in Table 3.

Trial	Length Of Log (in)	Force Registered (N)
1	3	0.2
2	3	0.16
3	3	0.12
4	3	0.1
5	3	0.19
6	18	1
7	18	0.9
Avg (3 in)		0.154
Avg (18 in)		0.95

Table 3: Casing Removal Test Results

As the above table shows, the force required for 3" long logs was in the vicinity of .15 Newtons. This force was just a little more than the force required to move the bracket against gravity. To check the consistency of these results, 18" long logs were tested. The results were in the vicinity of 1 Newton which was approximately 6 times that of the 3" long logs. These numbers are proportionally reasonable given the testing environment.

3.3 Cutting Force Test

Blade geometries and cutting forces were determined with the next phase of testing. A fixture to measure the knife force was constructed. It was composed of a height adjustable rotating arm mounted in a wooden frame. One end was machined to hold an X-acto blade and the other end was attached to the same dynamometer used for the casing tests, the Shimpo FGV-50XY. The entire apparatus can be seen below in Figures 15 and 16.

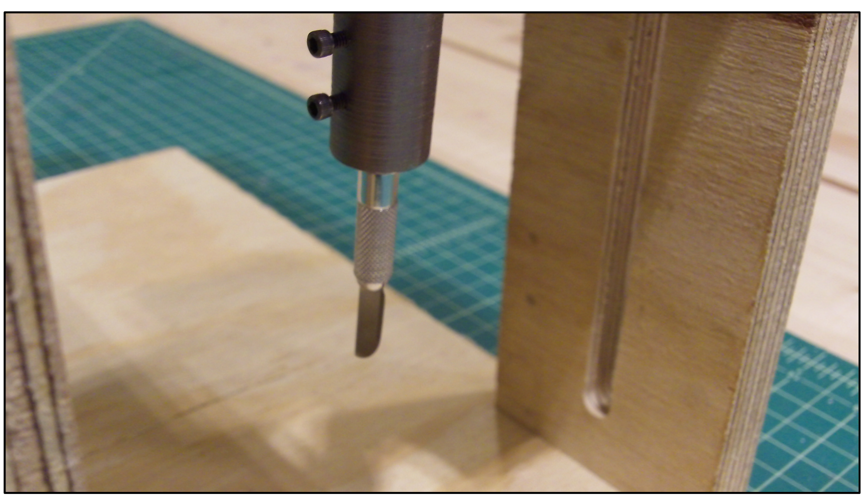


Figure 15: Knife Assembly Of Cutting Force Test

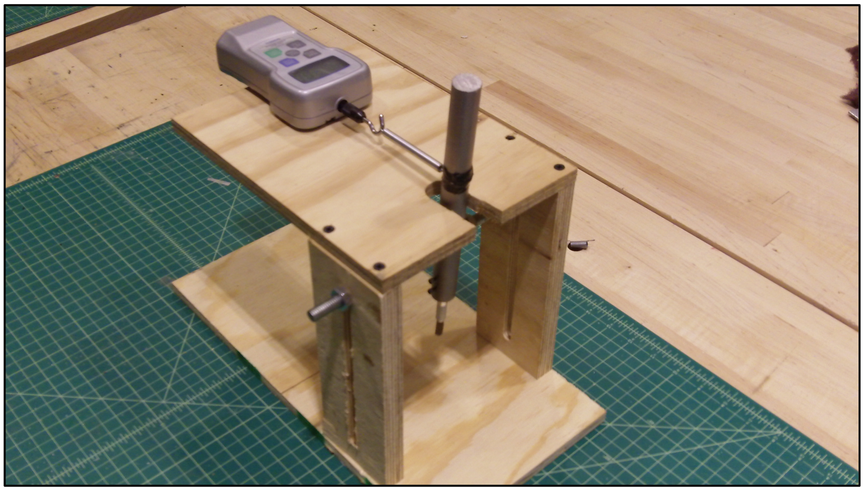


Figure 16: Cutting Force Test Fixture

Performing the actual tests was actually quite easy. The log was slid under the blade so that the cut was made approximately in the middle of the log, per the same orientation used on an assembly line. The results would be much more meaningful the closer the simulation was to actual industrial performance.

Two blade geometries were tested with this apparatus: straight and curved. Previous research suggested that these two geometries would be the most efficient at removing the casing. After several trials were completed with the various blade geometries, a definite pattern began to emerge. From Table 4, it is evident that the straight blade requires significantly less force to puncture the casing as compared with curved blades. Thus the prototype should incorporate straight blades, should blades be included in the design.

Trial	Force Registered (Straight Blade) N	Force Registered (Curved Blade) N
1	4.4	5.4
2	2.8	6.7
3	4.1	5.1
4	4.6	6
5	5.1	5.9
6	5.5	5.5
Average	4.41	5.77

Table 4: Cutting Force Test Results

It is important to note that these values represent the force required to engage the blade with the casing. The force to cut through the casing once the blade has punctured the surface is rather trivial.

3.4 Hot Wire Test

After the initial concept selection was conducted, a modification was made on the original SSR concept. This modification entailed heating a thin wire to cut through the casing. The theory behind this idea is simple: a thin wire has some resistance, enough to create a small voltage potential across the ends. If lots of current is pumped through the wire, it should get hot enough to cut through cellulose casing. Per the background research discussed earlier, this is a viable method of cutting plastic, already used in industry. It was thought that it would be possible to modify this concept and apply it to this project. The wire should get hot enough the cut the casing but not damage the product. Several benefits to using a wire exist:

- Wires do not need to be resharpened
- It is inexpensive to replace the wire, should it become damaged or worn
- No moving parts required
- No special power supply required: simple DC power at minimal voltage is required

The only concern with this concept is the arguably dangerous current levels needed to heat the wire to workable temperatures. Upwards of three amps may be required to heat the wire.

The research on this concept indicated that the best type of wire to use was nickel-chromium with a gauge between 10 and 20 thousandths. The wire in this range has low enough resistance, but it is molecularly strong enough to withstand the high temperatures generated when amps of current are passed through it.

The testing of this concept proved very easy, as can be seen in Figure 17 below. A small length of wire was cut and two leads from a DC power supply were attached at both ends. Setting the current to it's maximum, the voltage was increased incrementally until the wire became visibly red-hot.

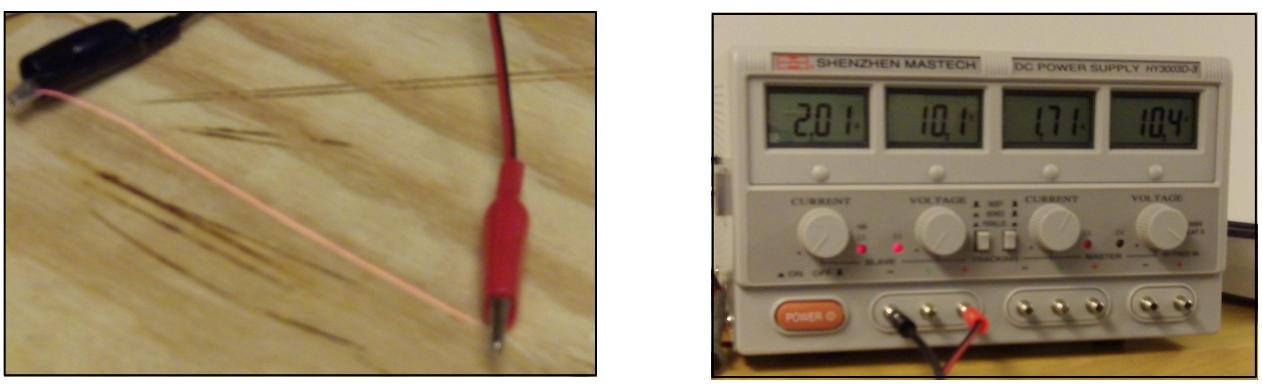


Figure 17: Hot Wire Test Fixture With DC Power Supply

All the tests were conducted with 3" long meat logs. Variables in the testing procedure included the diameter of the wire and the contact time the wire had with the product. In alternating the contact time, it was hoped that the effects of possible searing of the product might be observed or whether better separation of the casing and product occurred.

The tests were conducted initially with 12.5 thousandths wire and the results from all these tests can be seen in Table 5 below. The thinnest wire in the testing pool, the 12.5 thousandths wire heated up the fastest. Unfortunately it never successfully separated the cellulose casing from the meat log. This was because the wire was too thin to retain any energy once it came in contact with the near-freezing meat log (remember that the meat logs are kept at ~35° F to keep them rigid, improving the quality of cut). Since the wire's energy was almost instantaneously dissipated, the resulting cut resembled a perforation like that in a notebook or chequebook.

To try to overcome this problem, thicker wire was used. Thicker wire, it was believed, could hold more energy and thus would not cool down as fast when brought into contact with the meat log. The next group of tests conducted utilized 15.9 thousandths wire. Using the same test layout, the results with the thicker wire were less promising. The thicker wire, inherently, had more resistance and thus required a bigger voltage potential to garner any kind of workable temperature. Even after waiting for several minutes, the wire did not heat up to searing temperatures.

The same behavior was observed with the 20.1 thousandths wire. These thicker gauges of wire required more current than the DC power supply used could source. As noted in the table, the current setting was at its maximum at 3 amps but the voltage potential across the lead was less than 10. Thus the wire could not heat up to a temperature that would sear the cellulose casing. Had more power been available, the thicker gauges of wire may have heated up to workable temperatures. As such, this concept was not successful and thus further research and development was halted. It was decided that conventional blades would be used in remaining concepts. It should be noted that incorporating the hot wire concept is still a viable option, if the proper power supplies are available.

Tests With 12.5 Thousandths Wire					
Trial	Voltage (V)	Current (A)	Contact Time (sec)	Level Of Burn (1-5: 5 is Unacceptable)	Level Of Casing Removal (1-5: 5 is Completely Removed)
1	15	1.78	2	2	3
2	15	1.82	11	3	3
3	20	2.34	4	3	3
4	20	2.38	8	4	3
5	25	2.91	3	3	4
6	25	2.89	11	4	4
Tests With 15.9 Thousandths Wire					
Trial	Voltage (V)	Current (A)	Contact Time (sec)	Level Of Burn (1-5: 5 is Unacceptable)	Level Of Casing Removal (1-5: 5 is Completely Removed)
1	5	2.01	3	2	2
2	5	1.98	8	3	3
3	10	2.5	5	3	2
4	10	2.6	10	3	3
5	13	2.97	2	2	3
6	13	3	12	2	3
Tests With 20.1 Thousandths Wire					
Trial	Voltage (V)	Current (A)	Contact Time (sec)	Level Of Burn (1-5: 5 is Unacceptable)	Level Of Casing Removal (1-5: 5 is Completely Removed)
1	3	2.4	2	1	1
2	3	2.6	9	1	1
3	5	2.8	3	2	1
4	5	2.75	11	1	1
5	9	3	3	2	2
6	9	3.01	10	2	2

Table 5: Hot Wire Test Results

4.0 Final Design

After analyzing the results from the test performed, it was concluded that the original Slice, Suck and Roll design would offer the best engineering solution. Though it would have been nice to incorporate the hot wire into the scope of the SSR, the results from the experiments and the resources available did not justify its inclusion. Thus, computer assisted drawings (CAD) with SolidWorks were done. Component integration was discussed, allowing for easy assembly once the parts were machined. The following sections describe the prototype in detail.

4.1 Design Overview

Figure 18 below shows an isometric view of the final prototype: the **A**utomatic **M**eat **Ca**sing **R**emover, also known as **AMCaR**. It is composed of several subassemblies, all of which will be discussed in further detail.

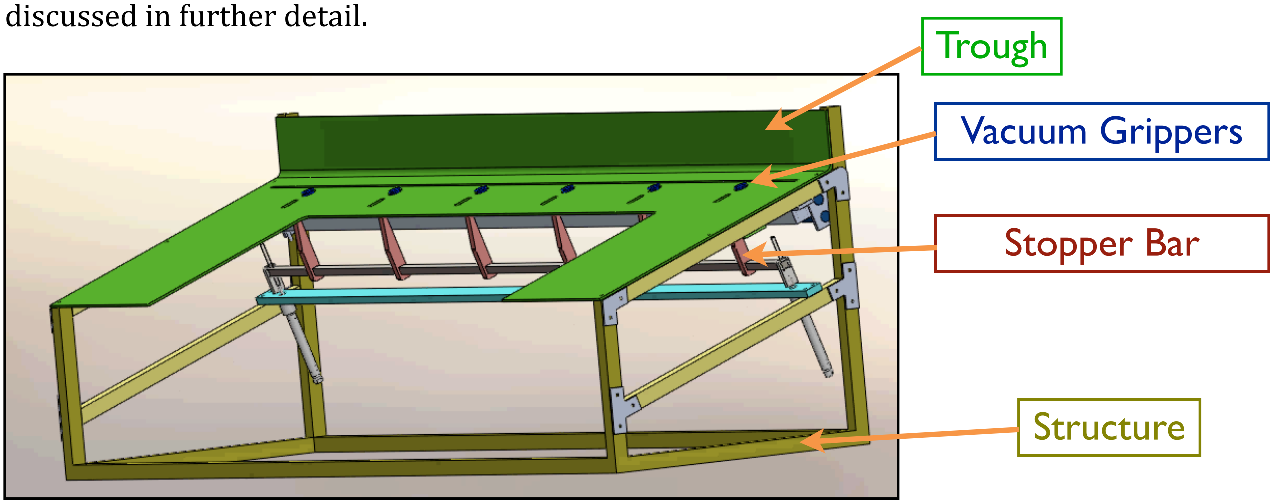


Figure 18: Isometric View Of AMCaR

One major benefit of AMCaR is its simplicity. There are 5 major steps involved with the AMCaR design as compared to about 15 steps with the Webber CCP. The flow chart in Figure 19 (seen below) illustrates the functionality of AMCaR. This flow chart serves as a simple exemplification as to the basic functions of AMCaR.

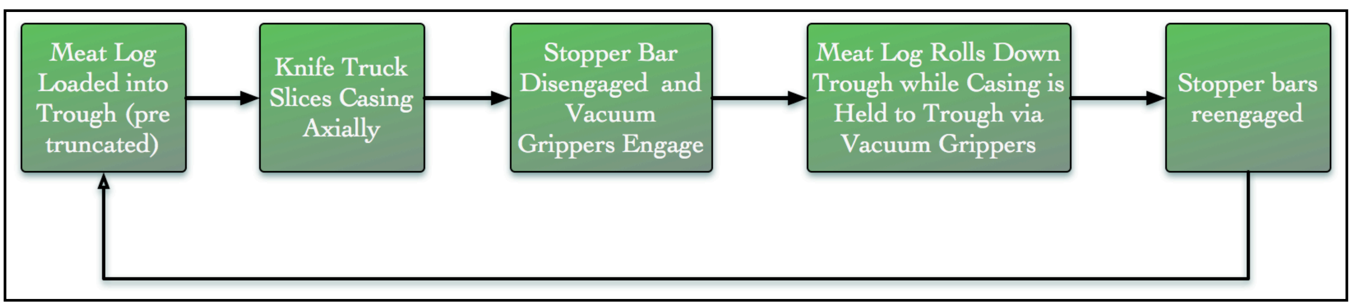
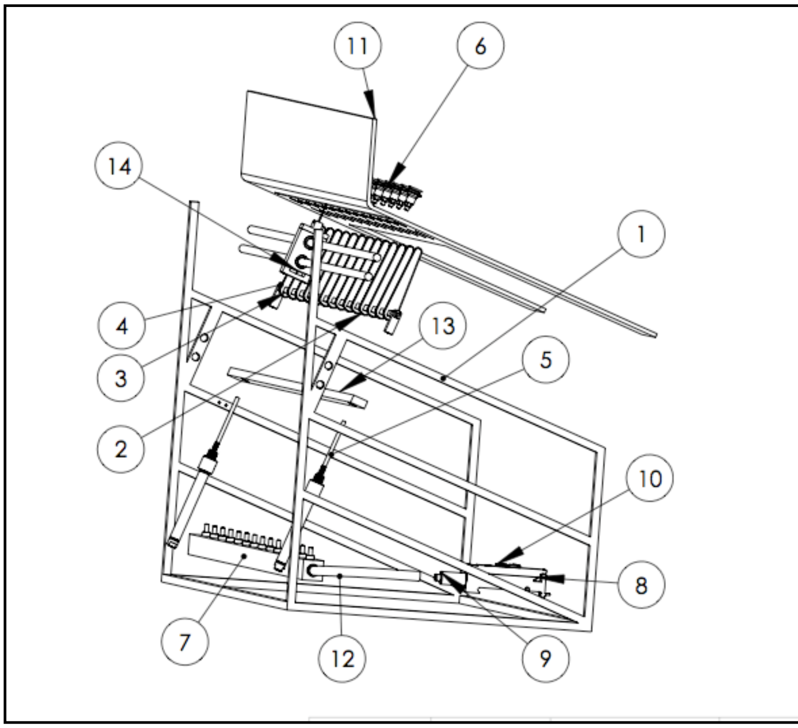


Figure 19: AMCaR Flow Chart

Note that several steps occur simultaneously. For example, when the meat log rolls down the trough, the vacuum grippers engage the casing, separating it from the product. These simultaneous processes are just one facet of the design that makes it so preferable to the Webber CCP and why it is believed the actual throughput testing will in fact yield higher results.

The layout of AMCaR is consistent with the discussion in Section 2.1. The log is loaded transversally into the trough and thus the size of the trough only has to be one meter wide. Also note that because meat logs are loaded transversally into AMCaR there is no explicit length constraint. The trough has to be long enough for the casing to lay flat.

Figure 20 illustrates the subsystems and components of AMCaR.



ITEM NO.	PART NUMBER	QTY.
1	Support Structure	1
2	Stopper Bar 2	14
3	Stopper Bar Shaft	1
4	Pneumatic Attachment Arm	2
5	Pneumatic Cylinder	2
6	B15-2.10.01AC	14
7	Hose Connection Bar	1
8	Vacuum Pump Housing	1
9	Vacuum Pump Nozzle	1
10	Vacuum Pump Unit	1
11	Trough 2	1
12	Hose	1
13	Mounting Bar for Pneumatic Pumps	1
14	Knife Assembly	1

Figure 20: Exploded View Of AMCaR

4.2 Knife Truck Subassembly

The knife truck subassembly is located on the back of AMCaR. Two metal bars run along the width of AMCaR which guide the knife truck (see Figure 22). The truck itself is composed of small blocks of aluminum. The blade rests atop the block, secured by two set screws. An exploded view of the subassembly can be seen below in Figure 21.

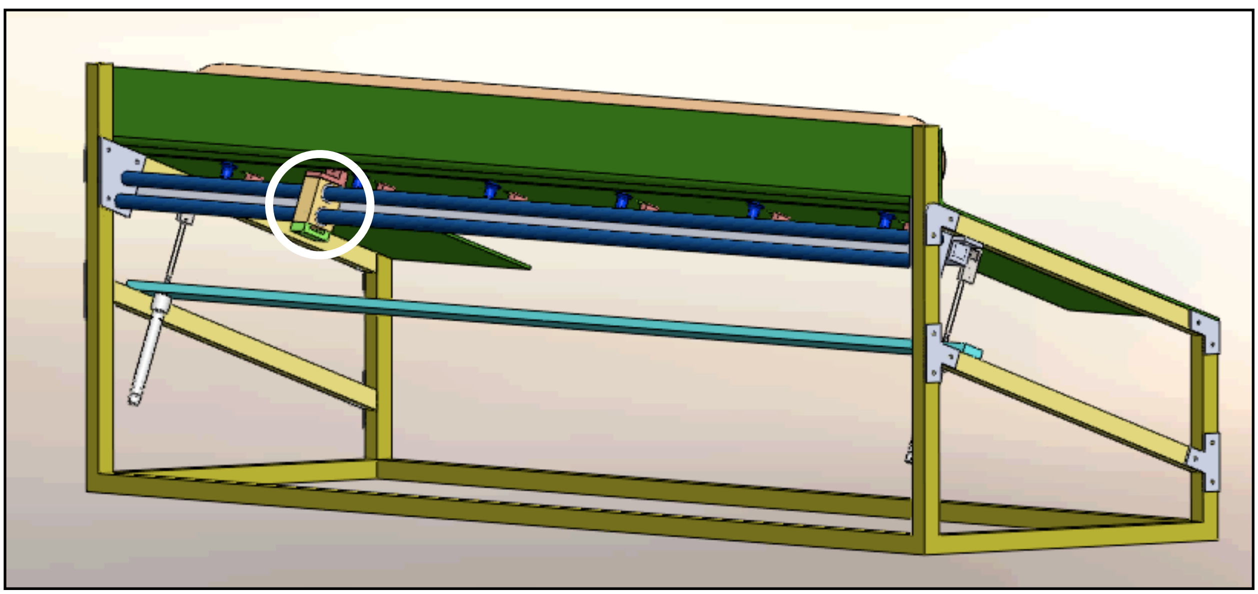
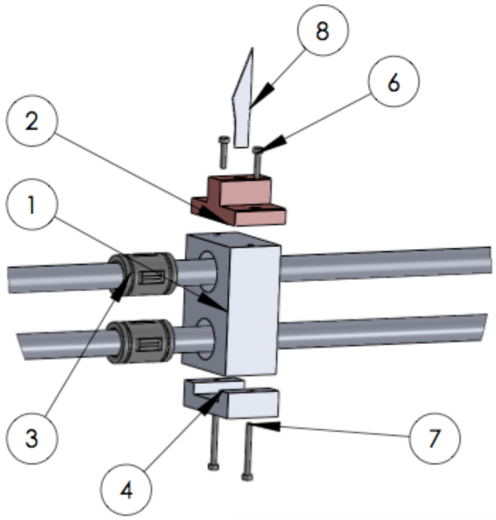


Figure 21: Knife Truck Subassembly Location (denoted by circle)



ITEM NO.	PART NUMBER	QTY.
1	Knife Truck	1
2	Knife Holder	1
3	6489K61	2
4	Belt Attachment for Knife Truck	1
5	Knife Truck Holding Bar	2
6	B18.3.1M - 2 x 0.4 x 10 Hex SHCS -- 10NHX	2
7	B18.3.1M - 2 x 0.4 x 20 Hex SHCS -- 16NHX	2
8	Blade	1

Figure 22: Exploded View Of Knife Truck Subassembly

4.3 Stopper Bar Subassembly

The stopper bar subassembly prevents the meat log from rolling down the trough before the vacuum grippers are engaged. It is composed of a square aluminum rod to which 5 acrylic stopper fingers are attached. This metal rod is attached to another narrow aluminum rod. This narrow rod acts like a flange which is attached to the pneumatic cylinders. The whole subassembly is attached below the trough and its location can be seen in Figure 23 below.

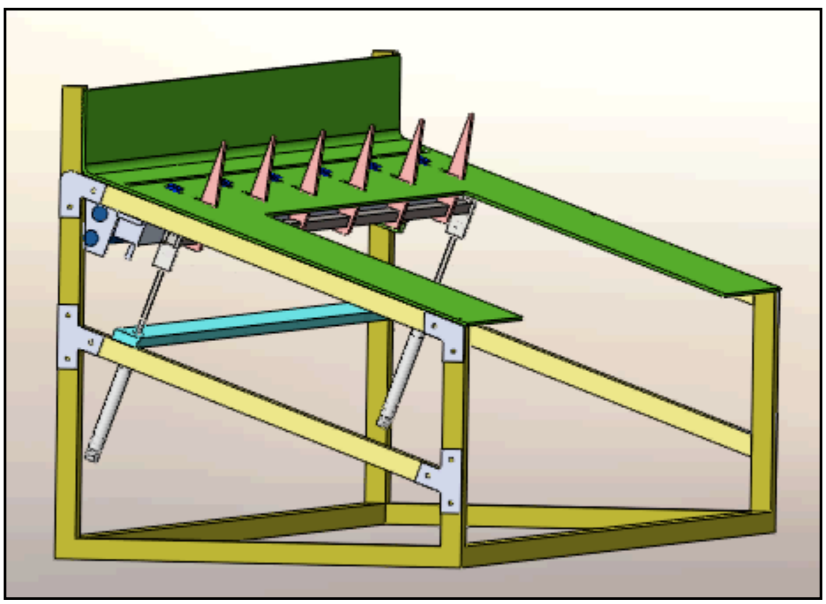


Figure 23: Stopper Bar Location

Holes in the trough allow for unimpeded stopper finger movement. The whole subassembly can be seen in Figure 24

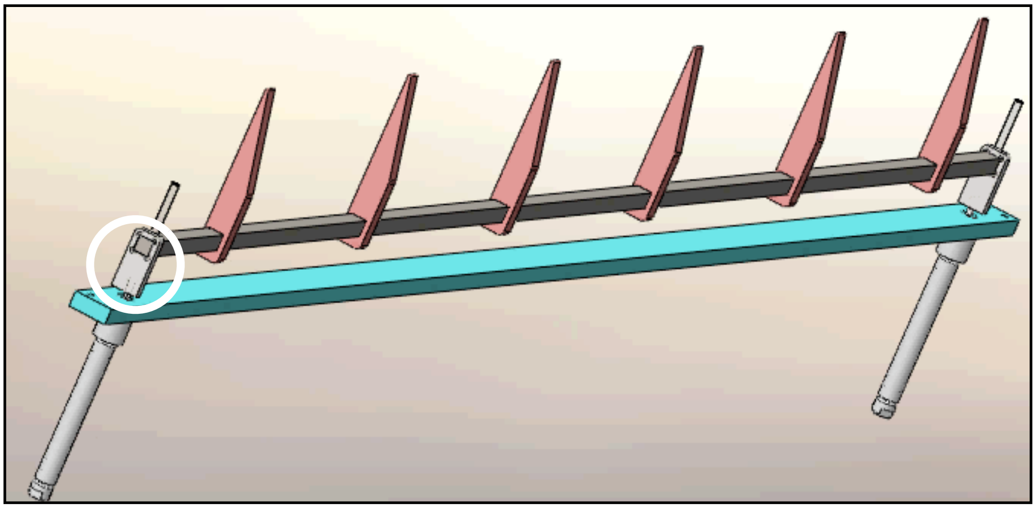


Figure 24: Stopper Bar Subassembly

Note the shape of the fingers. They are curved on one side so that if the pneumatic cylinders engage at different times, the fingers will be guided to the correct position. When disengaged and at its lowest position, the stopper fingers are still in contact with the trough, helping to keep them aligned at all times.

The stopper bar is engaged and disengaged by pneumatic air cylinders, located on either end. Compressed air is already used by many companies and it was determined that this would be the most efficient and safe way to power the stopper bars. When engaged, cylinder actuator extends 3" with 12 lb of force.

Two small metal brackets were machined, one of which is denoted in Figure 24 by the white circle. These two pieces connect the stopper bar to the air cylinders. There is a small threaded hole at the bottom to connect to the threaded actuator on the cylinder. The stopper bar is press fitted into the square hole on the bracket.

The teal bar acts like a big flange so the whole stopper bar subassembly can be attached to the support frame. In future iterations of this design, this piece may be replaced with two small separate flanges at either end.

4.4 Vacuum Gripper Subassembly

The vacuum gripper subsystem prevents the casing from engaging the meat log as it rolls down the trough. They are attached at the top of the trough so that they are in contact with the meat log immediately after it is loaded. The vacuum grippers can be seen in Figure 25 below.

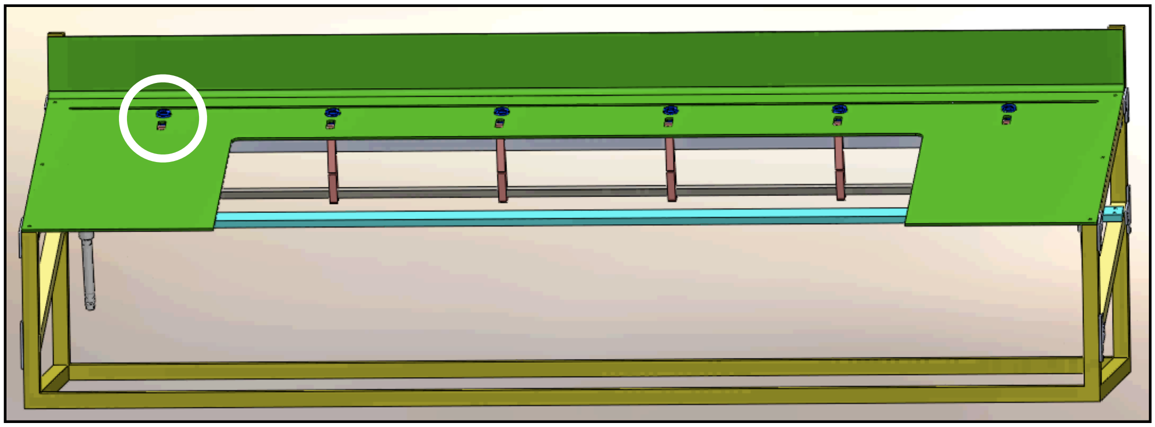


Figure 25: Location Of Vacuum Grippers (one is circled and there are six total)

The grippers are attached to an air circuit that engages when the stopper bar is released. The circuit can be designed so that the retraction intake and gripper intake are attached to the same line. This would ensure that the two systems engage at the same time.

A close up of the subsystem reveals that the grippers actually depress about 1/4". This vastly improves contact with the product. Because of the suction cups' round shape, the contact surface area improves, resulting in a much stronger seal. This further reduces the chance that the casing might slip off as the product rolls down the trough. A close up of the vacuum grippers can be seen in Figure 26 below.

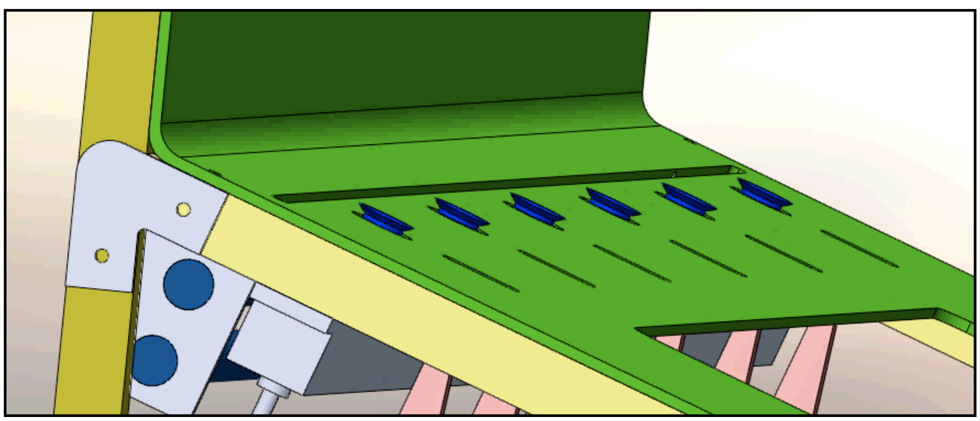


Figure 26: Close Up Of Vacuum Grippers

4.5 Support Structure

The support structure of AMCaR is composed entirely of 80/20 stock, otherwise known as the *Industrial Erector Set.*™ This material is very strong, made out of aluminum. It was chosen for its structural integrity and its customization ability. 80/20 stock is slotted so the height of all the bars in AMCaR is completely adjustable. This makes installation very easy. Because the entire support frame can be disassembled, it can be easily moved or adjusted. Easy installation in an industrial environment is another feature which AMCaR offers, especially when compared to the Webber CCP. The figure below illustrates the concept of 80/20 stock and how it is constructed.

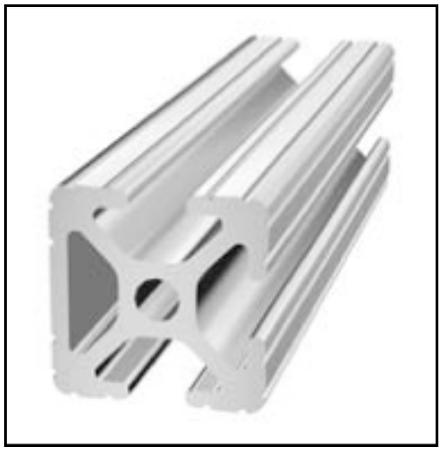


Figure 27: 80/20 Stock

Special t-nuts are inserted in the slots along the length of the bar, allowing them to be attached to each other. This is why 80/20 stock is so adjustable and customizable.

Stock 90 degree brackets were purchased from the 80/20 company, but the special 20° brackets were custom machined. The 20° interface was mitered to improve structural integrity. The bars are extruded from their initial cross section, much like sketches are extruded to solids in CAD software. All of these features make for a very strong and robust frame, capable of supporting the weight of meat logs.

4.6 Trough

The trough is angled at 20° so that the meat log rolls away when the stopper bar is retracted. This geometry was determined after conducting testing. The threshold between rolling and not rolling was desired and 20° was around that threshold. That is, it was desired to have the trough at such an orientation so that the meat log would just barely want to start rolling. A trough angle too steep would result in the log rolling too quickly, which might impact the vacuum grippers effectiveness of maintaining contact with the casing.

Though casing disposal was not part of the scope of AMCaR, the trough was designed with this in mind. The gap in the trough is where the casing would be after the log has rolled off. Once the meat log has rolled off the trough, it will be mostly over the hole of the trough. Redirecting the vacuum gripper air line to the hole should effectively suck the casing into a disposal container. Figure 28 illustrates this concept.

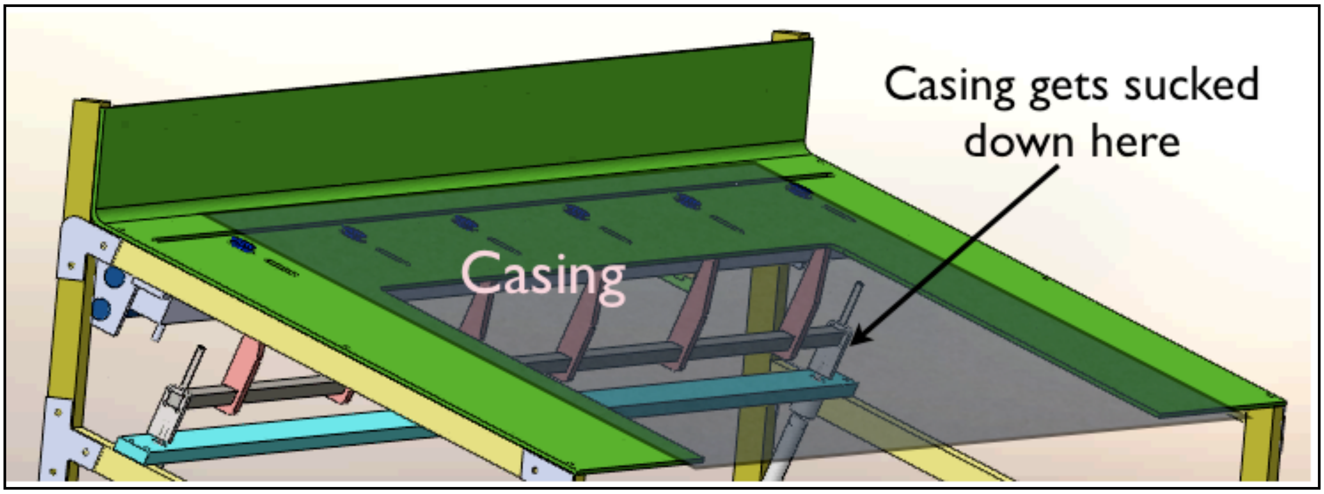
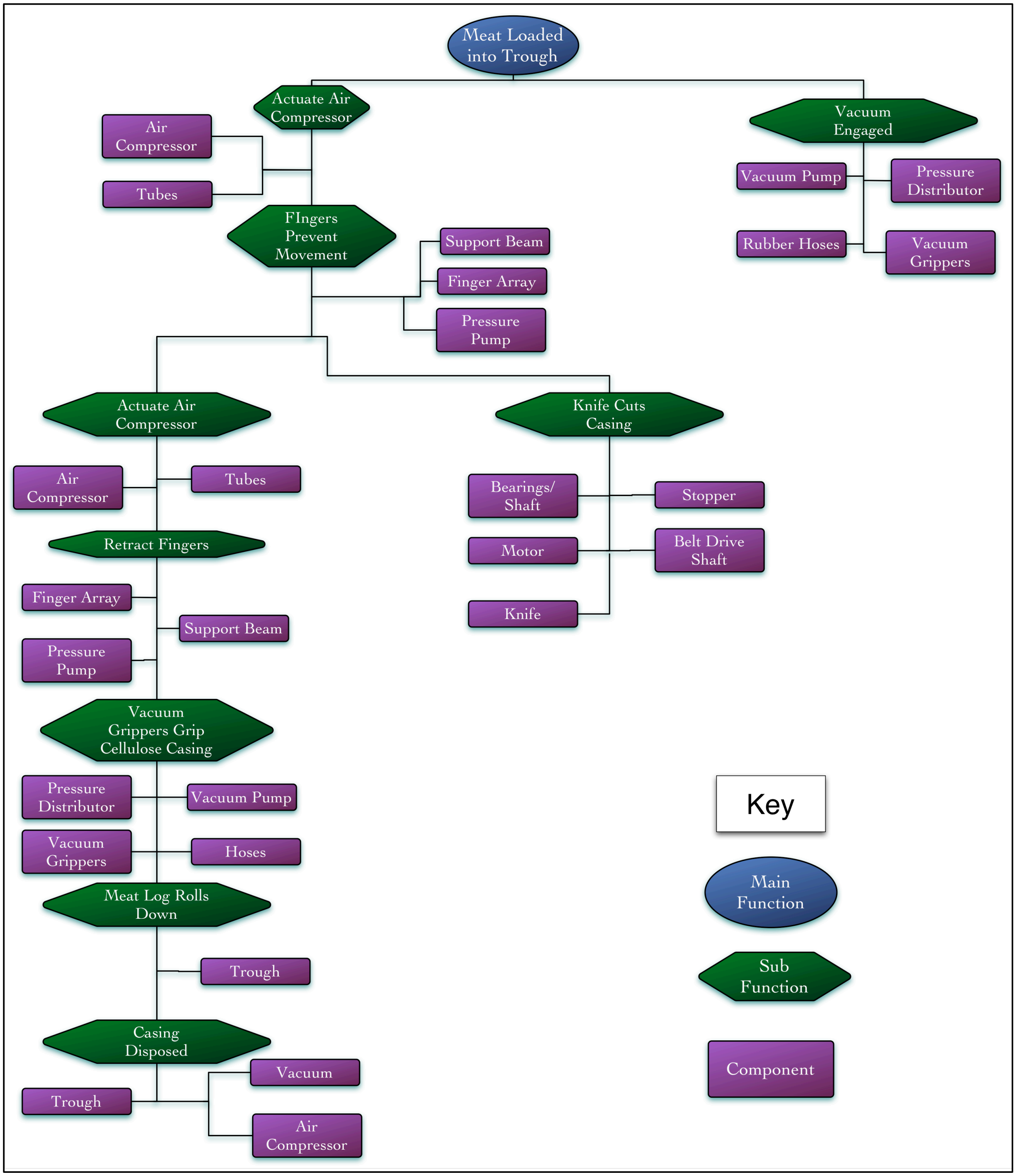


Figure 28: Casing Disposal Concept

4.7 Functional Diagram

The functional diagram below summarizes the full layout of AMCaR. The first function, loading the truncated meat log into the trough, is denoted in blue. The subsequent functions are denoted by green diamonds. Whenever these functions are in the same horizontal plane, that means they occur at the same time. For example, at the beginning of the process, both the air compressor and vacuum are activated simultaneously. Each function has parts associated with it, denoted by purple rectangles. These parts allow the function to occur. Compared to Figure 19, this functional diagram provides a much deeper picture of the overall design of AMCaR. The functional diagram shows how the various components are related, what functions occur simultaneously, and what parts are involved with each function.


Meat Loaded into Trough
Actuate Air Compressor
Air Compressor
Tubes
FIngers Prevent Movement
Support Beam
Finger Array
Pressure Pump
Vacuum Engaged
Vacuum Pump
Pressure Distributor
Rubber Hoses
Vacuum Grippers
Actuate Air Compressor
Air Compressor
Tubes
Retract Fingers
Finger Array
Support Beam
Pressure Pump
Vacuum Grippers Grip Cellulose Casing
Pressure Distributor
Vacuum Pump
Vacuum Grippers
Hoses
Meat Log Rolls Down
Trough
Casing Disposed
Vacuum
Trough
Air Compressor
Knife Cuts Casing
Bearings/ Shaft
Stopper
Motor
Belt Drive Shaft
Knife
Key
Main Function
Sub Function
Component

5.0 Prototype

All portions of the AMCaR were manufactured, save for the support structure. Due to shipping errors, the 80/20 stock ordered did not arrive in time to complete the full assembly of AMCaR. However, all other components were constructed and were fully functioning.

5.1 Knife Truck Subassembly

Pictured below is the machined knife truck assembly. Formax proved blades, one of which was inserted into the holder block. This can be seen in Figures 29 and 30.

Figure 29: Actual Knife Truck Subassembly

Figure 30: Knife Truck Against End Bracket

The knife truck works exactly described in the Final Design Section. The blade height is adjustable via the set screws. Once this portion of AMCaR had been built, a few simple tests were conducted to verify that the blade indeed sliced through the casing. These tests were successful and verified that the blade was stationary while the meat was cut.

5.2 Stopper Bar Subassembly

The stopper bar subassembly was machined per the description in the Final Design Section. A picture of the final subassembly can be seen in Figures 30, 31 and 32.

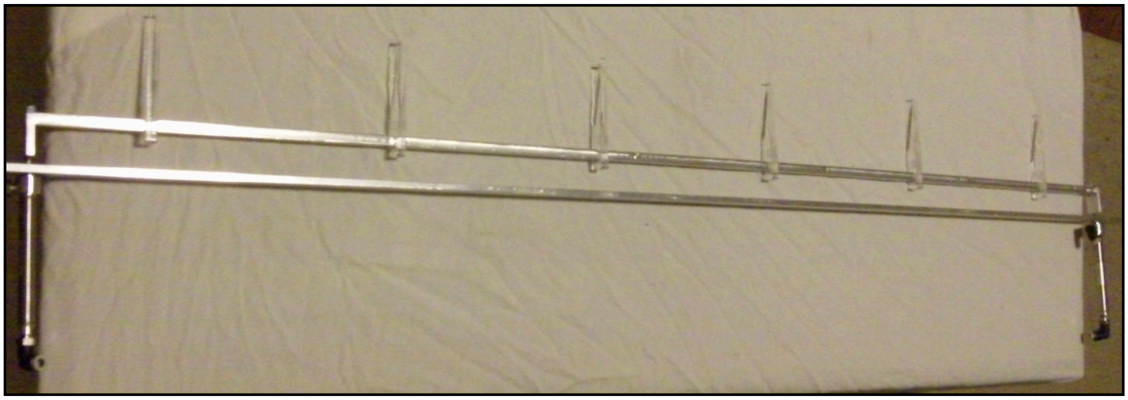


Figure 31: Actual Stopper Bar Subassembly

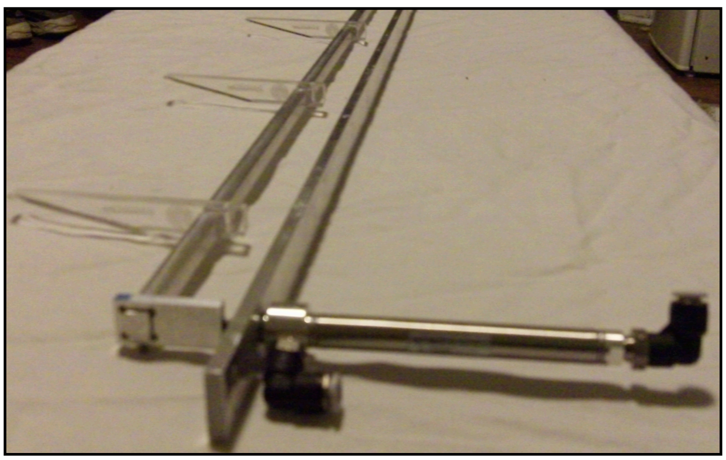


Figure 32: Actual Stopper Bar Subassembly (Side View)

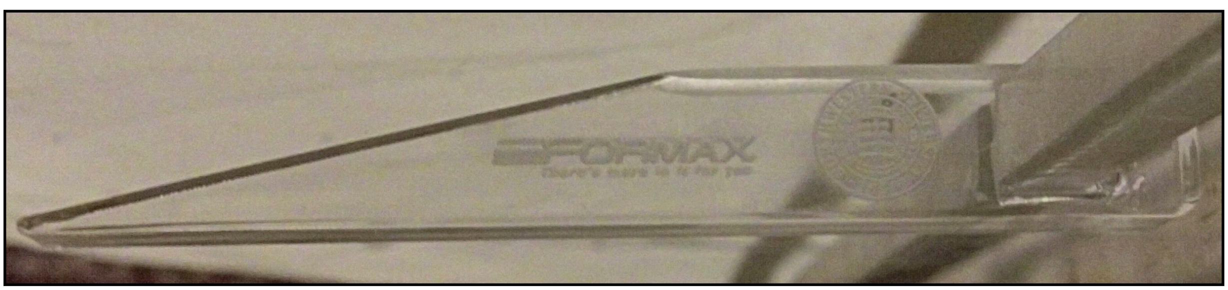


Figure 33: Close Up Of Stopper Bar Finger

Tests with the pneumatic cylinders have yet to be performed, though unless the parts are faulty, the stopper bar should function as expected. Once AMCaR has been fully constructed, most of the verification tests can be performed.

5.3 Vacuum Grippers

The vacuum grippers fit inside the trough and extend about 2" above the surface. Because they depress about 1.5", they will stick out 1/2" after the meat log has been loaded, thus maintaining constant surface contact. A picture of the final vacuum gripper subassembly can be seen below in Figures 34 and 35.

Figure 34: Actual Vacuum Gripper Subassembly

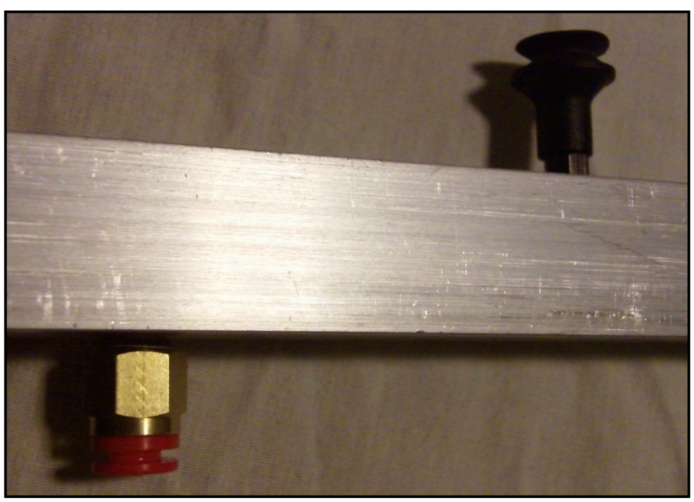


Figure 35: Air Intake On Vacuum Gripper Bar

Tests were performed at Formax, as the machine shop does not have the proper air compressors needed to generate the suction force required for the vacuum grippers. The main test involved loading the meat log onto the trough, engaging the vacuum grippers and verifying that they do indeed withhold the casing from the product as it travels down the trough.

5.4 Trough

The trough was machined out of Rigitex. It's pebbled surface prevents the casing from making a seal along the edges of the trough as the meat rolls down. If the casing forms a seal around the edges, then it may prove difficult in removing by vacuum suction. This is discussed in more detail in section 5.5. The machined trough can be seen in Figure 36 and 37 below.

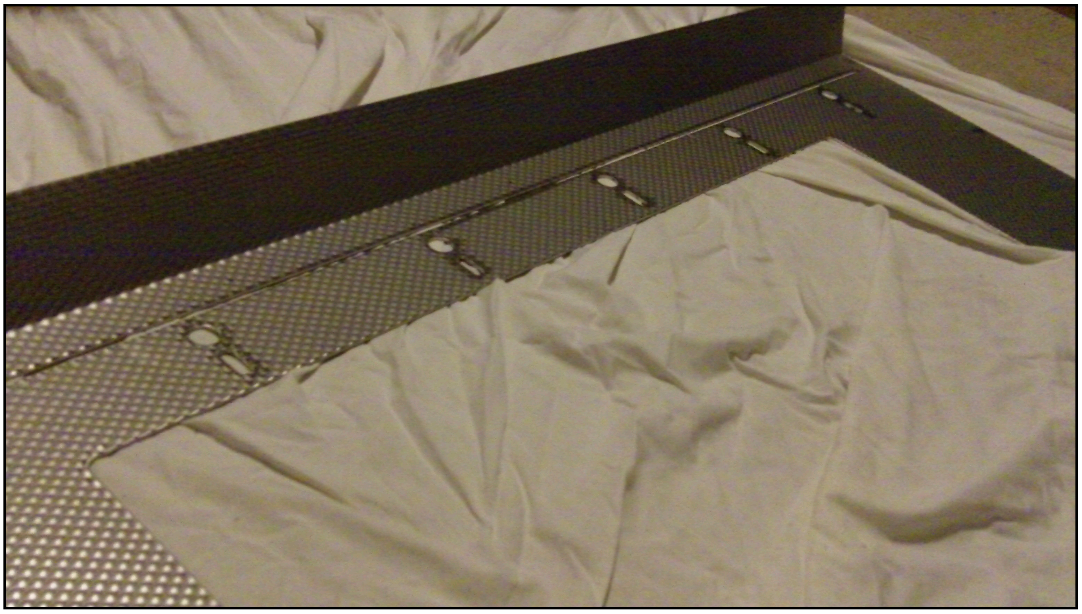


Figure 36: Actual Trough

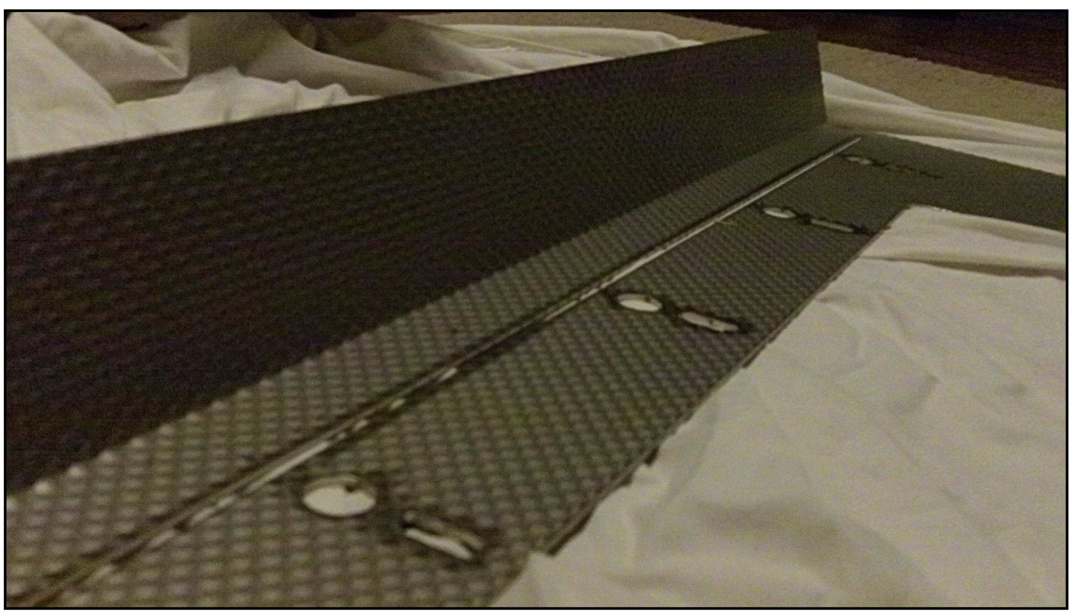


Figure 37: Close Up Of Trough

5.5 Complete Assembly

The figure below illustrates the complete AMCaR assembly. It is light enough to easily move, yet sturdy enough to perform all the required actions with no possibility of undesired yielding. The mitered joints and machined brackets help make the support structure incredibly strong.

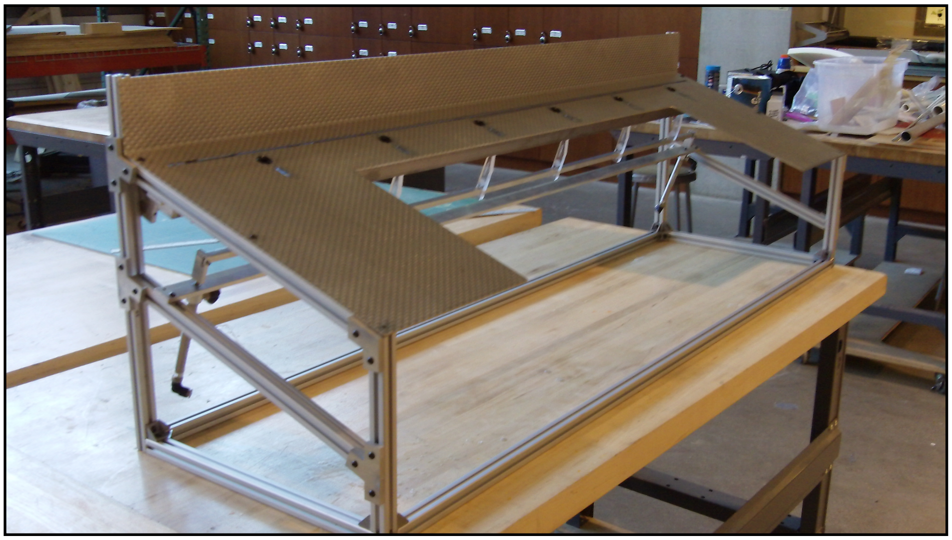


Figure 38: Complete AMCaR Assembly

5.6 AMCaR Scope

The scope of AMCaR is to provide a proof of concept. The prototype is scaled for 4 feet long meat logs, but can easily be lengthened, once all the concepts are verified. Because AMCaR is primarily a proof of concept, the focus was not on automating all the components, but rather focusing on functionality. The components that are automated include the stopper bar and the vacuum grippers. All other actions of AMCaR are performed manually.

Once AMCaR was assembled, tests were conducted to prove that it could process 6 meat logs per minute. As this is one of the main product design specifications, this was the first test conducted. Because of the promising results from the testing, extending the length of AMCaR to work with full length product should not be a problem.

The meat logs are loaded manually into AMCaR and are pretruncated. As was stated above, the current method of removing casing involves removing the ends with a shearing mechanism. It is assumed that this same device will be used to truncate the logs and then the logs will be loaded into AMCaR.

The stopper bar and vacuum grippers will function as they would in a factory setting. All that is needed is to hook up these components to an air compressor. These components will prove that the stopper bars will indeed prevent the meat log from unintentional rolling and that the vacuum grippers are strong enough to maintain contact with the casing as the product rolls down the trough.

The knife truck assembly will be operated by hand. It is a trivial task to automate this portion of AMCaR and, again, proof of concept was the main objective. In fact, the knife truck is already been machined to be attached to a rubber belt. Note Figure 39 below.

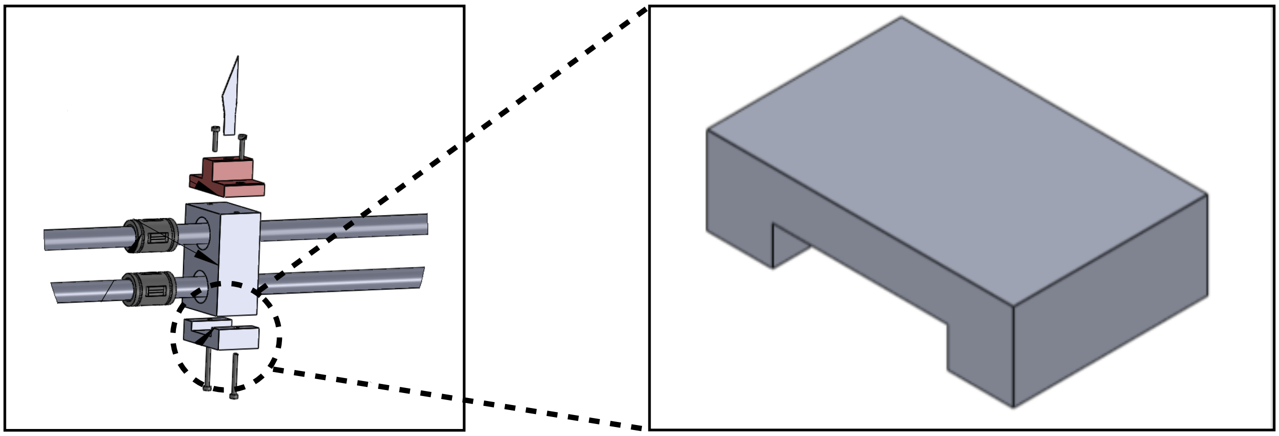


Figure 39: Zoomed In View of Belt Attachment

Automatic casing disposal was also not considered to be a part of the scope of AMCaR. However, methods for disposing the casing have been considered. See section 4.6 for a further discussion.

5.6 Bill Of Materials

The table below summarizes the cost of making AMCaR. Thanks to Formax, the cost of AMCaR remained under budget, totaling $278. Formax provided the 80/20 and machined the more complicated parts, such as the trough. A detailed discussion of manufacturing processes can be found in section 8.0.

Item Number	Quantity	Name	Material	Source	Dealer Part Number	Cost
1	1	Support Structure	Aluminum	Provisur	--	
2	14	Stopper Bar 2	Aluminum	Provisur	--	
3	1	Stopper Bar Shaft	Aluminum	Provisur	--	
4	2	Pneumatic Attachment Arm	Aluminum	Provisur	--	
5	2	Pneumatic Cylinder	Stainless Steel	McMaster	FD45K33	39
6	14	Suction Cups	Plastic	FPE	B15-2.10.01AC	70
7	1	Hose Connection Bar	Aluminum	Provisur	--	
8	1	Vacuum Pump Housing	Aluminum	Provisur	--	
9	1	Vacuum Pump Nozzle	Aluminum	FPE	DE89-083	3
10	1	Trough	Aluminum	Provisur	--	
12	1	Hose	Rubber	FPE	YY348-238	5
13	1	Mounting Bar for Pneumatic Pumps	Aluminum	Provisur	--	
14.1	1	Knife Truck	Aluminum	NU Shop	--	
14.2	1	Knife Holder	Aluminum	NU Shop	--	
14.3	2	Linear Bearings	Stainless Steel	McMaster	6489K61	38
14.4	1	Belt Attachment For Knife Truck	Aluminum	NU Shop	--	
14.5	2	Knife Truck Holding Bar	Stainless Steel	McMaster	98776-KE	120
14.6	2	Screws	Stainless Steel	McMaster	89939-3	0.50
14.7	2	Screws	Stainless Steel	McMaster	99087-8	0.50
14.8	1	Blade	Stainless Steel	Provisur	--	--
					Total Cost	**278**

Table 6 Bill Of Materials

6.0 Engineering Analysis

6.1 Analytical Stress Analysis

Optimization of cost or weight were not components of this project and as such precise analytical engineering analysis was not required. Because of the low weight of the product as compared to the overall weight of the design, any forces generated would be negligible. Nonetheless, to verify that individual components could withstand the force of the meat product, some force analyses were conducted. Such areas where the potential for material failure exist include the fingers on the stopper bar. This location experiences some of the greatest stresses during the casing removal process, as these fingers prevent the meat log from rolling down the trough when it is initially loaded. Assuming that the log is falling fast enough so that all the force is absorbed to the stopper bar fingers, the following force analysis can be done. Figure 40 illustrates the scenario relevant to the calculations.

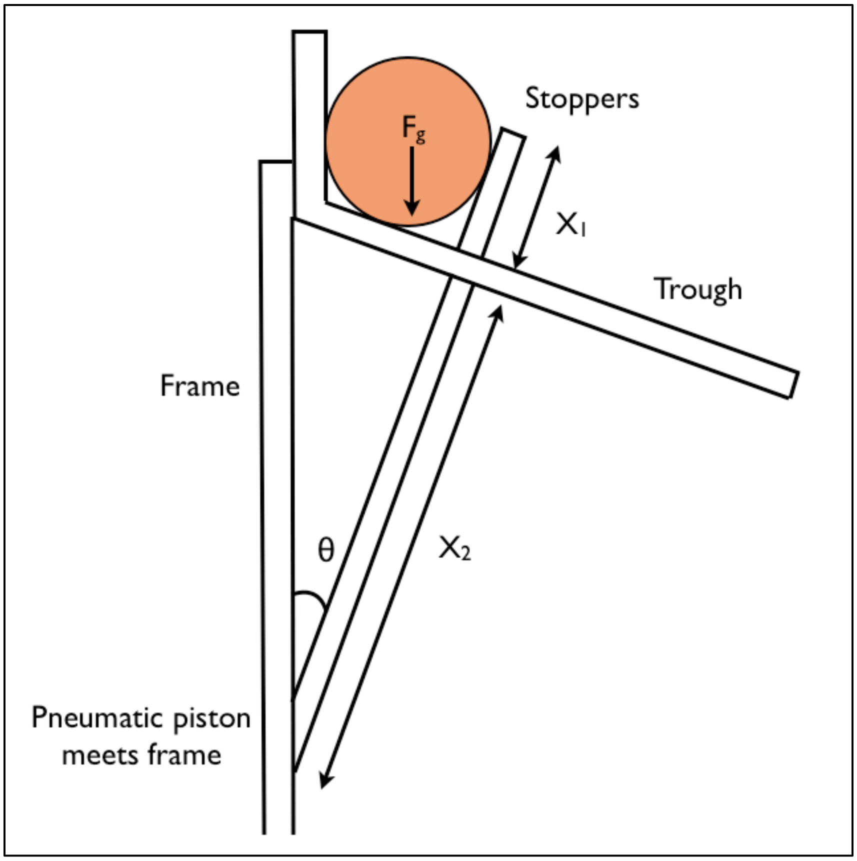


Figure 40: Stress Analysis Diagram

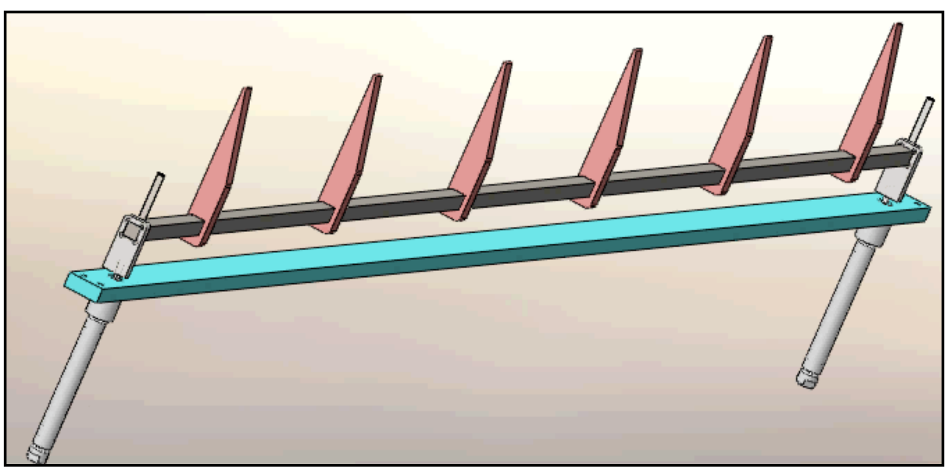


Figure 41: Isometric View Of Stopper Bar

Density of Meat Product

$\rho = .901$ g/cm

Volume of Meat Product

$V = \pi * r^2 * l = \pi * 5^2 * 100 = 2500\pi$ cm^3

Mass of Meat Product

$m = \rho * V = 7.075$ kg

Force Applied

$F = ma = 7.075*9.81 = 69.4$ N

The force applied will be distributed among the five fingers on the stopper bar (see Figure 41 above). This translates to less than 14 Newtons of force per finger. This force is much too small to cause any kind of deformation in the acrylic.

Assuming the mass hits the very top of the stopper bar fingers and all the force is applied normally to the fingers, the force on the pneumatic pump can be calculated. Figure 42 below shows the scenario of this calculation.

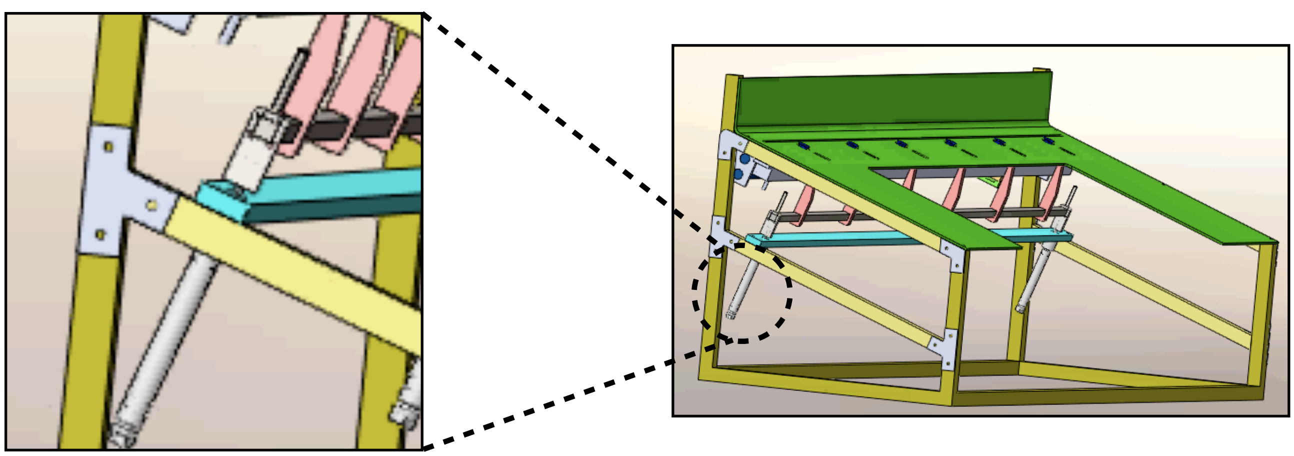


Figure 42: Pneumatic Pump

If: $F_s = 69.4$ N

$X_1 = 6$ cm

$X_2 = 11.4$ cm

Then:

$F_p = F_s*(X_1/X_2) = 69.4*0.53 = 36.5$ N

This 36.5 Newtons between the two pneumatic pumps is just over 18 N per pump. While this is much more than the 7 N applied to each tooth on the stopper, this is still significantly less than would cause the .5 cm aluminum shaft of the pneumatic pump to fail, even after thousands of cycles.

6.2 Throughput Analysis

One main requirement for the prototype is for the machine to accommodate 4-6 logs per minute. Once the scope of the prototype was outlined, a theoretical throughput analysis could be performed. Table 7 below illustrates the throughput believed that can be achieved with the prototype.

Step	Function	Time (sec)
1	Load meat log into machine with cut ends	3
2	Cut across casing with knife truck	3
3	Release stoppers and engage vacuum	0.5
4	Meat log rolls down and leaves casing behind	2
5	Casing disposed and knife truck moved back	1
	Total Time	9.5

Table 7: SSR Functions And Their Times

Please note that these are very conservative estimates and by these calculations, the prototype would achieve about 6 meat logs per minute. However, it is very difficult to encompass all the variables that are present in an industrial meat packing facility and thus the calculations are approximate. Once the actual prototype is constructed, an actual throughput analysis can be performed. Tests to simulate the prototype's actual environment can be conducted, further increasing the accuracy and validity of the analysis. As such, it is believed that the throughput reached by the prototype will indeed be faster than this.

7.0 Design Evaluation

Overall, the AMCaR is a very successful design. It meets all of the requirements posed in the PDS in and does so in a much smaller space compared to the Webber CCP. The concepts developed will be filed for US patents in the coming months.

Requirement: Able to remove casing from 100 mm diameter, one meter long meat logs at a rate of no less than 6 logs per minute

AMCaR is able to do this by slicing the casing off and letting the meat log roll down the trough. The vacuum grippers prevent the casing from keeping contact with the product. The throughput analysis conducted conservatively estimates the throughput of AMCaR at 6 logs per minute. Though AMCaR was not designed to handle full length meat product, it can be scaled accordingly. Once the concepts were proven at a scale of 4 feet, it is feasible to increase the length of AMCaR to 1 meter in length.

Requirement: Minimize product waste

AMCaR works with pretruncated logs, the ends of which are recycled. This process can be automated and thus even less product could be truncated from the log. AMCaR also reduces the process complexity by 50%, which wastes less time. Removing the casing with the Webber CCP involves about 15 steps, whereas with AMCaR, this process is reduced to 6 steps. Simplifying the process improves throughput, increases efficiency and reduces the risk for accidental malfunction.

Requirement: All parts should be properly sealed or easily accessible for washdown procedures.

AMCaR involves very few moving parts no electrical parts, the latter very appealing in a washdown situations. Because the frame is so spacious, there are no small areas where product may get stuck. In addition, the openness of the frame allows it to be effectively cleaned with each washdown. The expansive surface area of the Rigitex trough allows it to be very easily cleaned. Since the trough is at an angle, no cleaning solution can pool up.

Requirement: Maximum allowable cut depth along the lateral axis of the meat log is no more than 0.5 mm. The design may ultimately incorporate interchangeable blades.

The knife truck assembly fulfills these requirements. Because the blade is adjustable, an operator may first determine the ideal height of the blade and then lock the blade into position. In addition, the knife truck is situated below the trough and the trough acts as a safety barrier, should the knife become misaligned. That is, if the blade somehow gets dislodged, the trough prevents the blade from cutting more than 0.5 mm into the product. The set screw design of the knife block allows for interchangeable blades and the process of changing blades is very simple. The operator has to loosen the set screws, replace the blade and tighten the set screws to secure the new blade.

Requirement: The design should be capable of integrating with the rest of the assembly line and may integrate with a robotic arm.

AMCaR's layout involves loading the product transversally, meaning it only needs to be as long as the meat log itself. Because the support structure is constructed out of 80/20 stock, installing it should be very easy. The entire structure disassembles so that it can be installed in sections, rather than having to move the entire apparatus at once. This is beneficial if the factory layout is cramped. In addition, the adjustability of AMCaR makes it ideal for a variety of assembly line layouts. In terms of incorporating a robotic arm, AMCaR's functionality removes the need for such a costly addition. Removing the need for a robotic arm reduces the complexity and cost of the layout significantly.

8.0 Manufacturing Processes

The majority of the components for the prototype were machined at Northwestern using standard machining processes available in the Northwestern Prototyping Shop. Aluminum for the vacuum bar, brackets, pneumatic piston bar and knife holder, acrylic for the stopper teeth and steel rods for the knife truck sub-assembly were ordered through McMaster-Carr. The majority of machining processes that were performed were done so on a Bridgeport mill. Processes performed on the mill include facing, drilling and tapping. A horizontal band-saw was used to cut the knife truck rods, vacuum bar, pneumatic piston bar and stopper teeth bar to length. A water-jet cutter was used to cut the 1/4 inch aluminum 20 degree brackets for the support structure and a laser cutter was used to cut and etch the custom stopper teeth. Formax supplied the Rigitex for the trough and formed it using sheet metal forming processes and used a mill to cut out the slots for the knife truck, vacuum holes and stopper bars. They also machined the sleeve bearings and knife truck.

The AMCaR would be a low production machine and so it would not be practical to use rapid, high volume manufacturing processes such as investment casting or injection molding. It is recommended that the final prototype be made entirely from stainless steel using standard machining processes such as; milling, turning, facing, drilling, tapping, etc. While sand casting could be used to make some of the parts, casting results in a porous material which is not good for food processing applications. Formax has indicated that they are phasing out sand casted parts from their machines and moving everything over to machined stainless steel.

9.0 Recommendations To Formax

Though the proof of concept of AMCaR was an overall success, there are aspects of the design that need to be further tested and developed.

- Long term reliability testing of AMCaR needs to be conducted. Though the initial tests results were promising, these were conducted in a laboratory setting. Testing results from a real factory environment would help confirm that the AMCaR's concepts are sound.
- The knife truck assembly needs to be motorized. Since it has already been designed to incorporate a drive belt, this is a trivial task. Purchasing and installing a motor should not require any effort and the knife truck should work with no major problems. The angle of the truck may need to be adjusted, but that is easy, give it is attached to the 80/20 frame.
- An air tight casing removal compartment needs to be installed. This is perhaps the most challenging aspect to develop. As described in section 4.6, the concept of casing removal has been incorporated into AMCaR, the installation is all that is left. Adapting the concept seen in a refrigerator door may be a viable option. Instead of incorporating a door, there may be a drawer under the trough that can be opened when the compartment is full and when closed, makes an air tight seal, exactly like a refrigerator door.
- Investigation of automatically shearing off the ends needs to be investigated. This should not prove too complex. The current method is easily automated: attaching a motor and modifying the shearing mechanism would be the recommended course of action.

10.0 Summary

An impressive amount of work was completed in the allocated three month time frame.
A professionally machined, working prototype resulted from the hard work put into the project.
AMCaR successfully removes the cellulose casing from meat logs in a simple 6 step process.
AMCaR is a device that meets all the requirements outlined in the PDS and does so with a degree of simplicity and elegance not found anywhere else in its industry. By utilizing the current sources of power (compressed air and vacuum) and its high amount of adjustability, the device can be easily installed in a variety of assembly line layouts. Indeed, AMCaR may be the first step in streamlining the entire meat packing industry.

11.0 Acknowledgements

This project would not have come to fruition were it not for the support of the following people. Their help and contributions to the project are greatly appreciated.

- Dr. Wei Chen
  Professor, Northwestern University
- Tom Wolcott
  Director of R &D, Formax

Appendix A: Product Design Specifications

Product Goal Statement

To design a device to be used in meat manufacturing plants that removes the casing on 100mm round, meter-long meat logs so that they can later be sliced and repackaged.

DESIGN SPECIFICATIONS

Performance
- Able to remove cylindrical meat log casings at a rate of no less than 6 per minute without damaging the meat product
- Minimizes product waste
- All parts are properly sealed or easily accessible for wash-down procedures

Specifications and Standards
- Capable of removing casing from 100 mm standard size meat logs
- Maximum allowable cut depth along the lateral axis of the meat log is no more than 0.5 mm
- May integrate with standard robotic arm
- The device will package meat in compliance with plant standards specified by the American Meat Institute and the Food and Drug Administration
- Capable of integrating with the rest of the assembly line
- Design may ultimately incorporate interchangeable blades
- Able to withstand hygienic cleaning protocols

Size
- The device is no longer than 4 meters and no wider than 1 meter
- Weight restrictions to be determined by whether the final design attaches to a robotic arm, gantry system, or conveyer belt

User Safety
- Safety guards prevent device from accidental activation during maintenance

Materials Used
- Final prototype will be made of aluminum, but final product will be made of stainless steel or plastic to comply with FDA and AMI requirements

Power Source
- If using robotic arm, may use 24V DC, vacuum or pneumatic power
- May use power from industrial power outlets in factory

Reliability
- Lifespan of device should be no less than 10 years with regularly scheduled maintenance

Patents
- Device cannot infringe on any existing American or European patents
- Device will be patentable in The United States of America and Europe

Operating Temperature
- Device will be designed to operate at a temperature of 45 degrees Fahrenheit
- Device will continue to operate after prolonged exposure to meat of 22-24 degrees Fahrenheit
- Device will continue to operate after exposure to 212 degrees Fahrenheit in steam cleaning processes

Ergonomics
- Device will minimize human interaction, installation time, cleaning and maintenance

Customer

- Meat manufacturing plants that produce sliced meat log products

Quantity

- Device will be manufactured on the order of 1000 or as required by meat processing plants

Cost

- Device is low quantity, high quality, and therefore cost is not a major issue

PROJECT PLANNING

Week 3

- Research current competitor designs
- Review meat log literature and current meat log casing removal procedures
- Brainstorm further ideas and create selection matrix to finalize first solution candidate
- Conceptualize possible designs and sketch out feasible ideas

Week 4

- Detailed design of solution candidate 1
- Deliver drawings to Formax for fabrication

Week 5

- Testing of solution candidate 1
- Possible redesign and iteration of solution candidate 1

Week 6

- Brainstorm further redesign characteristics to implement in solution candidate 2
- Deliver drawings to Formax for fabrication of solution candidate 2

Week 7

- Testing of solution candidate 2
- Begin compiling documents for final project report
- Begin CAD for final design

Week 8

- Finalize CAD models
- Deliver drawings to Formax for fabrication of final prototype
- Finish final project report

Week 9

- Test final prototype
- Begin outline of project keynote

Week 10

- Present keynote

Role of Members

Noah

  Primary log recorder
  Secondary CAD modeler
  Secondary shop-guy

Krystian

  Primary CAD modeler
  Secondary final report compiler

Sean

  Primary shop-guy
  Primary client contact

George

  Primary keynote compiler
  Primary final report compiler
  Secondary log reporter

Plan for Group Meetings
The team will meet every Friday afternoon from 1:00-3:00 to discuss next steps and execute the proposed project plan.

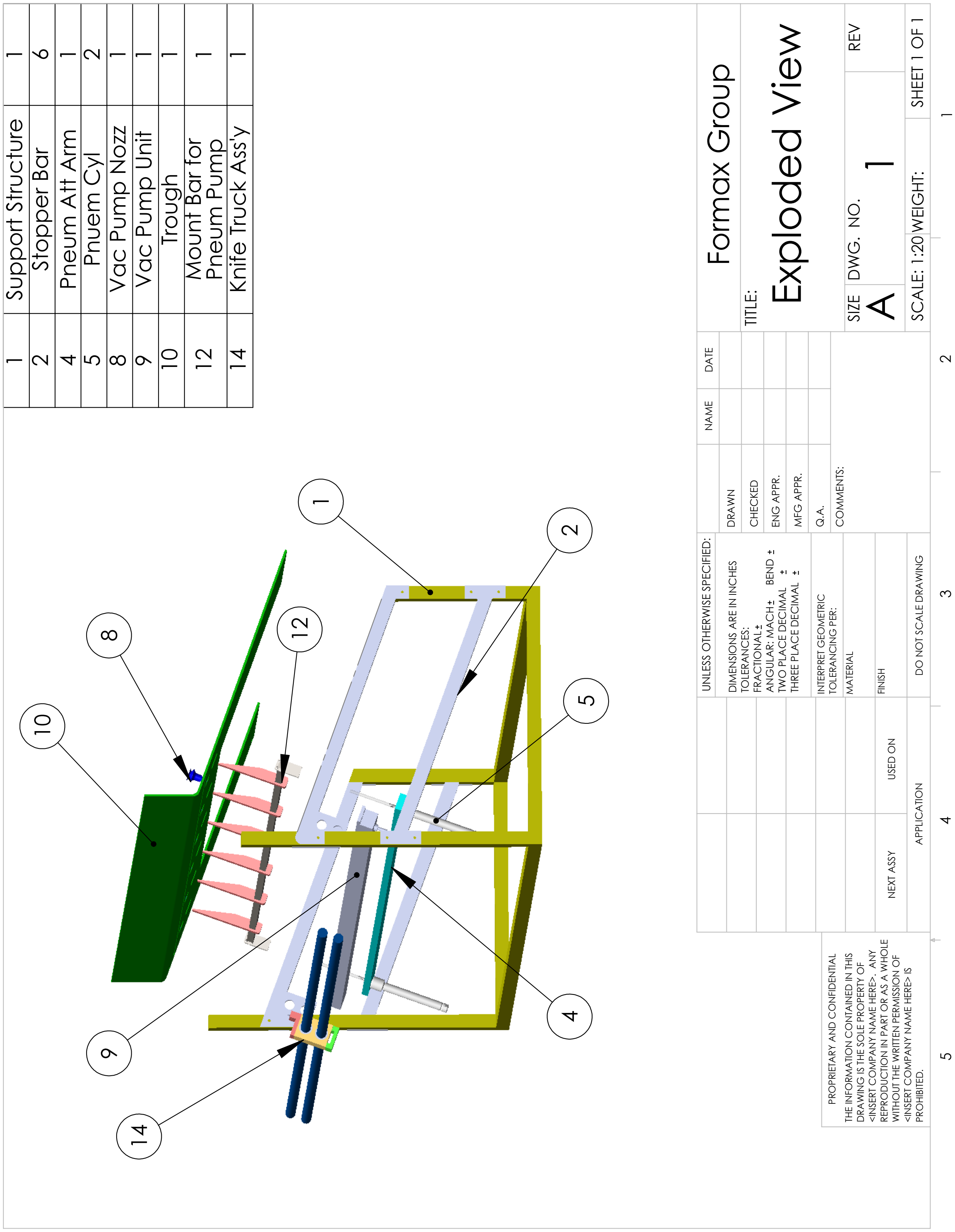
Interactions with Client
The team will be in contact with the client primarily through e-mail with the occasional phone call and site visit to test the prototypes. Sean will conduct the correspondence through e-mail.

Task	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10
Research	■							
Brainstorm	■							
Concept Selection	■			■				
Conceptual Design	■	■						
Detail Design 1		■						
Detail Design 2				■				
Deliver CAD of Design 1 to Formax		■						
Deliver CAD of Design 2 to Formax				■				
Test Design 1			■					
Test Design 2					■			
Final Prototype							■	
Final CAD					■	■		
Final Report					■	■	■	
Keynote Work							■	■

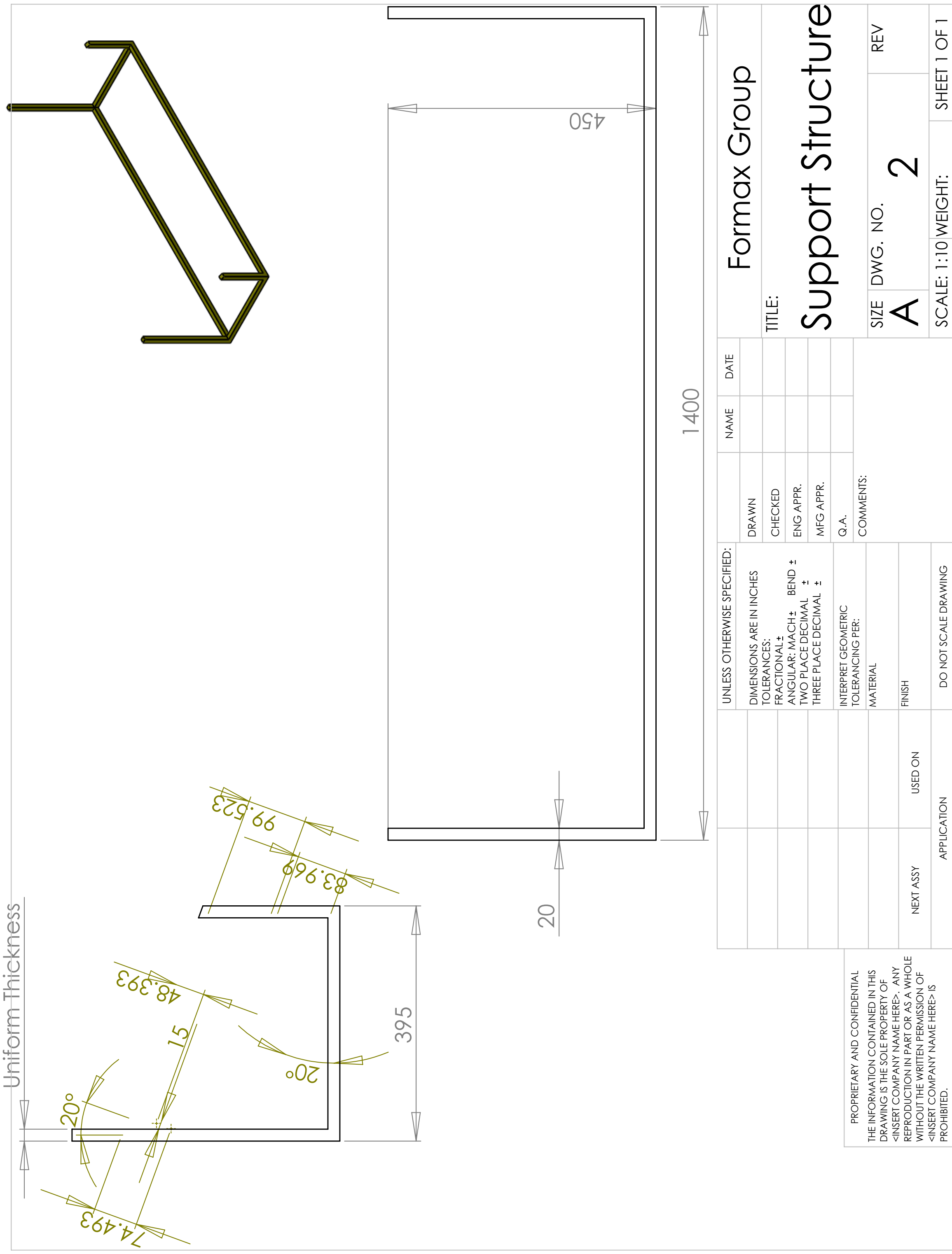
Gantt Chart

Appendix B: Prototype Drawings

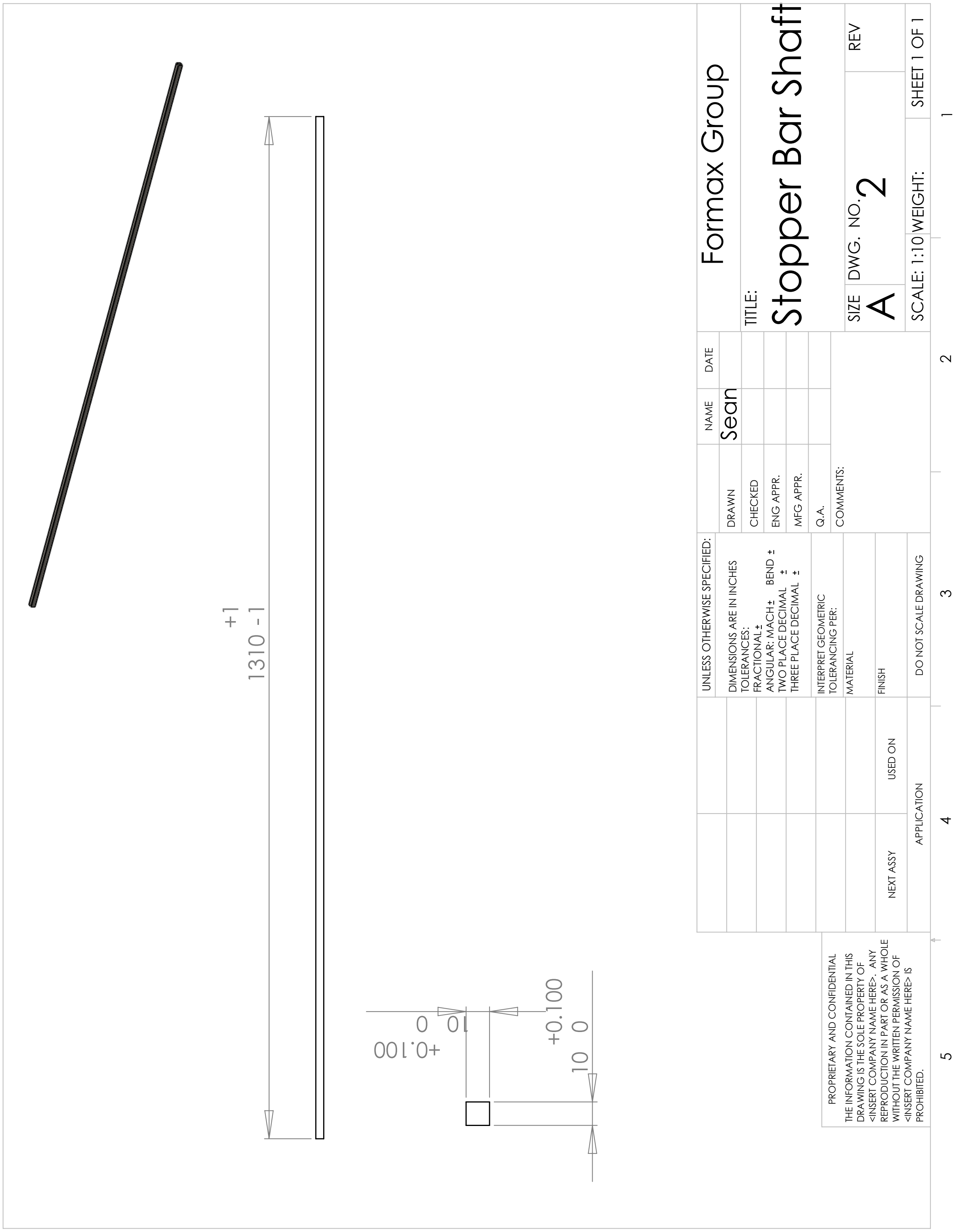
Full Assembly -- Exploded View



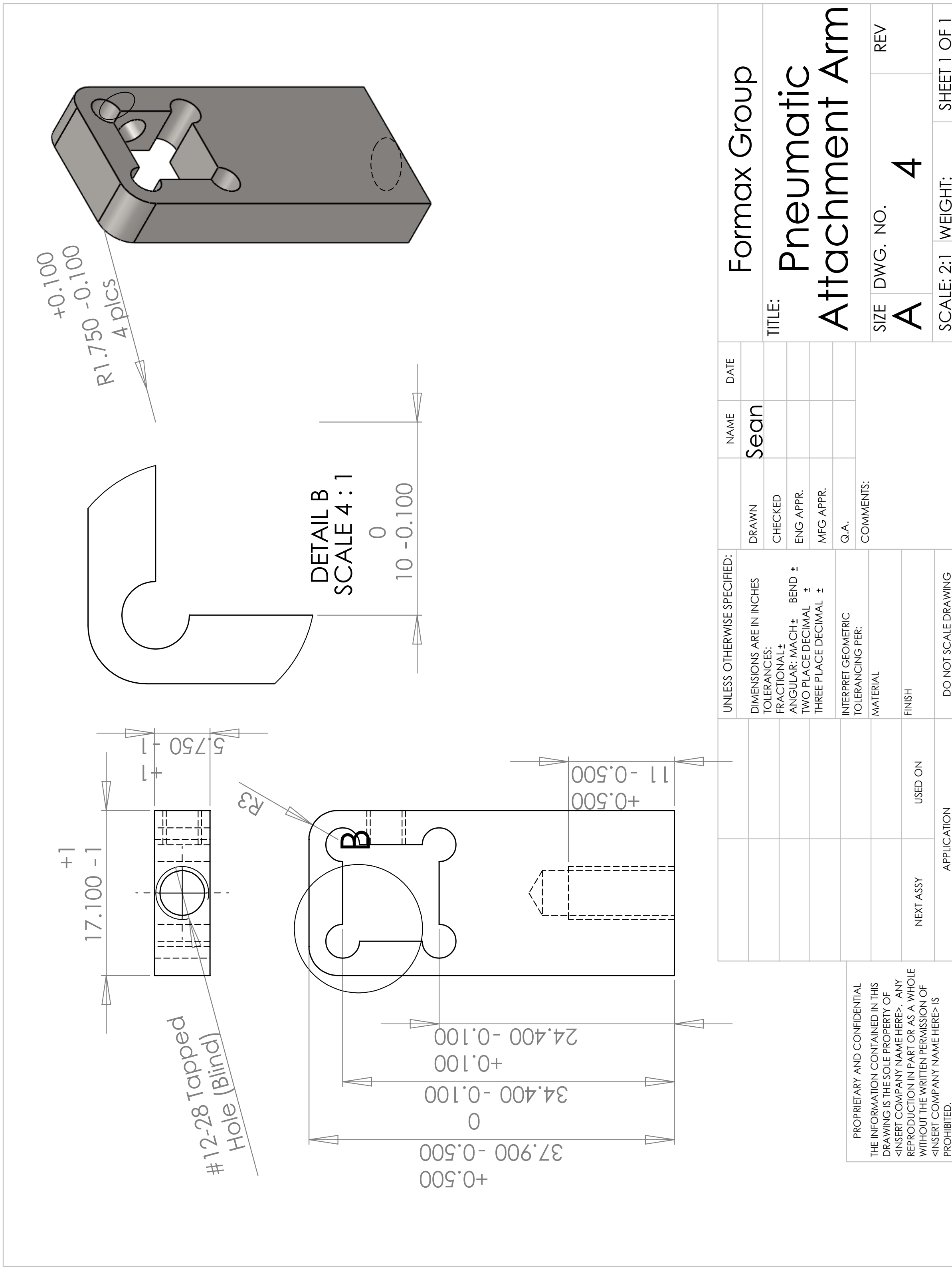
Support Structure



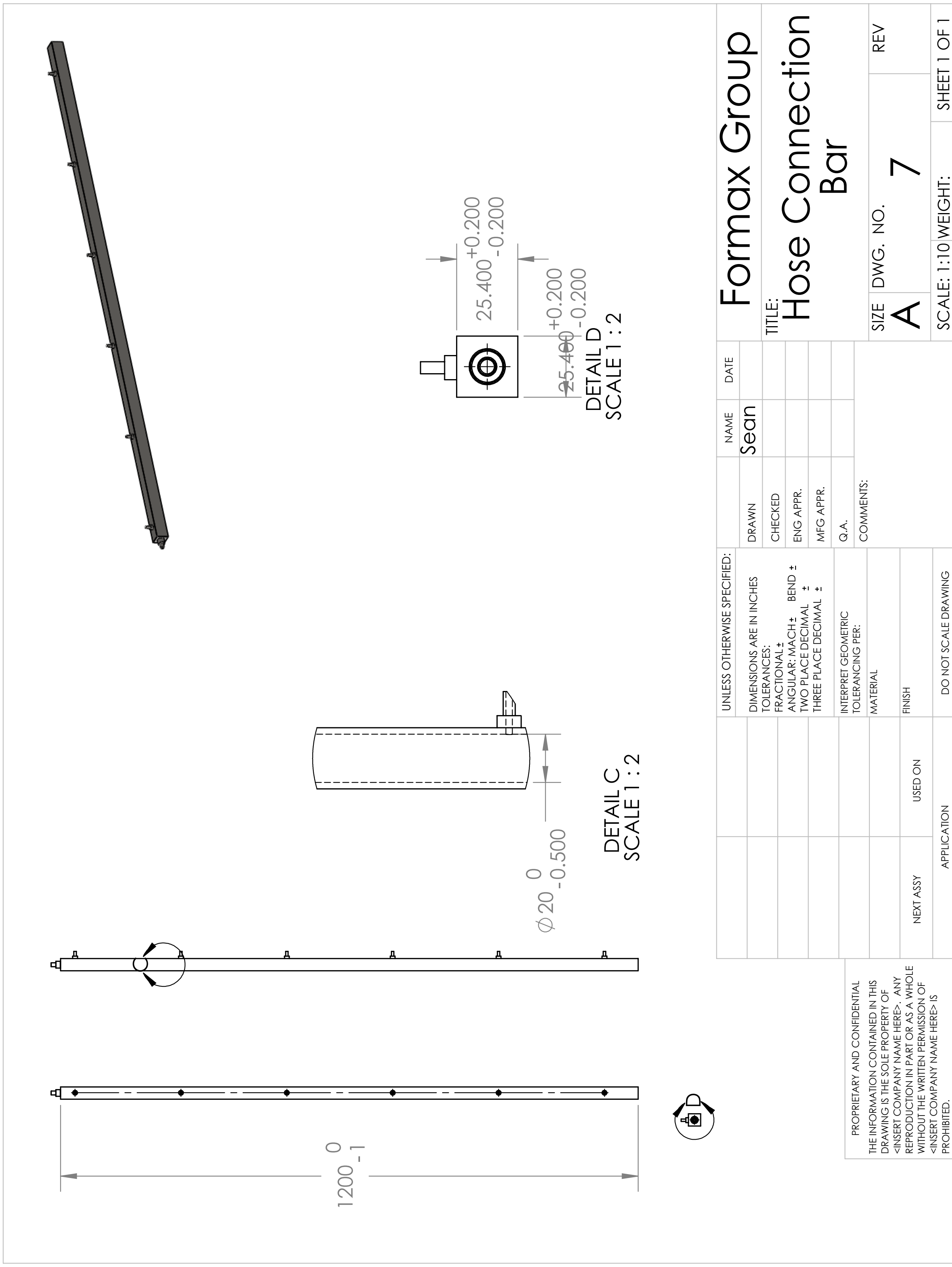
Stopper Bar Shaft



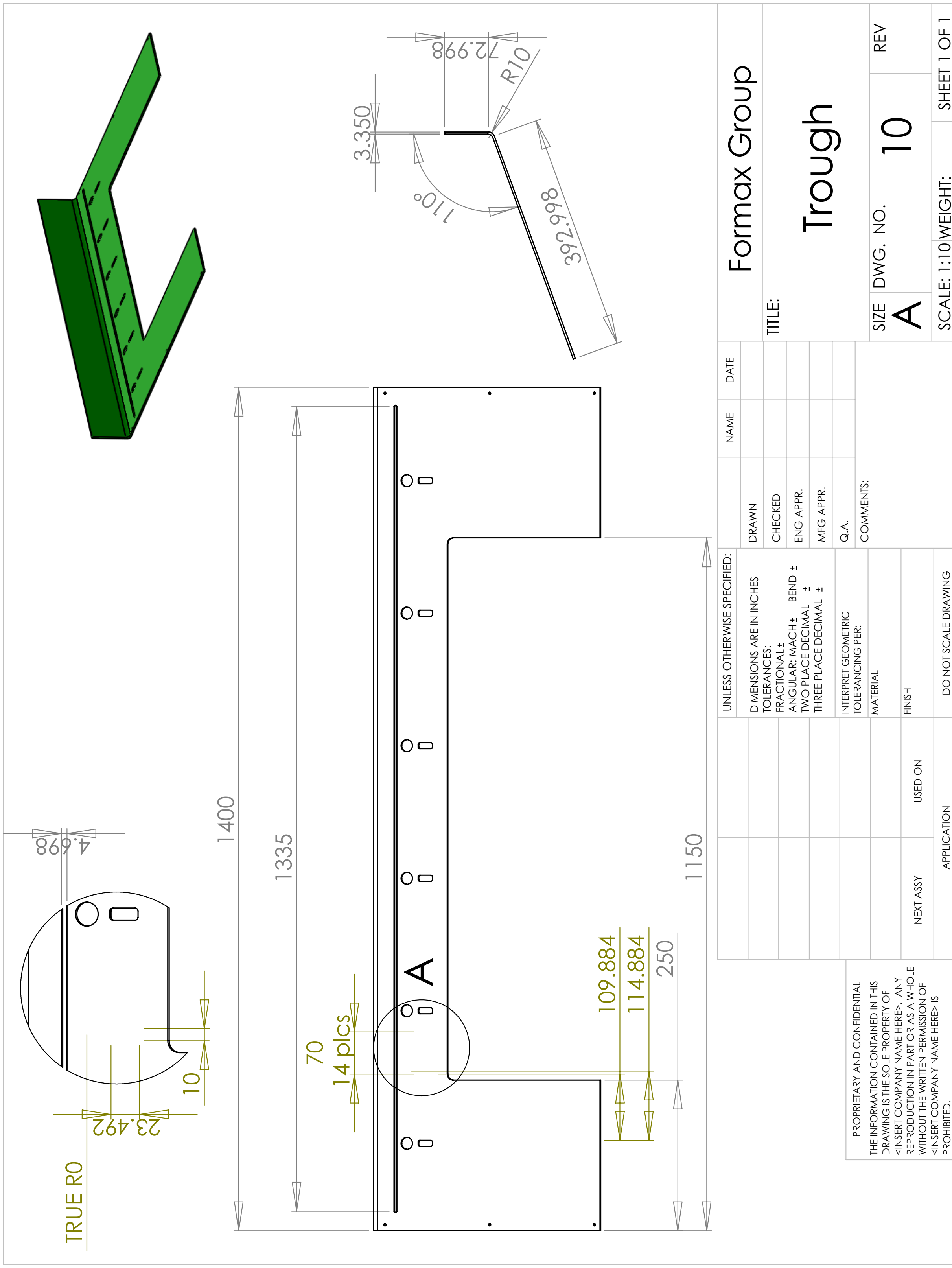
Pneumatic Attachment Arm



Hose Connection Bar



Trough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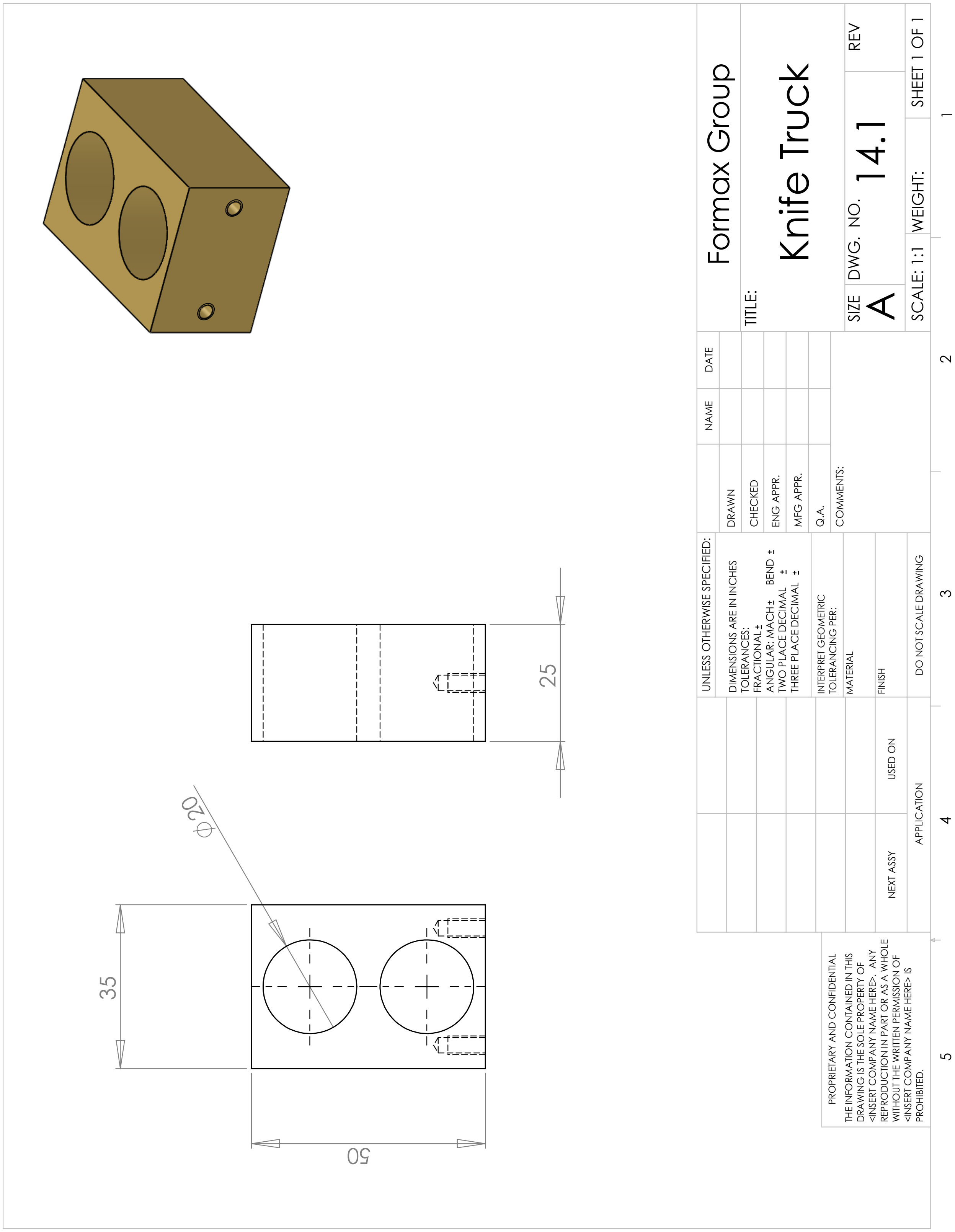
Knife Truck



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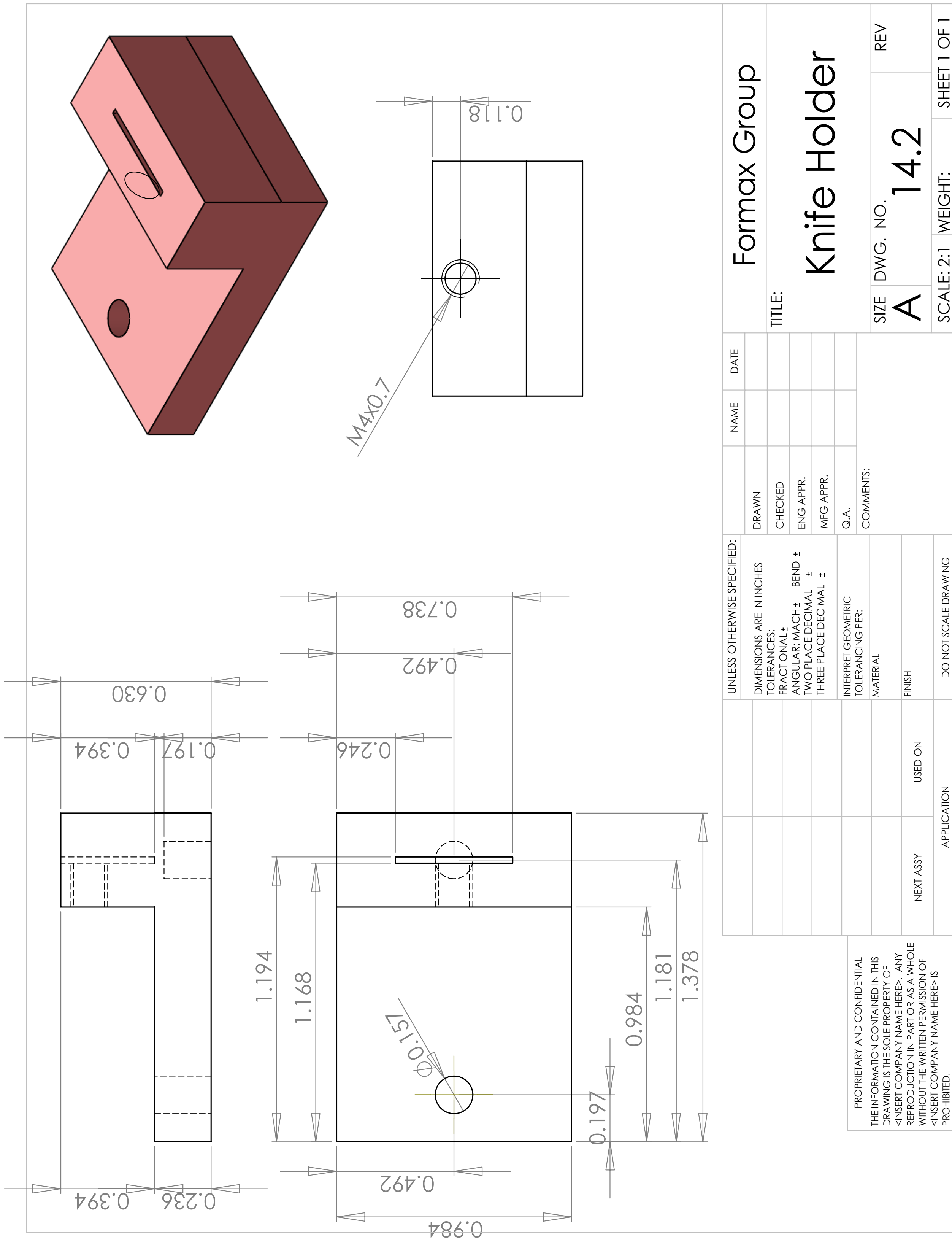
Knife Holder



Belt Attachment