Chip Removal Tool Project

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Bachelor of Science

by

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Chip Removal Tool Project

Sponsor: Heli-cal Products Co., Inc.
December 4, 2009

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Statement of Disclaimer

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Jobber Length Jobber-length drills are the most common type of drill. The length of the flutes is ten times the diameter of the drill

Pallet A 9.75 x 14.00 inch tooling fixture. Two pallets can be mounted to a table at a time.

Swarf Also known as turnings, chips, or filings — the debris or waste resulting from metalworking operations.

Table Area Working area inside the Fanuc robodrill. The robodrill can actively work on one table at a time, while the second table is located in the side tool changer.

Workpiece Piece of material currently being machined

Executive Summary

The Cal Poly senior project team worked with Helical Products Inc. to develop an automated method for removing swarf and chip buildup from the drill bits of their CNC milling machines. The removal methods in this report were designed for and tested using a Fanuc Robodrill while keeping the potential in mind for their use in other CNC milling machines. After extensive background research, preliminary and prototype design and testing the final chosen design is shown below. The cleaning device is made from flexible sheet metal and placed on a fixture that occupies one of the two pallet locations inside the CNC machine. The sheet metal is flexible enough to accommodate the full range of dill bit sizes requested by Helical and strong enough to hold the chips in place as the drill bit is removed from the cleaning device, cleaning the drill bit.

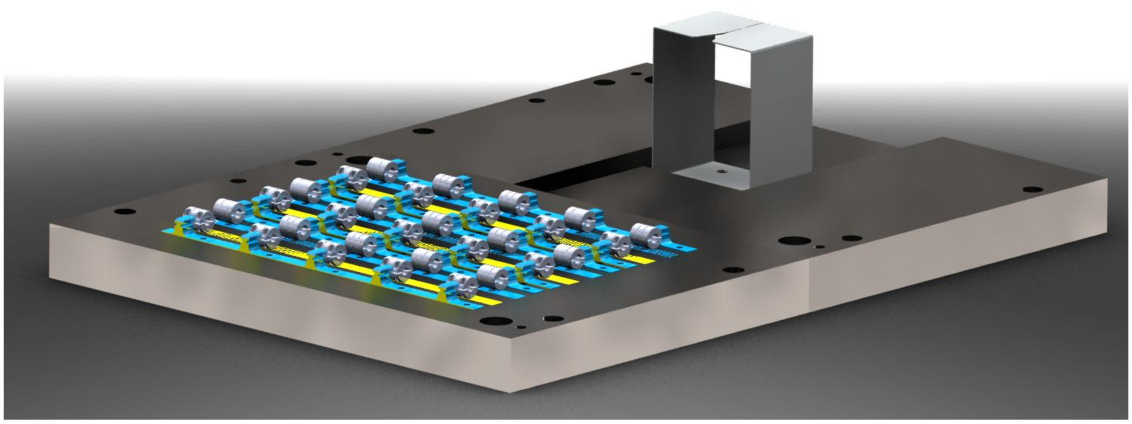


Figure 1. Final design including fixtures for parts and cleaning device.

Chapter 1 Introduction

Helical Background

Alex Ek, Manufacturing Engineering Manager of Helical Products Co., Inc. has requested the design and building of a device for removing entangled chips from the tools used to manufacture their products. Chip buildup on tooling can be a costly and time consuming manufacturing issue. There are two primary reasons that Helical is experiencing excessive chip build up. First, material such as stainless steel produces long thread-like chips that get entangled and accumulate on the drilling tools. Second, due to the work hardening property of stainless steel, the material hardens during the machining process causing premature wear of tool and difficulty of chip control. Using a pecking cycle to break the stainless steel chips is inefficient and therefore requires a more expensive drill bit associated with a dramatic increase in machining time.

The productivity benefits of CNC machine tools are lost when a manual tool cleaning process is utilized. This manual operation has proved to be a difficult, hazardous, and time consuming process. The challenge faced by Helical Products is to find a solution which removes the entangled chips without disrupting the highly efficient CNC machining process. Left unaddressed, this disruption in the machining process will cost Helical time and money. Not only is the current method of intervention a time consuming process, but it remains a hazardous task that puts the CNC operators at risk to injury.

The final design must automatically remove the chips from the specified tooling and operate within a 5 second time interval per tool. The design must be completely safe to use by the machine operator and cause no harm to the equipment. There can be no scratches, marks, or damage to the parts being machined. A complete and innovative solution will be reached while working under the authority of Helical.

Our Plan: Flexibility and Integration

The chip build up problem at Helical requires a solution that is flexible while allowing for various types of machining processes and the ability to be integrated into current machining processes and all future machining processes. Therefore, we believe a successful solution must meet the following objectives:

- Automatic operation with minimum human intervention
- Integration with CNC machine control
- Minimize cleaning time for tool, thus maximizing productivity
- Must not scratch, mark, or damage tools or product
- Accommodate drills of jobber length #56 to 3/8”
- A solution that is robust and reliable, to satisfy the high operational hours demanded by Helical Products

To meet these objectives, Chip Assist has developed a set of engineering requirements based on Helical’s needs. To develop the engineering requirements we created a Quality Function Deployment (QFD) diagram based on Helical’s requirements (Appendix B). Below is a table summarizing the engineering specifications of this project.

Table 1. Engineering requirements

Spec #	Parameter Description	Requirements/ Target	Tolerance	Risk	Compliance
1	Automatic Operation	No human intervention	N/A	M	A,I
2	Cleaning Cycle Time	<5 [seconds]	Max	H	A,T
3	Integration with CNC control	Can be accomplished with existing code	N/A	L	I
4	Reliability	99%	Min	H	A, T
5	Life of Tool between maintenance	1000 [hours]	Min	H	A,T
6	Damage to tools or Product	None	Min	M	I
7	Fits Fanuc Robodrill	N/A	N/A	L	I
8	Drills	Jobber length #56 to 3/8	N/A	H	A,I
9	Cost, per tool	1000-3000 [USD]	Max	L	A

KEY: Compliance Methods: Analysis (A), Test (T), and Inspection (I)

Metal Chip Removal Mechanism Specifications

1. The automatic operation specification requires that no human intervention need take place during that machining process. Reducing the need for human intervention reduces the chance of injury to the CNC machinist and also decreases the production time of the product.
2. The cleaning cycle time must be cost effective and efficient. A maximum cleaning cycle time of 5 seconds will be an improvement on the current chip removal process. This specification is listed as high risk because if the cleaning time is too long it will drastically affect production.
3. The integration with CNC control specification is very important in that the machining process and chip removal mechanism are operated by the same controller.
4. The chip removal mechanism must be robust and reliable, cleaning tool failures will result in possible damage to CNC machinery and/or the product.
5. The mechanism must last at least 1000 hours between maintenance. The CNC machines at Helical are operated up to 10 hours a day and a failure to a chip removal mechanism may damage the machines or the product itself. This specification is listed as high risk due to the fact that building a robust chip removal mechanism may affect some of the other engineering requirements such as cost.
6. The chip removal mechanism must not damage any of Helical’s product, CNC machinery, or CNC tooling. In the event of an unforeseen collision between the chip removal device and a machining tool, the cleaning device must yield first.
7. The initial chip removal mechanism is to work with a Fanuc Robodrill. Ideally, the chip removal mechanism would eventually be integrated into Helical’s various CNC machines.
8. The mechanism must accommodate a wide variety of drills that are used daily at Helical. Drills of jobber length #56 to 3/8” have a variety of different widths and lengths to accommodate with the chip removal mechanism. This specification is listed as high risk because the CNC machine knows where the tip of each drill is but not the length of each drill itself.

Maximum cost per tool refers to the material and hardware costs to create each tool. The cost of each tool is dependent on material selection, reliability, and robustness of the mechanism.

Management Plan

Project management is a key component in obtaining a successful chip removal design, by effectively directing the teams time. A Gantt chart has been generated to help plan and organize required tasks. The chart is broken up into the three-phases: design, implementation, and testing. Expected completion of project is December 4th, 2009. The Gantt chart can be seen in Appendix D.

The division of labor is necessary to efficiently complete all the required tasks. A management plan was generated from our method of approach and will assist throughout the design period. John Cote will actively coordinate with Alex Ek of Helical and determine group meetings when design aspects need discussion. John will also act as a coordinator for the design team by ensuring adequate completion of required tasks. Brett Mori will plan and establish travel accommodations when necessary. Throughout the design process, it may be necessary to see the machinery first hand. This will help in assuring that the design and prototype are going in the direction desired. The design modeling will also be completed by Brett as needed. Micah Wells will document the project progress until completion. This will include documentation of scheduled tasks and all other aspects of the design. The documentation will benefit the team if changes are needed, by utilizing it as a reference. Micah will also assist in information gathering for the design as necessary. Kyle Rowland will lead in prototype fabrication. This will include any required material gathering, tooling, etc. Kyle will also focus on document revision and formatting with the assistance of John. Any changes to these roles will immediately be expressed to all parties involved in the project.

Part of our management plan is to keep Helical updated on the progress of the team while providing information on upcoming expectations. Helical can expect the following reports delivered on these dates:

Final Design Report	April 13, 2009
Critical Design Review	April 20, 2009
Project Update Report	June 1, 2009
Final Project Report	December 4, 2009

Chapter 2 Background

The Need for Chip Removal

The production of chips is an unavoidable result of many machining processes. Because a majority of material removal processes utilize rotary cutting, as the material is removed numerous chips will form in different ways. The resulting chips can interfere with the continued process. Therefore, it is not satisfactory to only remove the chip from the work piece but from the entire work area. This prevents any unnecessary wear or damage to the tool and workpiece.

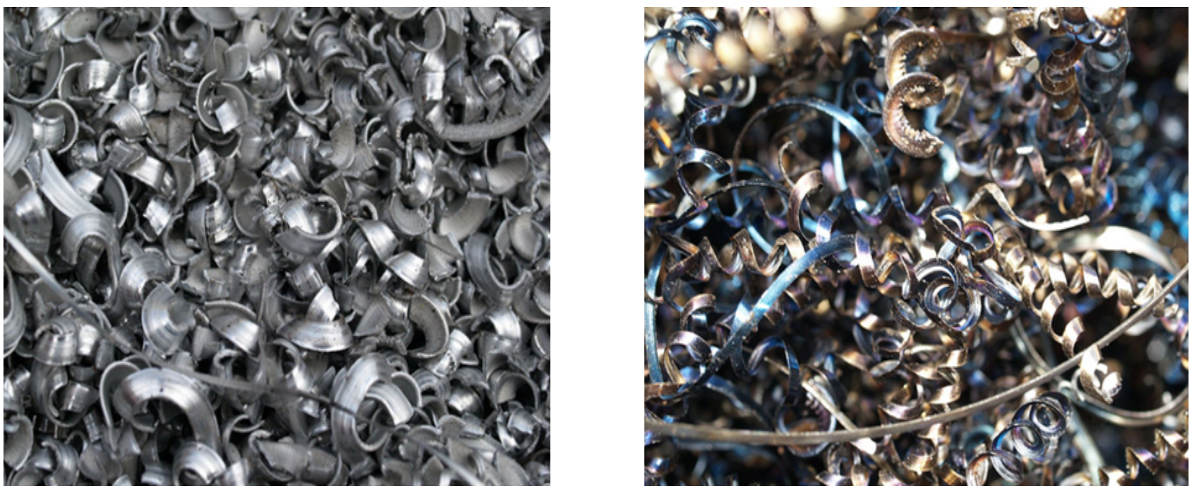


Figure 2. Examples of Broken (Left) and Bushy (Right) metal shavings.

Chips can be placed into two general categories, broken and bushy. Chips that would be considered broken are short and usually only have slight twist to them. Broken chips form when the cutting edge of the tool is not continually removing material and as the cutter or drill rotates there are breaks in the removal process. This type of chip is easy to manage and is only a concern when large amounts of chips accumulate in the work area. Bushy chips, also known as "birds' nests," will quickly become a problem if not removed from the work area. These long, spiral chips will often form in drilling operations and can very easily get wrapped around the cutting tool. If the tool gets wound up with chips the machining operation will need to stop and the chips will need to be removed.

Fanuc Robodrill

The current system that needs chip removal assistance is the stare-of-the-art Fanuc Robodrill CNC Drill model α-T14*i*Bs. Some major features of the machine are the 14 tool umbrella changer and stroke in the horizontal plane of 500 by 400mm. Helical has also purchased a 2-pallet changer that allows for parts to be continuously run while new parts are loaded onto the pallet. Spindle speeds range from 80 to 80,000 RPM and feedrates from 1 to 15,000 mm/min. The table area is 650 by 400mm and will serve as the mounting surface for any passive chip removal device. The chip removal mechanism will need to be located in this area in order for the spindle mounted tool to be cleaned.

Figure 3. Fanuc Robodrill with side tool changer[2].

Current Chip Handling Methods

There are several techniques used today to control formation and interference of chips. These methods go to the formation of the chip to control the problem at the source. The use of coolant and compressed air will keep the tool and chips cool, preventing them from fusing together. Special tooling even has channels for coolant to flow built into the cutter to get the coolant to the bottom of deep holes.

A common method for keeping the length of the chips to a minimum is something called peck-drilling. This operation can be easily added to the machine code and will have the tool periodically retract from the workpiece to break/clear chips and allow coolant to flow into the hole. However there are some drawbacks to this process. Work-hardening can occur every time the tool retracts and coolant rapidly quenches the surface of the workpiece. This will cause additional tool wear every time it has to remove this work-hardened material. A special tool with the proper cutting-edge geometry is required for peck drilling, which is another drawback[1].

Other state-of-the-art tools that can aid in clearing chips are high-pressure through spindle coolant tooling. These will literally blast away any removed material and can operate at very high speeds. However these systems are expensive because it requires modification of the spindle to accommodate the coolant through the tool.

Figure 4. Milling cutter with through-spindle coolant ports[3].

The problem of chip handling can be solved many ways. Newer advanced techniques have high up-front costs but good results. Currently the machine operators at Helical are periodically removing chips from the tools by hand. This solution can be dangerous and frequently interrupts certain machining processes. A low-cost solution is desired to replace the current manual action increasing safety and product output.

Chapter 3 Design Development

Chip Diverter

A chip diverter is to limit the buildup of chips on the drill bit by diverting the chips away from the drill as the chips are forming. The concept shown in Figure 5 consists of three main features. The first feature is a set screw that is located on the top half of the diverter. This set screw would be tightened to hold the diverter in place on the drill bit. The second feature is the conical shape on the bottom of the chip diverter which is used to push the chips located on the outside the drill bit away from the bit, allowing them to fall off without getting caught in the drill bit. The last feature is the threads located inside of the chip diverter. These threads would fit into the flutes of the drill bit serving two purposes. The first purpose is to help hold the chip diverter in place on the drill bit and the second is to push chips located inside the flutes of the drill bit to the outside where they can be removed.

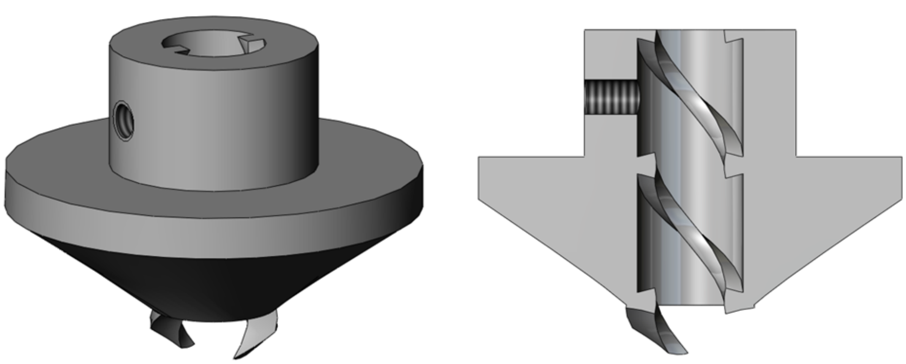


Figure 5. Chip diverter concept solution.

This concept meets our design specifications by providing the passive automatic operation, has no cleaning cycle time and would easily be integrated into the existing equipment. It would require no “real estate” on the CNC table and would be inexpensive to produce. A primary drawback is that multiple sizes would have to be made to fit different tools.

Cylindrical Brush

The cylindrical brush can be best described as semi-cylindrical tube with brushes located on the inside. The drill bit would enter the tube from the opening in the side, then reverse itself and withdraw from the tube. Brushes inside the tube would hold the metal chips in place as the drill bit is removed from the tube, and therefore cleaning the chips off of the drill. This operation could be performed several times to ensure that the drill is reasonably clean before continuing normal machining operation. Once the chips are removed from the drill and located inside the brushes, there is a need to remove the chips from the brushes before the next cleaning cycle. The current idea for removing the chips from the brushes is to use a pneumatic cylinder to push the chips located inside the cylinder out, readying the cylindrical brush for the next cleaning cycle.

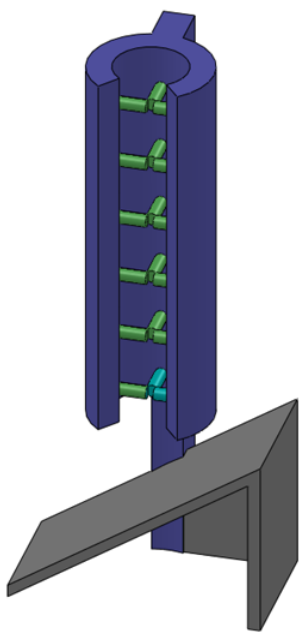


Figure 6. Cylindrical brush concept solution.

The internal brush allows for cleaning of a wide range of tools. The flexible brushes would accommodate different drill widths without damage. Maximum drill length can be incorporated into the overall height of the brush. However, reliability is questionable until further testing is performed due to ability to clear out chips from a brush inside a small space.

Fork

The fork concept is shown in Figure 7. The forks themselves have a range of sizes to accommodate different sized drill bits. The system itself is passive and uses the axis already available on the Robodrill to position the drill bit in the slot and then to pull the bit through, removing the chips attached to the outside of the drill bit.

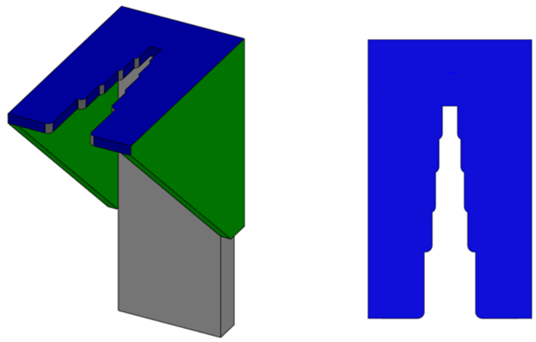


Figure 7. Chip removing fork concept solution.

The chip removing fork meets all of the design specifications stated in Table 1. It is small and can easily be placed in the CNC work area. It can reach the top of the tool and chips have nowhere to go but down and off the tool. The question remains however that if the slot for the tool is left oversized to accommodate all tool widths, will the chips be removed sufficiently? This will be determined in the testing phase.

Compressed Air

The advantages of air nozzles are that they are very easy to install and position. Normally the nozzles are attached to the end of a flexible tube but for the sake of repeatability, it could be set in a fixed location for the cleaning cycle. Because there is no physical contact with the tool, there is no possible damage or wear. Flying chips are not a concern because machining area is enclosed. If the airstream can produce enough pressure to remove the chips dependably, than this would be an ideal solution.

Figure 8. Examples of compressed air nozzles.

Concept Selection

In developing conceptual ideas we have followed a simple yet iterative engineering design process. We first began by defining the problem and establishing a need. Next, brainstorming is used as the primary idea generation. The brainstorming sessions follow four fundamental rules that ensure efficiency and usefulness: delay judging the ideas until later, number ideas (quantity matters), build on previous ideas and jump to new ones, and be creative. Many of the top concepts developed in the design process have both advantages and disadvantages. In order to be able to compare all ideas we used a weighted decision matrix also known as a Pugh Matrix (Appendix A2). The decision matrix allows us to compare all ideas in an orderly fashion while simultaneously evaluating all concepts to our stated specifications and requirements. The eleven concepts decided suitable for evaluation were each compared to a datum cleaning method in the weighted design matrix. Each concept was evaluated using a (+) if the concept outperformed the datum for the specific requirement, a (-) if it underperformed, and an (S) if the concept satisfied the criteria the same as the datum. The overall top concepts were then chosen by magnitude of the score achieved from the decision matrix.

Preliminary Testing Methods

The goal of the preliminary testing is to evaluate as many methods as possible of removing chips from the drill bits by manual means. This testing will provide us with information on the success rates of various methods of chip removal and based upon the information collected, as well as input from Alex Ek, we will choose a method and design a mechanical system to automate the chip removal process.

To test the fundamentals of each idea the team must generate mockups which attempt to perform the chip removal operation. The creations of the top concepts are as follows:

High Pressure Air- The high pressure air used in preliminary testing will be in the most basic form. Air nozzles with 80 psi will be used to determine if chip prevention can be accomplished from different nozzle positions. The nozzle location in the radial and vertical direction must be optimized in order to get the most efficient chip prevention. Different nozzle types will also be used to increase or decrease the air flow into the chip.

Exterior Brush- To replicate the exterior brush idea the team will be using different types of brushes and drill movements to check the efficiency of chip removal. The bristles of these brushes will range from very soft to that similar of a wire brush.

Interior Brush- The preliminary interior brush test will also include the different brushes used in the exterior brush tests. The brushes will be curved, or used in combination with each other to determine which method is most effective.

Slotted Fork- The preliminary slotted fork testing will be accomplished with an aluminum fork. This fork can be created from a piece of aluminum plating which is the desired thickness and outer dimensions. A slot which is slightly larger than the testing bit can then be cut into the aluminum plate and therefore creating the necessary fork.

The team believes that the generation of all these preliminary testing devices can be created on the Cal Poly campus, however if any manufacturing issues arise we will contact Alex Ek for assistance. Helical has a full time in-house tooling department which can assist in fabrication of any concept.

For the first stage of testing we will use steel wool of the appropriate coarseness to simulate chip buildup on the tool. Once the steel-wool is entangled with the tool, preliminary testing can begin. The only concepts which can be tested in this manner are the two brush orientations and the fixed fork, because the collar and high pressure air interfere during chip formation. A later phase of testing will take place at Helical. Mock-ups of the top concepts will be made and taken to Helical to be used directly on the chip buildup they currently experiencing. This will quickly reveal how each concept performs in the intended environment. Iteration on dimensions, materials, or overall concepts will then be made as necessary.

Results of Preliminary Testing

Further narrowing of top concepts was done after the first round of preliminary testing. Ideas that included a form of a brush as the chip removing means have been eliminated due to the difficulty of removing chips from the brush's bristles. It was determined that compressed air at pressures high enough to remove the chip buildup could not be used because OSHA standard STD 01-13-001 limits the dead end air pressure of nozzles used for cleaning purposes to 30 psi for cleaning purposes. The chip diverter concept is also not being perused due to tool integration difficulties.

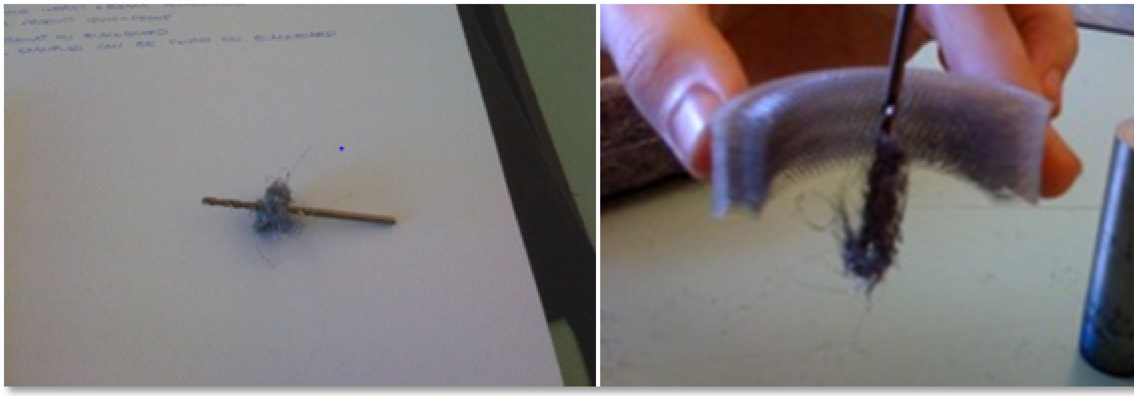


Figure 9. Preliminary testing using steel wool to simulate chips.

Testing reveals that pulling the drill through a slot in rigid material reliably and easily removes chips despite their quantity and tightness on tool. This slot simulates the Fork concept on page 12. A single sized slot however did not effectively remove chips on both the largest and smallest expected drill sizes. Therefore, in the next design iteration, a slot that adjusts to the tool size is proposed for a mock-up and retest.

Safety Considerations

Because our device will be enclosed inside the Robodrill work area, operators will be safe from any possible occurrence during the cleaning operation. The door to the Robodrill has an electromagnetic lock so the machine will not operate if it is open. If the hinged chip removing design is implemented, pinch points will need to be considered. When the device is being installed or undergoing maintenance, it will be handled by Helical staff. The design dimensions and geometry must account for possible harm done to hands and fingers. Sharp edges must be removed by beveling edges and rounding off corners.

Material Selection

The frame structure will need to be robust enough to withstand repeated impact of tooling at the chip removal location. Also, if something goes wrong and the tool collides with the device, it is preferable that the tool is broken and the chip remover stays intact. Therefore the final design will probably be made of some type of steel. A high carbon steel can withstand surface wear which is another concern because of the frequent metal on metal contact with the chips. If a flexible element like rubber is used as part of the device, it will need to be able to withstand constant presence of oil based coolant. It will also need to be durable enough to withstand chip contact while remaining flexible enough to accommodate the various drill sizes.

Maintenance and repair considerations

The device needs to be designed for low maintenance. Because of the relatively low forces involved, yield is not a concern. However, in the design with the flexible element, the only concern of wear is in the material that contacts the tool and chips. The flexible element is installed with fasteners, so that it can easily be replaced. It is uncertain how often this will need to be done, but a material will be chosen to reduce replacement as much as possible.

Final Concept Description

In all three top concepts the drill approaches the cleaning device from the front or back, pushes the guides apart, the spindle slowly reverses and moves upward as the chips are forced off. The rubber flap concept which can be seen in Figure 10a uses two flexible rubber flaps that are bolted in place. The bottom of the rubber flaps are contoured so that the flap will deflect upward as the drill bit is inserted from the side. The sloped and right angle flap concepts seen in Figure 10b, c use spring-loaded, self-closing hinges to hold the flaps against the drill bit while the drill bit is inserted. Each of the hinged concepts need an L-bracket installed on the inside of the hinges to prevent the hinges from closing more than 90 degrees. A #33 and 3/8 inch drill bit are shown in Figure 10a to demonstrate the range of sizes that need to be accommodated. All manufacturing and part drawings can be found in Appendix B.

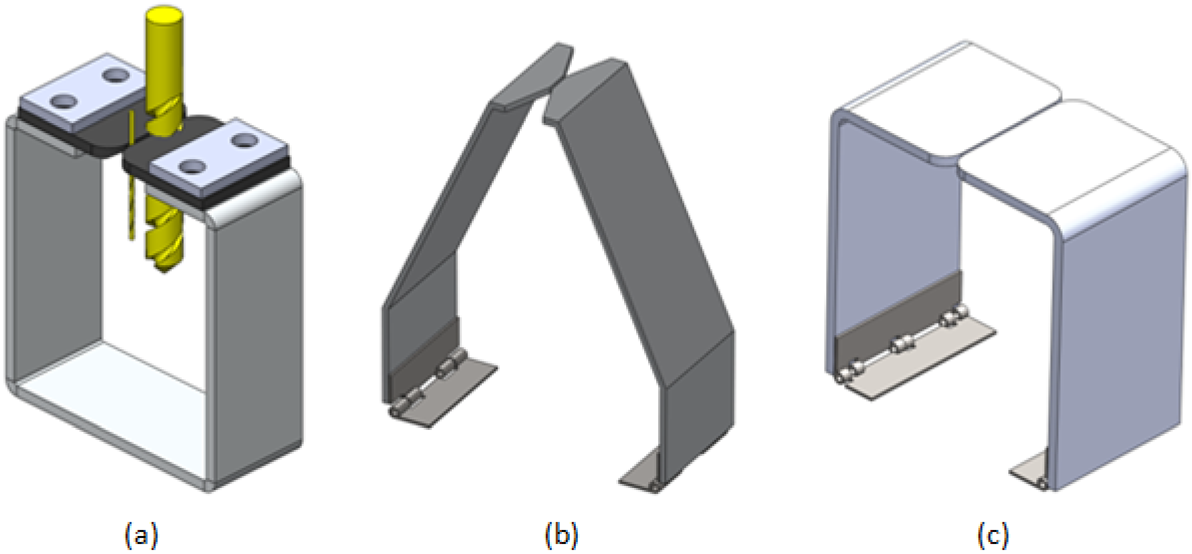


Figure 10. Top three concepts at the end of the initial design phase.

Prototype Construction

In order to test the three preliminary concepts, prototypes were constructed out of various materials. These prototypes were created to test the functionality of each concept. The first mockup resembled the hinged design and would serve as a great representation of both types of the hinge concept. This prototype was built using a 1/2" Pine foundation. Attached to this foundation were the desired spring-loaded hinges ordered from McMaster-Carr. The hinges used were lightweight surface-mount spring hinges which are identical to the listed hinges in the Bill of Materials. Each hinge was fastened to the wood base using 2 #6 X 5/8" wood screws. Attached to each hinge was a 1/8" galvanized metal bracket. The brackets used are designed for use in the construction industry and were purchased at Home Depot. When oriented in the desired position, the brackets have a height of 4", depth of 2 ½", and a width of 2".These dimensions have some variation from the desired specifications however the mockup is only to serve for concept feasibility testing. The metal brackets were attached to the hinges using 1/8" steel rivets. The rivets are more difficult to remove than any non-permanent fastener, but for preliminary prototype construction it is acceptable. The last task performed on the prototype was to create an entrance angle for the drill bit. A 45° angle was cut into each metal bracket where the drill bit would enter into the cleaning device. This was performed using a jigsaw with a metal cutting blade. The creation of this entrance angle would allow for the bit to easily slide between the two spring-loaded brackets. This wood bracket mockup would also serve as an appropriate design for representing the bent hinge concept.

Figure 11. Spring loaded hinge prototype created for testing.

The next prototype created was one similar to the rubber flap design. To create the mockup, a wooden foundation was created using the same Pine from the first mockup. This wooden base was created from three similar pieces of wood and joined with 4 5/8"drywall screws. To create the flexible element which comes in contact with the machining tool, 1/4" soft polyurethane rubber was used. The rubber came from a flexible hose cap purchased at Home Depot. The rubber was cut into a 3" square and attached using 6 5/8" drywall screws with small washers. Once the rubber top was installed, tin shears were used to cut a straight separation in the rubber. Lastly, 45° relief angles were cut on both sides of the rubber opening to provide an easier entrance for the bit.

Figure 12. Soft rubber flap prototype created for testing.

Another prototype was assembled to help show which aspects of the rubber flap design would work best. This prototype was created using the same process as before and only the flexible element was altered. The flexible element used was 1/8" firm polyurethane rubber. This rubber was thinner and less flexible than the rubber used before. A slot approximately 1/16" in width was cut along the entire depth in order to provide for the drill bit entrance.

Figure 13. Firm rubber flap prototype created for testing.

Prototype Testing

Initial prototype testing occurred on April 1st, 2009 at Helical in Santa Maria and our meeting with Alex proved successful. Due to the various production orders that Helical receives there was only one machine that had accumulated any chip buildup. The machine with chip buildup was a Fanuc Robodrill which had one fixture and one vise mounted on the pallet. The chip buildup was on a 1/8" drill bit used for machining stainless steel. After discussing the fundamentals of each prototype we decided to choose the spring loaded hinge prototype. This prototype was positioned in the vise and clamped as needed.

To start the testing Alex adjusted the machine to allow for manual control. The bit was positioned directly at the entrance of the chip removal device and low as allowable.

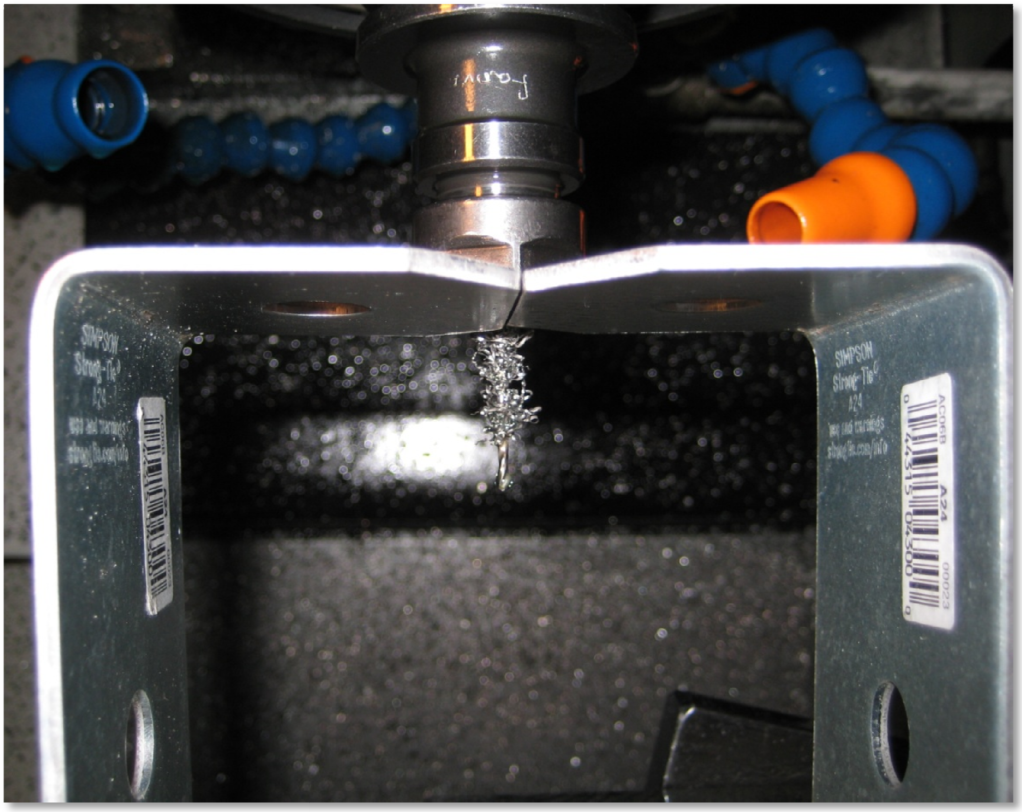


Figure 14. Position of bit directly before entering spring loaded hinge prototype.

Alex then moved the bit approximately halfway into the slot of the device as the hinged brackets kept constant contact on the bit. From this location the spindle was raised until the bit was completely clear of the device. The chip buildup was completely removed and remained within the opening of the device. To clear the chips from the device, Alex moved the bit through the slot of the device and the chips fell to the bottom.

The results of testing showed that the spring loaded hinge design worked as desired. We believe the device would not have been as effective if it were used with a 3/8” drill bit because the brackets would have to separate more and therefore possibly coming into contact with the bit mounting nut. We also believe that the metal we used was thicker than needed, whereas the hinges worked perfect and just as expected. We were unable to test the other mockups and expect that the soft rubber design would have worked well. The firm rubber seemed too stiff for incorporating the larger drill bits. Further testing will help in directing and determining the design path we take.

Chapter 4 Final Designs

Design Description

After the design phase, it was determined from preliminary testing that the device depth should be between 1.5 and 3 inches. This dimension allows for an adequate entrance and sufficient gripping surface area for chip removal. To create a reference point and firsthand exposure to our design, we created a 16 gauge 1020 steel prototype with a height of 4.5 inches. Our spreadsheet of stiffness calculations showed that the clamping force was approximately 9 lbs. We knew that 9 lbs. of clamping force was likely more than needed from our testing of the hinged-bracket prototype earlier this quarter, however, we could easily change the clamping force by changing the dimensions as needed. The estimated clamping force of the hinged-bracket prototype was 1 lb. and was never tested against a tightly wound chip. We believe that a clamping force of 1lb. would not be sufficient due to reliability of chip removal.

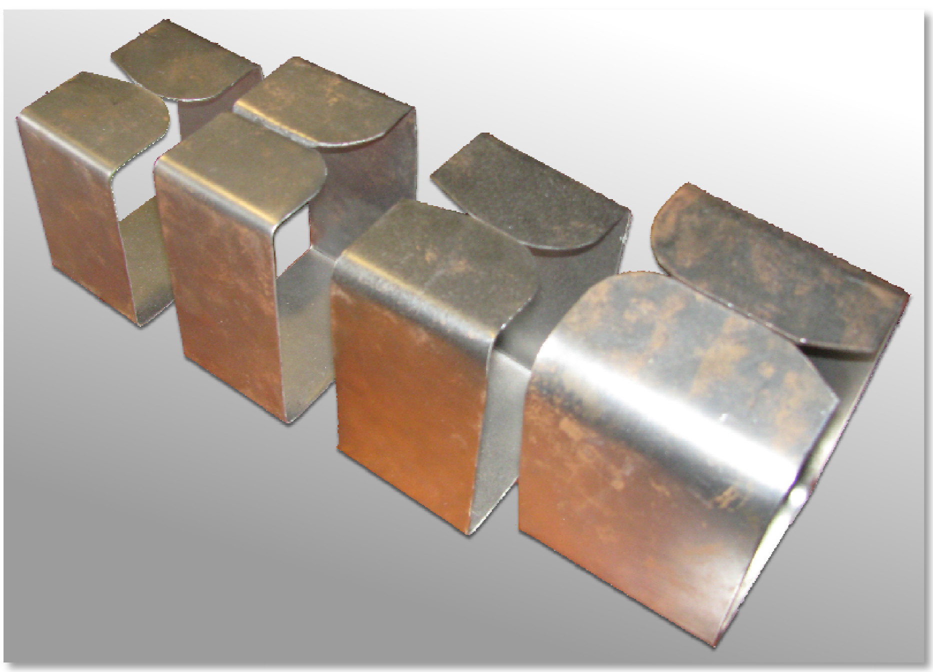


Figure 15. Steel prototype devices with varying height, material thickness, and bit entrances.

The 16 gauge metal was cut using a jigsaw and metal cutting blade. Once cut to the desired width, the metal was clamped with vise clamps and then bent by hand to the desired dimensions. Metal shears were used to cut in the entrance area which was chosen to be an 11/16 inch fillet located on each jaw. This process was accurate when used to build the device, and would serve as a way to build prototypes in the future.

Testing of the 16 gauge device proved to be very useful, because it was very difficult to insert various bits into the jaws. The clamping force was too large and the extreme pressure exerted on the larger bits created chip formations. This device removed all the steel wool chips that were used for testing. To combat this problem we tried various 16 gauge aluminum designs to lower the clamping force and therefore possibly withstand the sharp edges of the bits. Once tested, we found that 3-5 lbs. of clamping force was sufficient for chip removal; however the aluminum clamping surface seemed to become scratched and scarred easily. We now needed to find something with the durability of 16 gauge steel and the flexibility of 16 gauge aluminum.

Table 2. Clamping force calculations for varying height, thickness, and width

Drill Bit Size (in)	Clamping Force (lb)	Spring Equivalent (lb/in)	σ (psi)	I (in^4)	E (psi)	Base, b (in)	Thickness, t (in)	Height, h (in)
0.3750	0.11	0.31	9375	9.17E-08	30.0E+6	1.1	0.0100	3
0.3750	0.20	0.53	11250	1.58E-07	30.0E+6	1.1	0.0120	3
0.3750	0.39	1.03	14063	3.09E-07	30.0E+6	1.1	0.0150	3
0.3750	5.37	14.32	25562	5.46E-06	30.0E+6	2	0.0320	3.25
0.3750	6.45	17.20	22041	8.19E-06	30.0E+6	3	0.0320	3.5
0.3750	3.50	9.32	19200	5.46E-06	30.0E+6	2	0.0320	3.75
0.3750	2.88	7.68	16875	5.46E-06	30.0E+6	2	0.0320	4
0.3750	2.40	6.40	14948	5.46E-06	30.0E+6	2	0.0320	4.25
0.3750	2.02	5.39	13333	5.46E-06	30.0E+6	2	0.0320	4.5

At this point in the project we began to reevaluate our design criteria to help ensure we were going in the correct direction and still making progress. We looked at our stiffness spreadsheet in combination with different materials. We noticed that there were only a few options at this point and considered what would be best. The options are as follows: 1. Possibly use a thinner steel and see if it were able to withstand the sharp bits while still providing the needed clamping force,

2. Use a bimetal or two piece design that would have robust jaws and flexible side members, 3. Have a steel device with varying geometry so that both criteria may be satisfied.

We decided to make prototypes to see which of the 22 and 20 gauge steels could withstand the sharp bits. The 22 gauge steel could easily withstand the cutting edge, but seemed too thin. The factor of safety was very low for the 22 gauge designs. The 20 gauge design proved sufficient when the height was larger than 3 inches. We decided that a 3.5 inch tall 20 gauge steel design should satisfy all the requirements. If this design does not prove to work as expected then we will pursue a bimetal or variable thickness option. We did not immediately pursue this because we would like to find the simplest solution to this problem as requested by Helical.

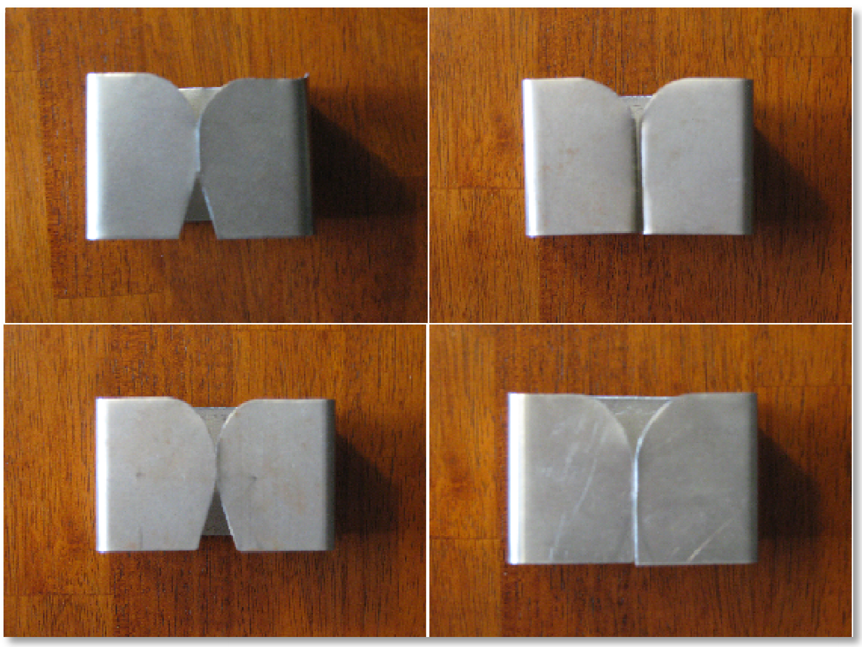


Figure 16. Some examples of different bit entrances

The last aspect of the design that needed to be optimized was the bit entrance section of the device. We cut many different round edges and chamfers to reduce the opening pressure on the drill bits as much as possible. If a sharp cutting edge was to get caught on the device entrance, the bit could bend or break depending on the diameter or the device could deform permanently. We noticed that the round constant radius edges worked most of the time. Occasionally, the cutting edge would catch and require an extremely large force to enter the device. The 45° entrance angles were not sufficient for the bit as it transitioned to the channel of the device. From a wide range of testing bit sizes and methods we found that the more acute entrance angles worked well. To help ease the movement into the channel, we rounded the edge that exists in that transition.

Figure 17. Chip removal device prototypes used to determine final design

Mounting Fixture

Initially the base plate that the cleaning fixture was to be mounted to was a flat piece of cast ground aluminum with four tapped holes to secure the fixture. Although this fixture would work to mount the cleaning device, the location of the fixture would change every time a new fixture was installed. The updated base plate for the cleaning fixture is shown below in Figure 18. The center of the plate is machined to provide two reference planes, one for locating the cleaning device and the other for locating the gauge. The cleaning device is to be placed over the four tapped holes in the center and against reference plane A. The gauge, which is constructed from a piece of angle iron with a notch for locating the cleaning device, is then placed on top of the raised area and against reference plane B.

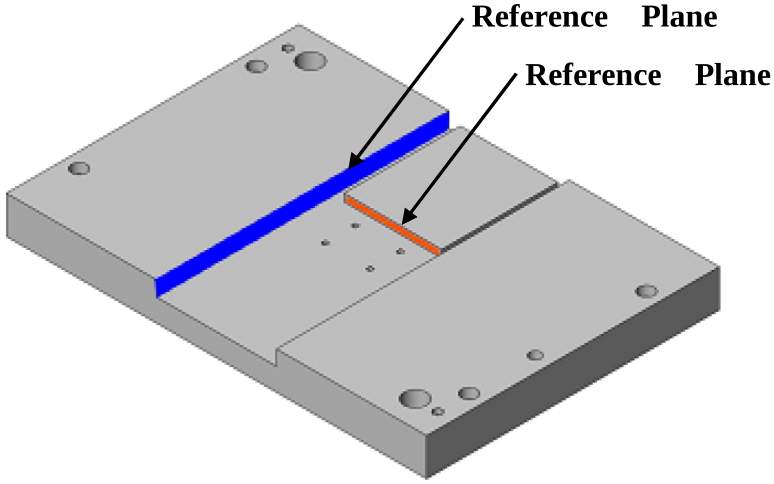


Figure 18. Base Plate with reference planes.

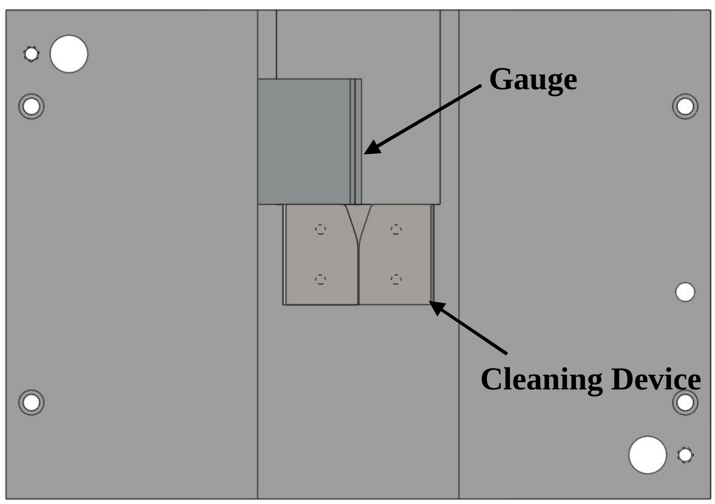


Figure 19. Top view of Base Plate with Cleaning Device and Gauge in place.

Figure 20 is a front view of where the gap in the cleaning device and gauge overlap. The cleaning device is to be positioned where the gap in the cleaning device and the notch in the gauge overlap. Once the cleaning device is in its proper position the bolts for the cleaning device are to be tightened and the gauge removed.

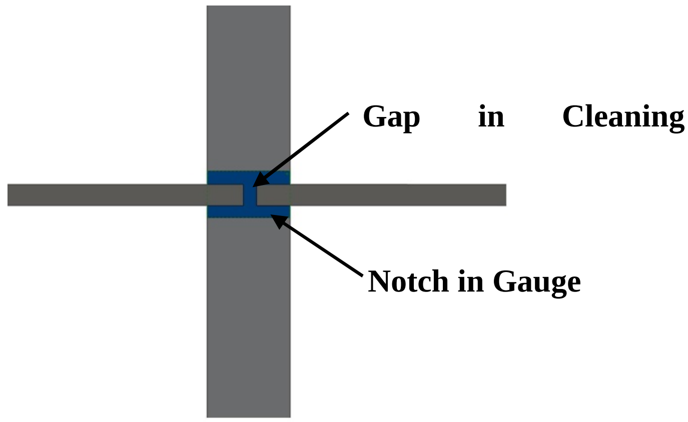


Figure 20. Front View showing notch in gauge used for locating the cleaning device

Conclusion

It has been agreed that the device and other tooling will be manufactured on-site at the Heli-Cal plant. Over the summer Heli-Cal will use the device in their manufacturing process to determine if the device meets all of the design requirements or if any further iteration is required. The Cal Poly team will provide some guidelines for collecting data during this testing phase.

Cost Analysis

During the design process it was beneficial to determine how much existing pallet production space could be removed. The chip removal design has to occupy or interfere with the minimal amount of real estate in order to maintain a profitable process. Instead of completely focusing on costs and profits we decided to assume that any time saved would correspond to lower production costs and therefore higher profits. The assumptions necessary for a cost analysis would compromise the credibility of the end result.

The optimization began with a detailed look of a pallet consisting of sixteen 0.75 inch diameter parts made of 17-4 stainless steel. The fundamental data used in the analysis was given to us by Alex Ek. The design specifications relating to time are also included and presented in Table 3.

Table 3. Data used in production real-estate optimization.	
Time To Load/Unload Each Part	11.25 sec
Machine Time Per Part	120 sec
Manual Cleaning Time Per Row	120 sec
Maximum Chip Assist Cleaning Time Per Row	5 sec
Assumed Part Count For Production Order	1000 parts

For this pallet Helical is currently operating at maximum capacity which is 16 parts per pallet. When the Chip Assist device is implemented into the system some percentage of real estate will be lost. Based on the number of parts per pallet, we calculated the total machine time and total labor time for an estimated order of 1000 parts. The calculated total production order time was then compared to the existing process in graphical form. The process comparison is shown in Figure 21.

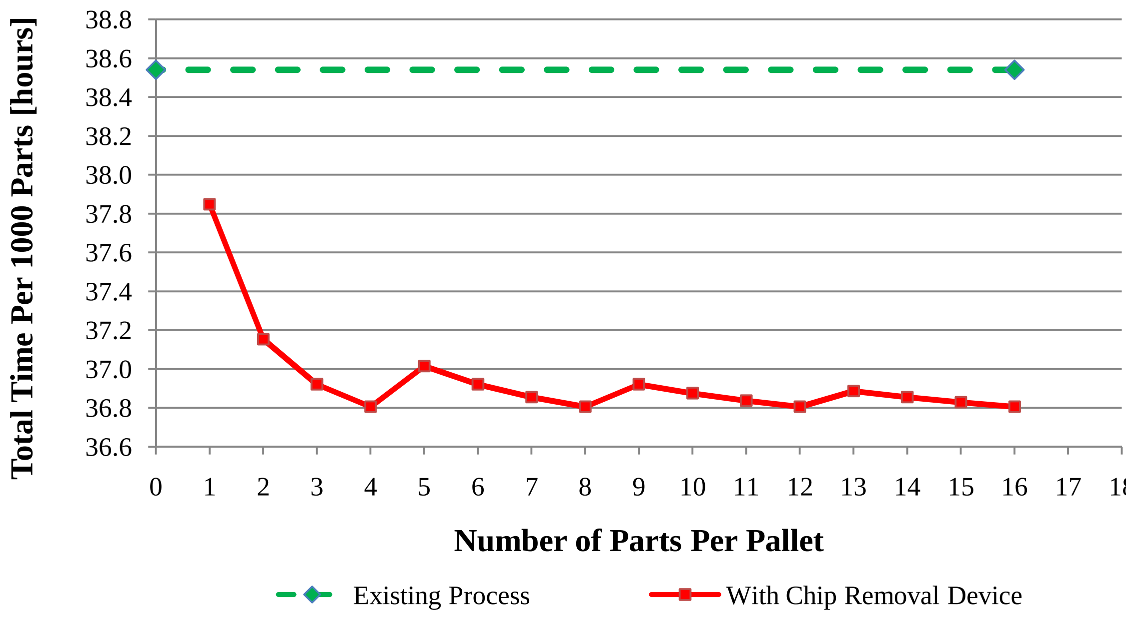


Figure 21. Comparison of total time to produce 1000 parts using the existing process and expected process using the Chip Assist device.

From this relationship it can be shown that the Chip Assist device will greatly reduce the production time when compared the existing process. If the chip removal device will not interfere with any existing real estate then the total savings for a 1000 part production order will be approximately 1.73 hours. Even if the device were to interfere or occupy all but one part location, Helical would still have a lowered production cost for a 1000 part order by 40 minutes. The graph shows that the more real estate we occupy with our design, will lead to greater production time due to the increased number of runs necessary to satisfy a given order.

The primary parameter that influenced the production cost was the chip removal time. The existing process takes 120 seconds/row whereas the Chip Assist device must operate in less than 5 seconds/row. This is why the change in production time is so noticeable. Our final design will minimize the amount of real estate loss in order to optimize production time. The complete spreadsheet utilized in this production real estate optimization can be found in Appendix C.

Regarding the actual cost of materials and labor to build the device, a proposed bill of materials for the mock-ups can be found below in Table 4. The materials may not need to be purchased as we need small quantities and they are common scraps found in any shop. If the materials are required to be purchased, we selected McMaster Carr as the source.

Bill of Materials

Table 4. Bill of materials for final design[4].

Item No.	Part No.	Description	Rev	Quantity Required	Unit of Measure	Manufactuer	Manufactuer Part No.	Manufacture Description	Cost
1	6544K11	Sheet Metal	A	1	Each	Mc Master-Carr	6544K11	General-Purpose Low-Carbon Steel, 20 Ga , 6" X 24"	$4.45

Chapter 5 Product Realization

The final prototype chip removal device was manufactured by using two basic sheet metal forming tools, a sheet metal shear and sheet metal break. The sheet metal shear was used to cut down the sheet metal to the proper length and width before the bends were put in place. The break was used to create the four bends in the sheet metal. Bend placement and bend angles were the most important aspects of manufacturing our final design. Since the chip removal device is used in CNC machinery repeatability is very important to ensure that the cleaning device operates seamlessly with the current tooling in place at Helical. The entrance angle of the chip removal device was created using hand held sheet metal shears.

With limitations to the manufacturing processes that we could use to construct the final prototype, the bend angles and entrance reliefs may differ from our planned design. The sheet metal shear and sheet metal brake are both manual sheet metal forming tools. We recommend that Helical uses CNC sheet metal shear and CNC controlled sheet metal press break. By using computer numerically controlled sheet metal forming tools, the bend placement and angles can have higher tolerances and better repeatability for future chip removal devices.

Chapter 6 Design Verification Plan

Test Descriptions

The following are short descriptions which portray the characteristics of each test method. These testing methods are referenced in the Design Verification Plan and Report which is Table 5.

Test 1 - Chip Removal Effectiveness, Manual

Pass/Fail test that will determine the effectiveness of the three initial prototypes. This test will be conducted at Helical on a Fanuc Robodrill. The test will include manually inserting the chip removal device into the CNC machinery and attempting to remove chip buildup from the drill bit. This test will be used for design validation of the first three prototypes that are to be constructed by Chip Assist.

Test 2 - No Interference with Existing Machinery

Pass/Fail test that will be used to verify that chip removal device will not interfere with any of the current CNC machinery that the device will be integrated with. This test will be performed using a Computer-Aided Manufacturing Software (CAM) that will verify that the chip removal device will not damage CNC machinery or products and ensure that the device will be integrated with the CNC control that operates the Fanuc Robodrill.

Test 3 - Cycle Time

Test will verify that the cleaning cycle time for each row of machined parts will be less than five seconds maximum. The cycle time test will be preformed after the chip removal device has passed test 2, the no interference with existing machinery test. This test will be performed at Helical Products on a Fanuc Robodrill machining an empty pallet. This test is a design validation test with an acceptance criterion of the cycle time being less than five seconds.

Test 4 - Chip Removal Effectiveness, CNC

Pass/Fail test that will determine the effectiveness of the final chip removal prototype. This test will be conducted at Helical on a Fanuc Robodrill on a complete pallet of 0.75” diameter parts. The test will include integrating the chip removal device into the CNC machinery and attempting to automatically remove chip buildup from the drill bit. This test will be used for design validation of the final prototype design. Test will verify the design requirements that the device must remove the chip build from the drill bits, operate automatically, and integrate with the current CNC control.

Test 5 - Accommodation of Different Drill Sizes

Pass/Fail test that will verify that the chip removal device will accommodate drills of jobber length from #56 to 3/8. The test is a repeated test of automatic chip removal effectiveness. This test will be conducted at Helical on a Fanuc Robodrill on a complete pallet of parts. For each run the parts will be varied in size each run to ensure that all drill sizes are tested in the final chip removal device.

Setup

The final chip removal device was delivered to Helical at the end of Spring Quarter. The device was coated with paint to help prevent any possibilities of corrosion while in use. Helical also created a device with the desired dimensions, but used stainless steel. With the assistance of Alex, a G-Code program was created which would allow for the working tool to enter the device and then rise and removing the chip buildup. This program was separate from the machining program. The cleaning program would need to be implemented in every CNC machine that would utilize the chip removal device. The cleaning program created was initially used on the Fanuc Robodrill. Minor modification to the cleaning program would be required if Helical wanted to use it on other CNC machines. Helical could now call upon this program at any point during the machining process. The cleaning program lowers the tool needed for chip removal to a height approximately ¼ inch from the chuck in reference to the top of the cleaning device. Once in this starting position, the tool is inserted into the cleaning device by opening the jaws of the device. The tool moves horizontally to approximately 2 inches into the device. At this location the tool is then lifted from the device whit it rotates in reverse. From testing it was noticed that chip buildup was easily removed when the drill bit was reversed.

Results

Helical utilized the chip removal devices throughout the summer in order to test its feasibility and usability. Alex was contacted throughout the summer to get updates on the devices. Early notification from Alex told us that devices looked very promising, but were not currently in use due to production demands. Later in the summer Alex notified us that Helical were able to use the devices in particular production runs. The chip assist devices worked every time they were used. Alex was completely satisfied with the chip removal device; however there were two minor issues that needed to be addressed. These two issues related to the entrance angle and the device stiffness. When large tools entered the cleaning device, there was significant binding between the cleaning device and tool due to the increases clamping force. The second issue deals with torsional bending of the device when a tools cutting edge binds up the cleaning device.

DVP&R

Table 5. Design Verification Plan and Report

TEST PLAN										TEST REPORT		
No.	Specification or Clause Reference	Test Description	Acceptance Criteria	Test Stage	SAMPLES TESTED		TIMING		TEST RESULTS			NOTES
					Quantity	Type	Start date	Finish date	Test Result	Quantity Pass	Quantity Fail	
1	Feasibility, Stepped Fork	Steel Wool Removal Test, Stepped Fork	Pass/ Fail	CV	5	A	2/25/2009	2/25/2009	Pass	5	0	Cleared chips effectively and did not have trouble removing chips from the removal tool
2	Feasibility, Cylindrical Brush Interior	Steel Wool Removal Test, Cylindrical Brush Interior	Pass/ Fail	CV	5	A	2/25/2009	2/25/2009	Fail	1	4	Chips cleared efficiently but chips were very difficult to remove from the brush
3	Feasibility, Cylindrical Brush Exterior	Steel Wool Removal Test, Cylindrical Brush Exterior	Pass/ Fail	CV	5	A	2/25/2009	2/25/2009	Fail	1	4	Chips cleared efficiently but chips were very difficult to remove from the brush
4	Chip Removal Effectiveness - Manual	Test will validate the removal device effectiveness by manually using the chip removal device to remove entangled chips from the CNC drills	Pass/ Fail	DV	4	A	6/9/2009	6/9/2009	Pass	4	0	Chip removal device very effective when manually positioning drill bit to chip removal device
5	No Interference with existing machinery	Test will verify that chip removal device does not interfere with current CNC machinery using CAM test program	Pass/ Fail	DV	4	A	6/9/2009	6/9/2009	Pass	4	0	No unwanted interference with CNC device
6	Cycle Time	Test will validate the cleaning cycle time of the chip removal mechanism	<5seconds	DV	10	A	6/15/2009	9/22/2009	Pass	10	0	See video provided by Alex Ek
10	Chip Removal Effectiveness - CNC	Test will validate the removal device effectiveness by machining a complete pallet of 0.75" diameter couplings	Pass/ Fail	PV	10	A	6/15/2009	9/22/2009	Pass	10	0	See video from Alex Ek
11	Accommodates Different Drills Sizes	Repeated cleaning cycle test to confirm that chip removal mechanism accommodates different drill sizes of jobber length #56 to 3/8	Pass/ Fail	DV	10	A	6/15/2009	9/22/2009	Pass	10	0	See video from Alex Ek

Chapter 7 Conclusions and Recommendations

It was noted that during regular operation that the top of the cleaning device would begin to rotate as the drill bit was inserted. If at a later date this rotation of the top of the cleaning device were to become a concern we recommend increasing the depth of the cleaning device to provide more torsional stiffness. The clamping force of the cleaning device increases linearly with the depth of the device, while the torsional stiffness increases cubically. That is to say a 25% increase in the depth would provide a 25% increase in the clamping force and a 95% increase to the torsional stiffness.

As mentioned earlier, another problem encountered during the testing phase is the tool "catching" on the edge of the cleaning device due to the sharp edges of the flutes. If the tool is oriented appropriately the flute will begin to cut into the edge of the device. The small grooves created on the device did not appear to cause any problems other than more frequent hanging of the tool. The negative impact this has on the life of the device is when the hung up tool is stuck too long and pushes the device to a yielding point. This causes the jaws to not return to their original location. The concern with the jaws getting bent is that the chips will no longer be effectively removed, every time. This fails to me the design requirement of automatic operation. In order to maintain the simplicity of our design only a few solutions to this problem make it into consideration.

The cause of the tool cutting into the device is related to the difference in hardness of the metals. The cutting tools and drill are made of high speed steel (HSS) whereas the cleaning device is made of a normal, non heat treated mild steel. HSS generally display a Rockwell Hardness of above 60, whereas mild steel is only 20-25. This is what causes the drill or cutter to do its job without wearing out. One possible solution to the problem would be to decrease this difference in hardness by heat treating the edge of the cleaning device or by attaching a harder material at the edge of the device jaws to guide the tool. The drawback with heat treating is that it is not easy to localize in a controlled manner. Heat treating the whole device is undesirable as this will change the bending characteristics which are currently satisfactory. Another negative impact of a device with a harder edge is increased wear on the tool's cutting edge. As the tool is pulled out of the device the edge of the flutes scrape the harder material which would cause increased wear of the tool. Because this would increase the complexity of the manufacture of the device and increase tool wear, it is not suggested that this solution be pursued.

Instead of modifying the Chip Assist to mitigate the catching problem, it is proposed that the machine code be changed to prevent this. If the tool spindle is run in a slow reverse speed, the cutting edge of the tool would not be able to cut into the Chip Assist upon entry. This is a minimal cost solution that requires no design changes to the device.

References

1. Agapiou, John S., and David A. Stephenson. Metal Cutting Theory and Practice. New York: C R C P LLC, 2005. Pg. 219.

2. "Pallet-Changer System offers repeatability of 0.0002 in., Methods Machine Tools, In." The complete source for the latest industrial news solutions. 18 Feb. 2009 <http://news.thomasnet.com/fullstory/464262>.

3. "EMUGE - Press Releases > Emuge Solid Carbide Thread Mill Series Offers Increased Efficiency, High-Confidence Machining." EMUGE - The leader in thread cutting technology and performance. 28 Jan. 2009 <http://www.emuge.com/news_events/solid_carbide_threadmill_11_8.html>.

4. McMaster-Carr. 13 Mar. 2009 <http://www.mcmaster.com/#>.

Appendix A

QFD – Quality Function Development

		Engineering Requirements												
		Weighting (1 to 5)	5 second cleaning cycle max.	Must not scratch or damage tools	Integration with CNC control	Automatic Operation	Not permanently attached	Drills-Jobber Length- #56 to 3/8	Fits Fanuc Robodrill	99% Reliable	< $100 Per Tool	Install within 30 min	Must last for 1000 hours between maint.	Must yield before tool during collision	Productivity gain > real estate loss
Customer Requirements	Integration with CNC control	**5**			9	9						3			
	Automatic Operation	**5**	1	1	9	9				3	1	3			3
	Easy to Install	**3**					9					9			
	No Damage to tools	**5**		9										3	
	No Damage to product	**5**		1										3	
	User safety	**2**			5	5							6		
	Works on a variety of tools	**5**						9	9						
	Remove Metal Chips	**5**	2							4					
	Relatively Simple	**3**				4	3		2	2	6	4	3		
	Tool must be engaged	**4**	4		4	4									
	Fits Various Machines	**2**			2	2	5		9						
	Reliability	**5**								9			9		
	Robust	**5**								5					
	Cost	**1**									9				3
	Easy to Clean - After Process	**2**	5										2		
	No Chip Build Up	**4**	3	4									6		4
	Time to complete process	**5**	9		3	3									
	Conserve Pallet Real Estate	**4**	5												
	Clear Chips after every row	**3**	7												
	Importance Scoring		139	71	135	147	46	45	69	111	32	69	94	30	34
	Importance Rating (%)		**95**	**48**	**92**	**100**	**31**	**31**	**47**	**76**	**22**	**47**	**64**	**20**	**23**

Chip Assist Decision Matrix

Concepts		1	2	3	4	5	6	7	8	9	10	11
Criteria	**Wgt**											
Automatic Operation	5	s	s	s	s	s	s	s	s	s	s	s
Reliablility	5	s	+	+	+	s	+	s	+	+	-	s
Cycle time	3	s	+	s	+	+	+	+	+	-	s	+
Ease of Integration	2	s	+	+	+	+	+	+	+	s	+	+
Damage to tools and workpiece	4	s	+	+	s	s	-	-	+	+	+	+
Tool adaptability	3	s	s	s	-	-	-	s	s	s	+	+
Build Cost	1	s	+	+	+	+	+	+	+	+	+	+
Realestate Loss (pallet area)	2	s	-	-	-	s	-	-	-	-	s	+
User Safety	5	s	s	s	s	s	s	-	s	s	s	s
Requires support system (air, electricity)	1	s	+	s	+	s	+	+	s	+	s	+
	#+	0	6	4	5	3	5	4	5	4	4	7
	#-	0	1	1	2	1	3	3	1	2	1	0
	#S	10	3	5	3	6	2	3	4	4	5	3
Weighted total		**0**	**14**	**10**	**7**	**3**	**3**	**-4**	**13**	**6**	**5**	**16**

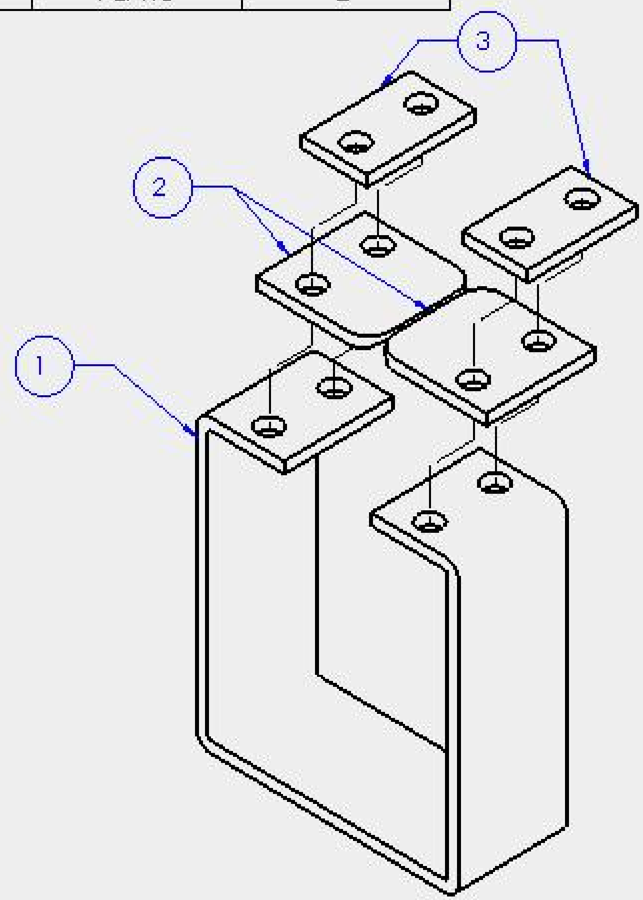
Concepts

1. Robotic Claw
2. Fixed Brush (Exterior)
3. Rotating Brush
4. Fixed Fork (Pallet)
5. Moving Fork (Wall)
6. Slanted Channel
7. Trap Door
8. Cylindrical Brush (Interior)
9. All inclusive
10. High pressure air
11. Chip Diverter

Appendix B

Assembly and manufacturing drawings index:

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	1001	SHEET METAL	1
2	1002	RUBBER FLAP	2
3	1003	PLATE	2



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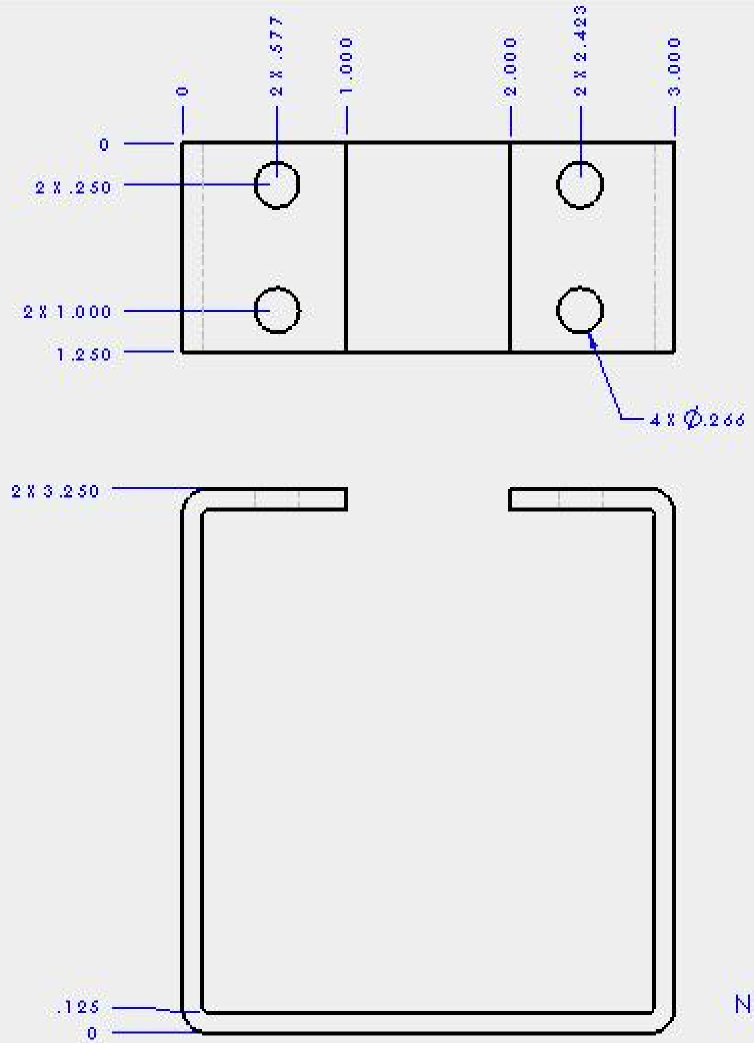
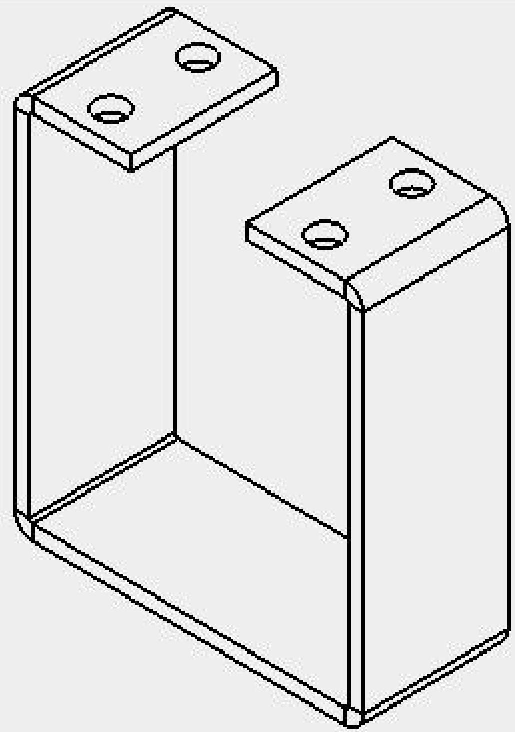
Date: 3/6/09	Tolerance:	Group: CHIP ASSIST	

Mechanical Engineering
CAL POLY





NOTE: SHEEL METAL IS 1/8" THICK 2024 ALUMINUM

Mechanical Engineering
CAL POLY

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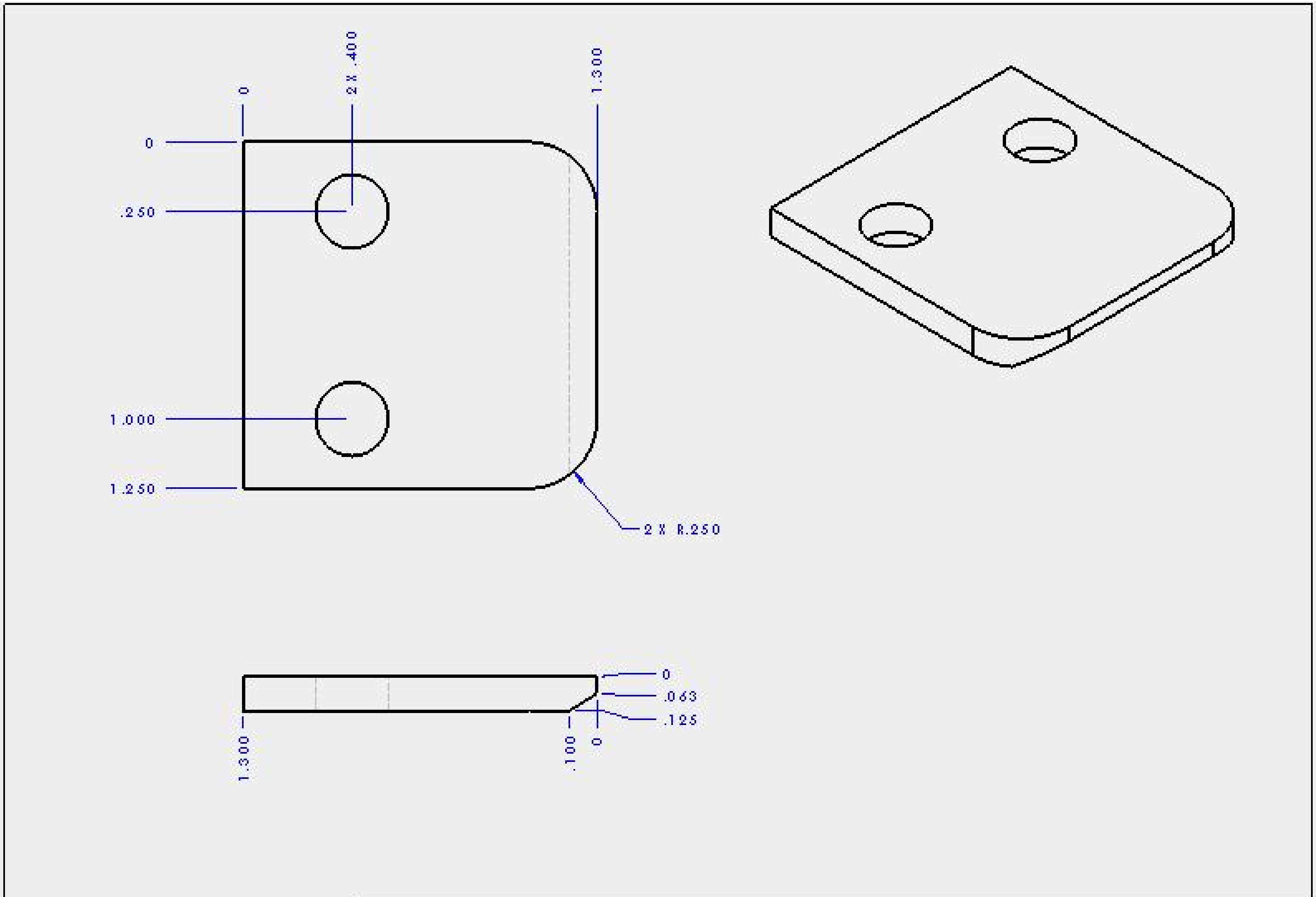

Mechanical Engineering CAL POLY

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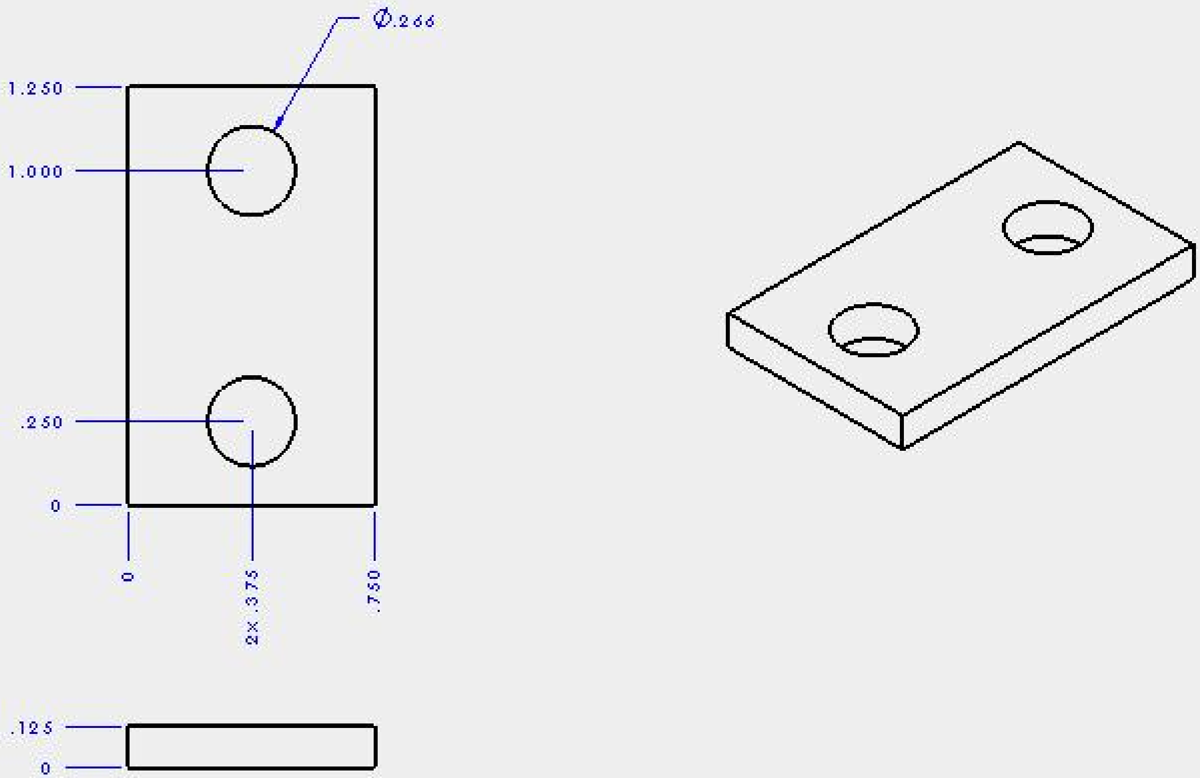

NOTE: SHEEL METAL IS 1/8" THICK 2024 ALUMINUM

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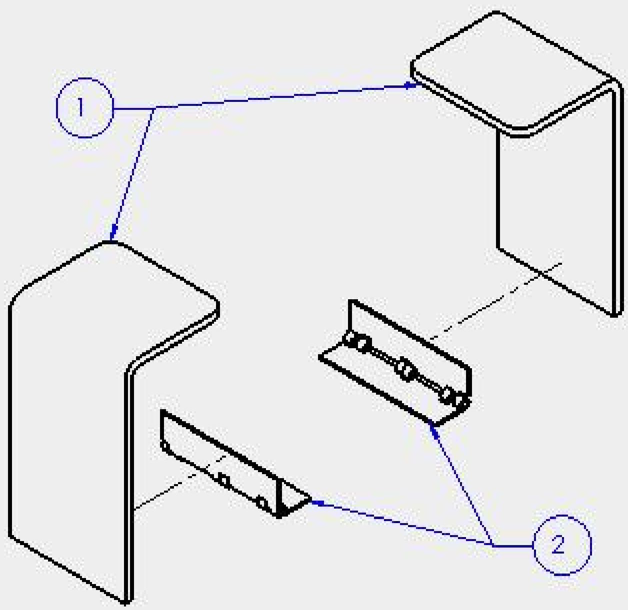
Date: 3/6/09	Tolerance: ±.01	Group: CHIP ASSIST	

Mechanical Engineering CAL POLY

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Flap	2001	2
2	15205A24	Self-Closing Spring Hinge	2



Mechanical Engineering
CAL POLY

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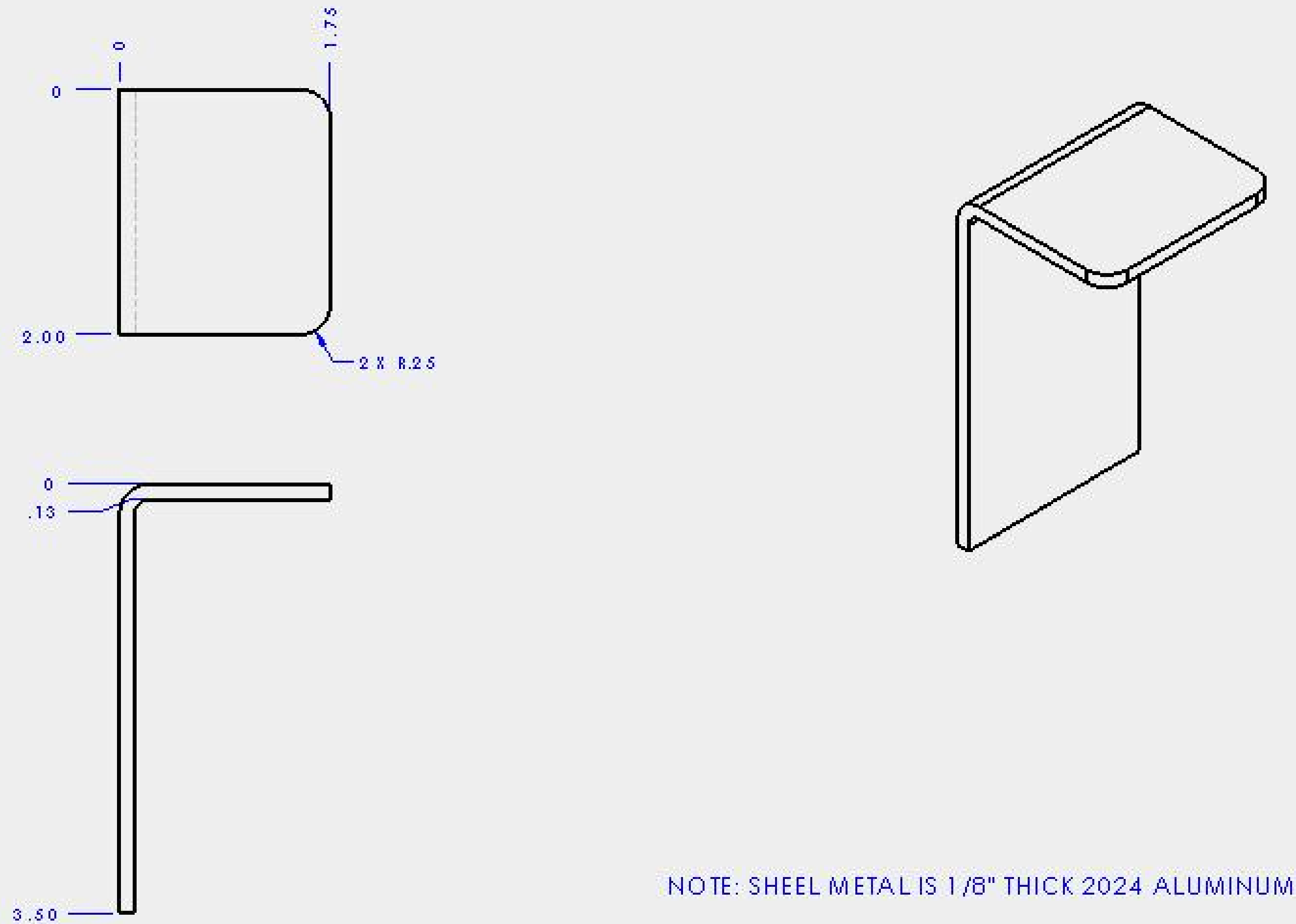
Date: 3/12/2009	Tolerance:	Group: CHIP ASSIST	



NOTE: SHEEL METAL IS 1/8" THICK 2024 ALUMINUM

Mechanical Engineering CAL POLY

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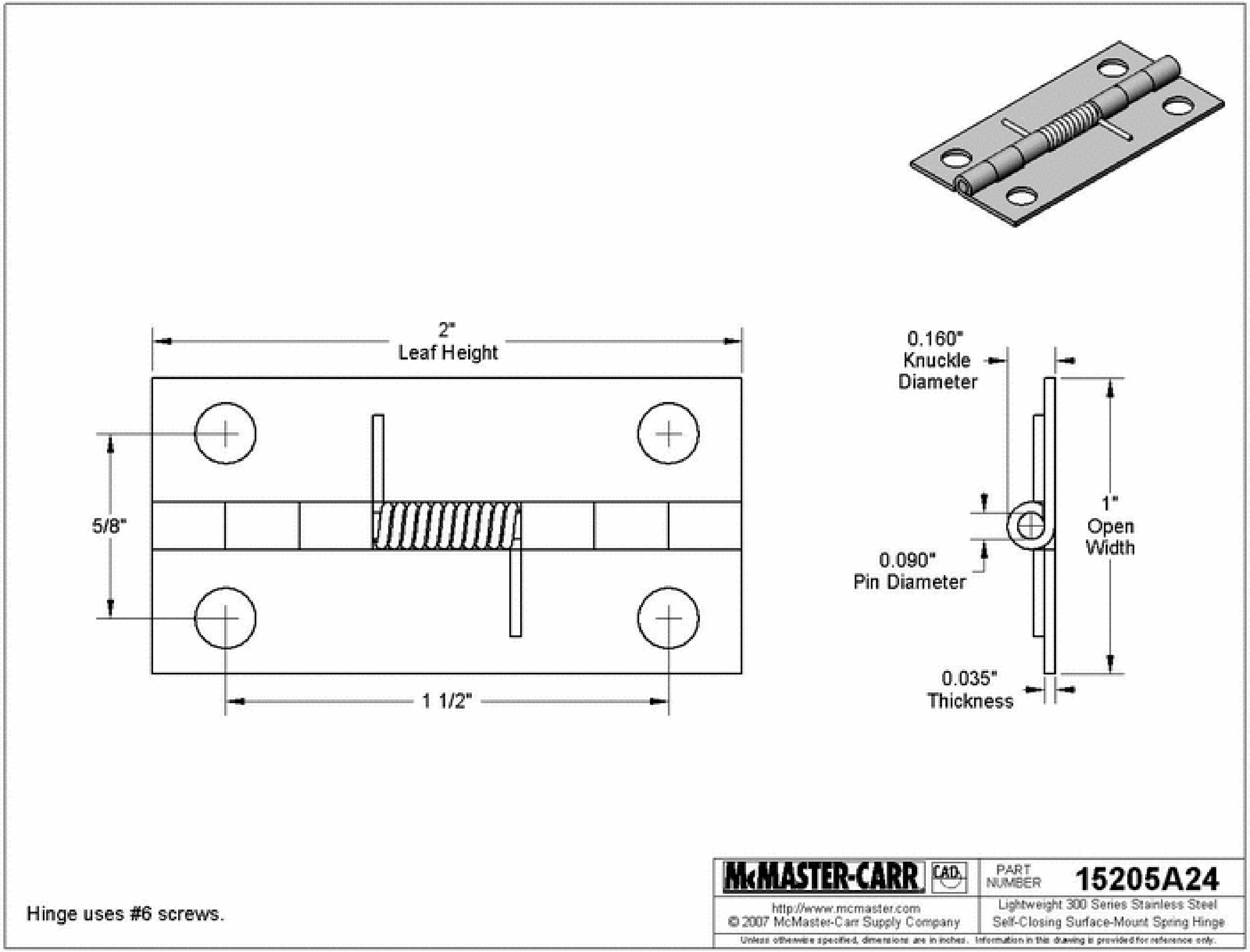
2"
Leaf Height
5/8"
1 1/2"
0.160"
Knuckle
Diameter
1"
Open
Width
0.090"
Pin Diameter
0.035"
Thickness
Hinge uses #6 screws.
McMASTER-CARR
CAD
PART
NUMBER
15205A24
http://www.mcmaster.com
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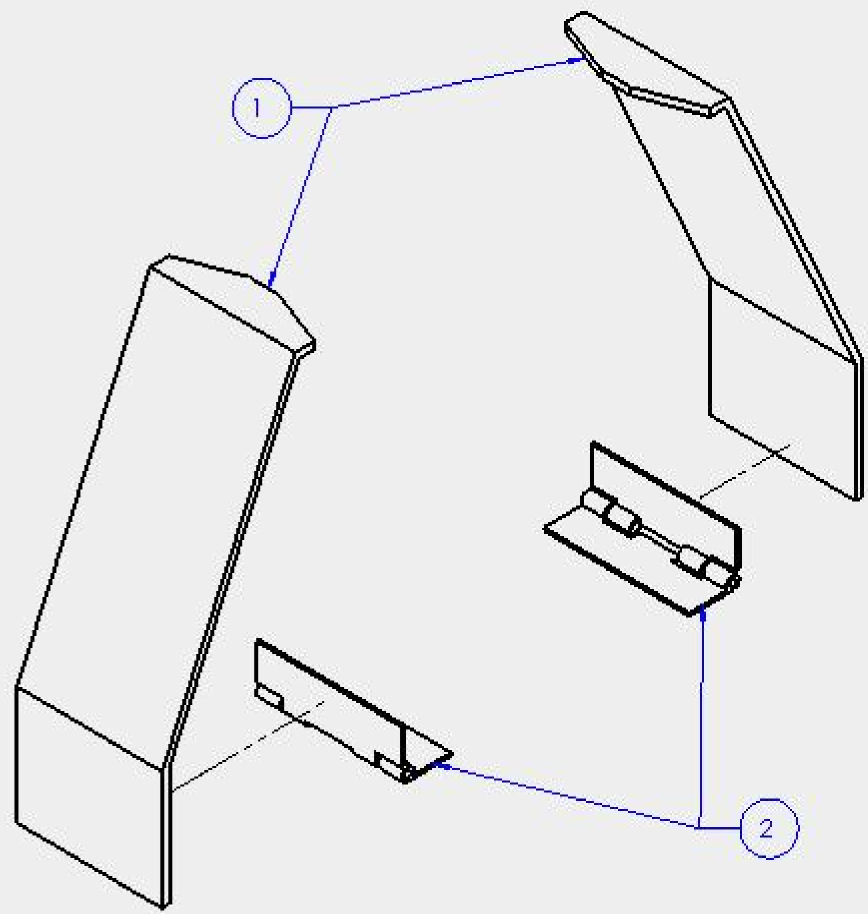
Lightweight 300 Series Stainless Steel
Self-Closing Surface-Mount Spring Hinge
Unless otherwise specified, dimensions are in inches. Information in this drawing is provided for reference only.

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	3001	Bent Flap	2
2	15205A33	1-1/4" Spring Cabinet Hinge	2

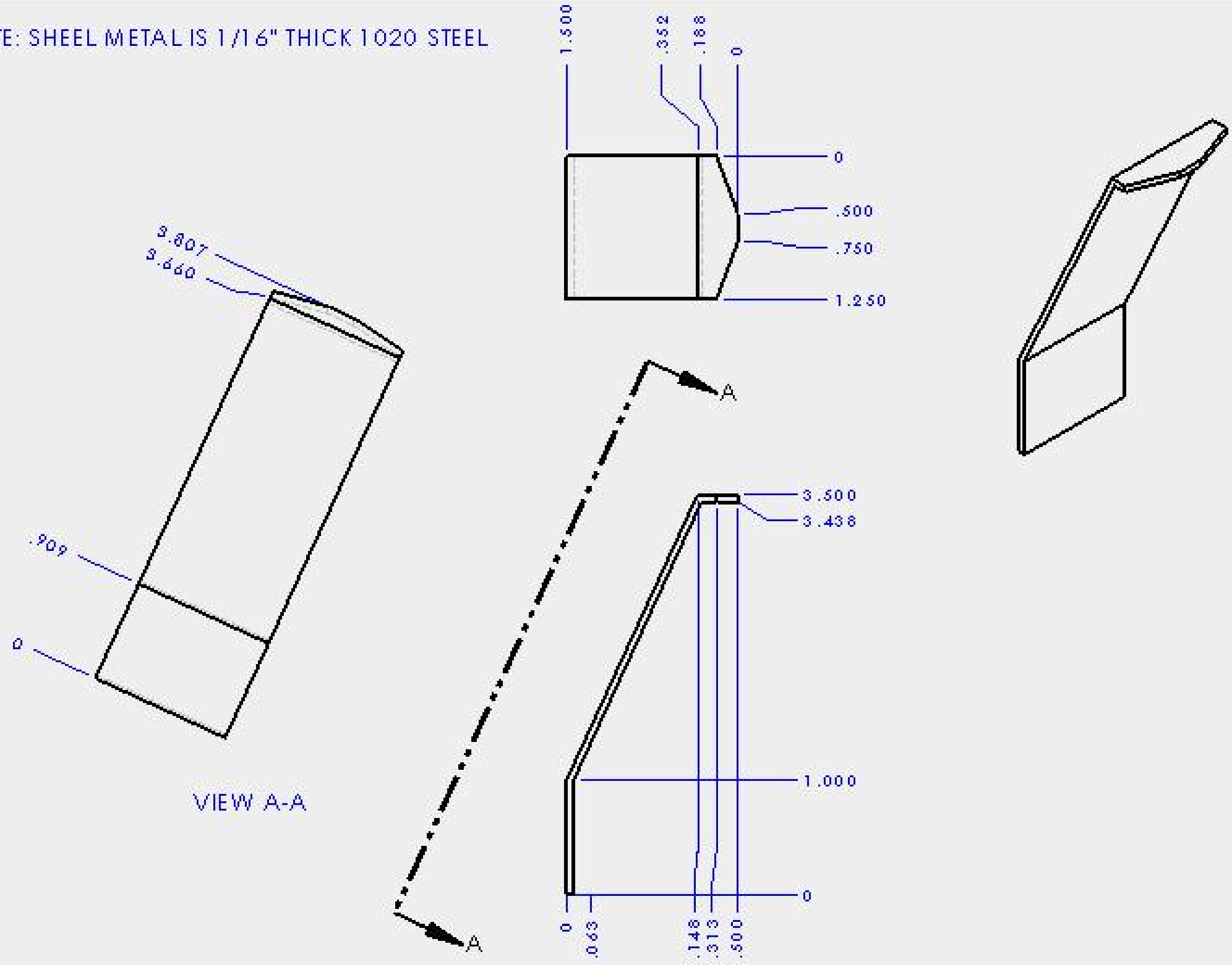


Mechanical Engineering
CAL POLY

Ckd by: BKM	Init:	Drawn By: MW	Init:

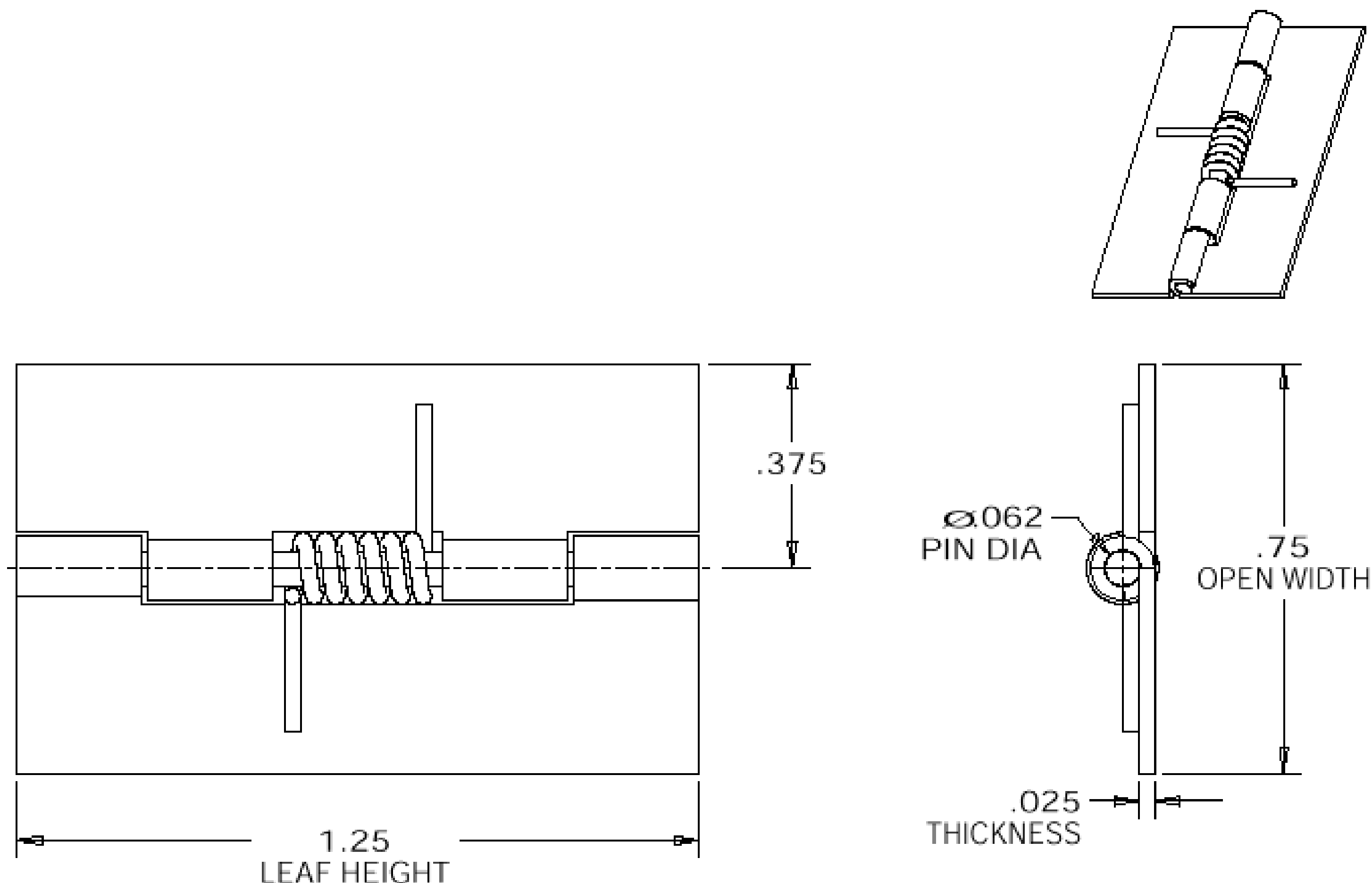
Next Assy:	Scale: 1:1	Material:
Drawing #: 3100	Units: INCHES	Title: BENT FLAP CONCEPT
Date: 3/11/2009	Tolerance:	Group: CHIP ASSIST

NOTE: SHEEL METAL IS 1/16" THICK 1020 STEEL



Mechanical Engineering CAL POLY

Ckd by: MW	Init:	Drawn By: BKM	Init:
Next Assy: 3100	Scale: 3:4	Material: 1020 STEEL SHEET METAL	
Drawing #: 3001	Units: INCHES	Title: BENT FLAP	
Date: 3/6/09	Tolerance: ±.01	Group: CHIP ASSIST	



McMASTER-CARR SUPPLY COMPANY	PART NUMBER: 15205A33
DATE: AUGUST 2001	Spring Cabinet Hinge W/O Holes, Style 4, 1-1/4" Leaf Height, 3/4" Open WD, Stainless Steel
SCALE: 4.000 : 1	
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES	http://www.mcmaster.com (c) 2001 McMaster-Carr Supply Company

Appendix C

Production Real Estate Optimization

EXISTING PROCESS Number of Parts Per Run	Percent Real Estate In Production	Run Time [min]	Load/Unload Time Per Run [min]	Manual Chip Removal Time Per Run [min]	Total Labor Time Per Run [min]	Total Machine Time Per Run [min]	Total Time Per Run [min]	Total Time Per Part [min]	Total Time Per 1000 Parts [hours]	Total Machine Runs Per Day	Total Parts Per Day
16	100.0	32	3.00	2.00	5.00	32.00	37.00	2.31	38.54	16.2	259

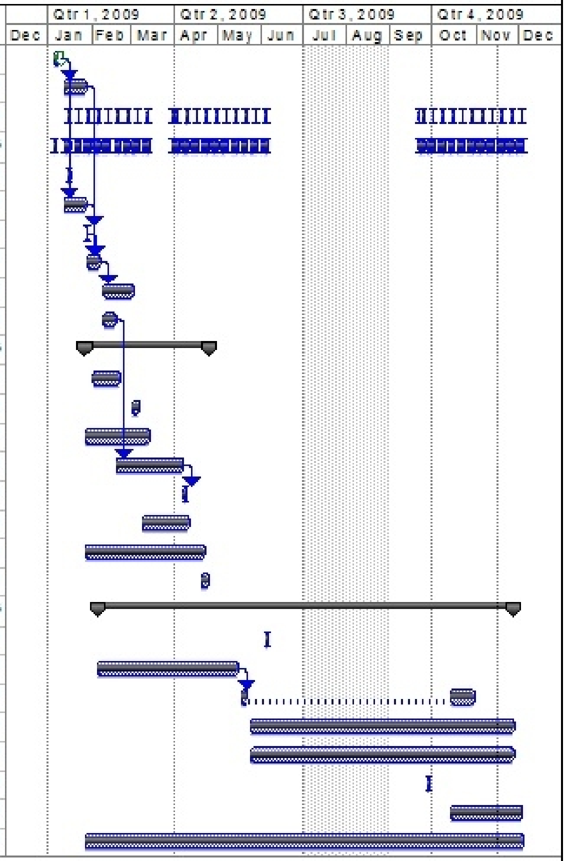
WITH CHIP ASSIST DEVICE Number of Parts Per Run	Percent Real Estate In Production	Run Time [min]	Load/Unload Time Per Run [min]	Max Device Cleaning Time [min]	Total Labor Time Per Run [min]	Total Machine Time Per Run [min]	Total Time Per Run [min]	Total Time Per Part [min]	Total Time Per 1000 Parts [hours]	Total Machine Runs Per Day	Total Parts Per Day
16	100.0	32	3.00	0.33	3.00	32.33	35.33	2.21	36.81	17.0	272
15	93.8	30	2.81	0.33	2.81	30.33	33.15	2.21	36.83	18.1	272
14	87.5	28	2.63	0.33	2.63	28.33	30.96	2.21	36.86	19.4	271
13	81.3	26	2.44	0.33	2.44	26.33	28.77	2.21	36.89	20.9	271
12	75.0	24	2.25	0.25	2.25	24.25	26.50	2.21	36.81	22.6	272
11	68.8	22	2.06	0.25	2.06	22.25	24.31	2.21	36.84	24.7	271
10	62.5	20	1.88	0.25	1.88	20.25	22.13	2.21	36.88	27.1	271
9	56.3	18	1.69	0.25	1.69	18.25	19.94	2.22	36.92	30.1	271
8	50.0	16	1.50	0.17	1.50	16.17	17.67	2.21	36.81	34.0	272
7	43.8	14	1.31	0.17	1.31	14.17	15.48	2.21	36.86	38.8	271
6	37.5	12	1.13	0.17	1.13	12.17	13.29	2.22	36.92	45.1	271
5	31.3	10	0.94	0.17	0.94	10.17	11.10	2.22	37.01	54.0	270
4	25.0	8	0.75	0.08	0.75	8.08	8.83	2.21	36.81	67.9	272
3	18.8	6	0.56	0.08	0.56	6.08	6.65	2.22	36.92	90.3	271
2	12.5	4	0.38	0.08	0.38	4.08	4.46	2.23	37.15	134.6	269
1	6.3	2	0.19	0.08	0.19	2.08	2.27	2.27	37.85	264.2	264

Appendix D

Gantt Chart of Project

Appendix C

ID	Indicators	Task Name	Duration	Start	Finish	% Complete	Work
1	✓	Consider Projects	1 wk	Mon 1/5/09	Fri 1/9/09	100%	30 hrs
2	✓	Background Research	2.2 wks	Mon 1/12/09	Tue 1/27/09	100%	40 hrs
3		**Advisor Meeting**	**144 days**	**Thu 1/15/09**	**Thu 12/3/09**	**100%**	**94 hrs**
51		**Project Logbook**	**153 days?**	**Mon 1/5/09**	**Fri 12/4/09**	**100%**	**113.18 hrs**
287	✓	First Visit To Heli-Cal	2.5 days	Wed 1/14/09	Fri 1/16/09	100%	16 hrs
288	✓	Develop Specification	11 days	Mon 1/12/09	Tue 1/27/09	100%	10 hrs
289	✓	Management Plan	1 day?	Wed 1/28/09	Wed 1/28/09	100%	4 hrs
290	✓	Project Proposal	7 days	Thu 1/29/09	Fri 2/6/09	100%	24 hrs
291	✓	Conceptualization	3 wks	Mon 2/9/09	Mon 3/2/09	100%	20 hrs
292	✓	Evaluation Of Chip Removal Concepts	6 days	Mon 2/9/09	Tue 2/17/09	100%	20 hrs
293	✓	**Design Chip Removal System**	**53 days?**	**Tue 1/27/09**	**Fri 4/24/09**	**100%**	**180 hrs**
294	✓	Interim Design Report	14 days	Mon 2/2/09	Fri 2/20/09	100%	10 hrs
295	✓	Cost Analysis	5 days?	Mon 3/2/09	Fri 3/6/09	100%	6 hrs
296	✓	Draft Design Report	33 days?	Tue 1/27/09	Fri 3/13/09	100%	10 hrs
297	✓	Design Mechanical System	24 days?	Wed 2/18/09	Mon 4/6/09	100%	72 hrs
298	✓	Evaluate Sponsor Feedback	0.5 wks	Tue 4/7/09	Thu 4/9/09	100%	8 hrs
299	✓	Make SolidWorks Drawings	3 wks	Mon 3/9/09	Fri 4/10/09	100%	24 hrs
300	✓	Final Design Report	50 days?	Tue 1/27/09	Tue 4/21/09	100%	20 hrs
301	✓	Critical Design Review	5 days	Mon 4/20/09	Fri 4/24/09	100%	30 hrs
302	✓	**Prototype and Testing**	**126 days?**	**Thu 2/5/09**	**Fri 11/27/09**	**100%**	**171 hrs**
303	✓	Project Update Report to Sponsor	1 day?	Fri 6/5/09	Fri 6/5/09	100%	4 hrs
304	✓	Material Procurement	12.2 wks	Thu 2/5/09	Fri 5/15/09	100%	40 hrs
305	✓	Machine And Assemble Prototype	18 days?	Mon 5/18/09	Fri 10/30/09	100%	40 hrs
306	✓	Testing Of Chip Removal Prototype	60 days?	Mon 5/25/09	Fri 11/27/09	100%	50 hrs
307	✓	Design Iteration	60 days?	Mon 5/25/09	Fri 11/27/09	100%	25 hrs
308	✓	Manufacturing and Test Review	1.5 days	Mon 9/28/09	Tue 9/29/09	100%	12 hrs
309	✓	Senior Design EXPO	37.5 days	Tue 10/13/09	Thu 12/3/09	100%	30 hrs
310	✓	Final Project Report	138 days	Tue 1/27/09	Fri 12/4/09	100%	40 hrs



Project: Heli-Cal Chip Removal
Date: Mon 11/16/09

Task		Milestone		External Tasks	
Split		Summary		External MileTask	
Progress		Project Summary		Split	

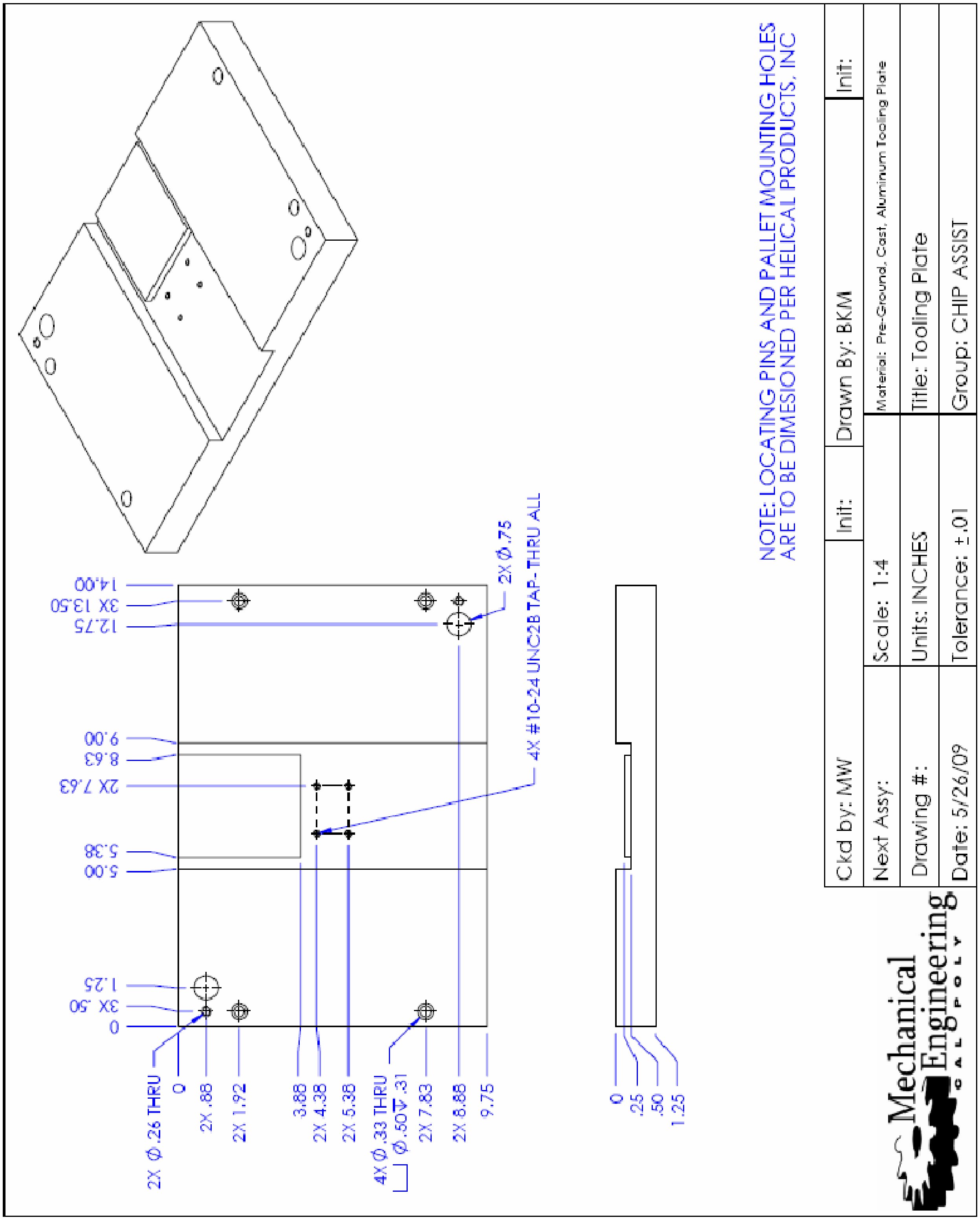
Appendix E

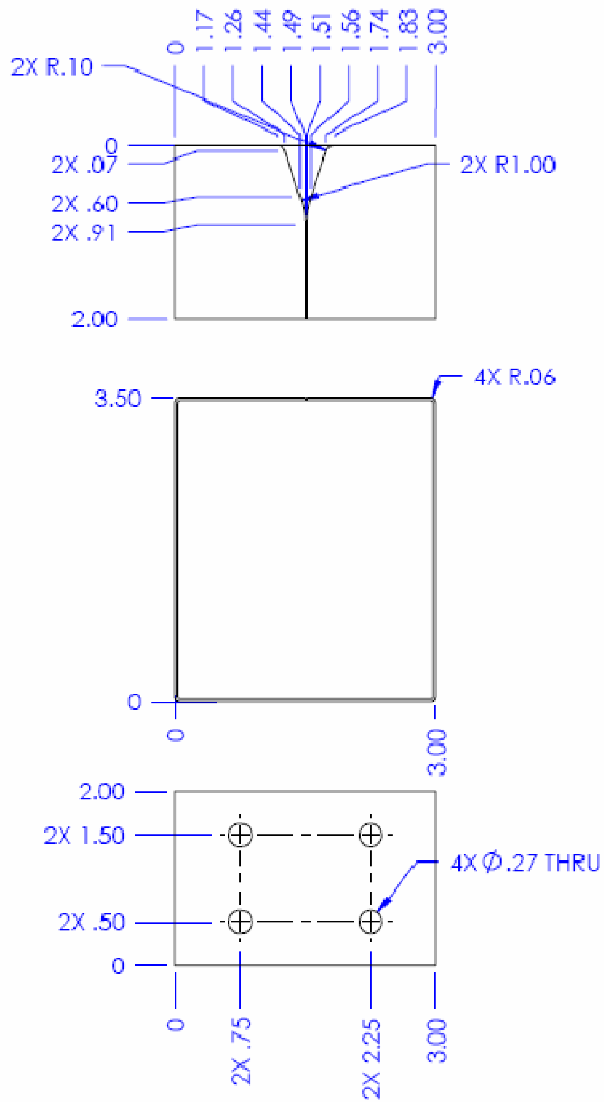
Testing Data Sheet

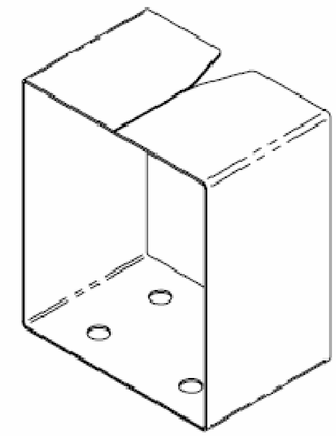
Chip Assist - Metal Chip Removal Testing Verification					
		Chips Removed			
Dat e	Manufacturing Operation	Yes	No	Cycle Time	Comments

Appendix F

Final Design Manufacturing Drawings







NOTE: SHEEL METAL IS 20 GAUGE 1020 STEEL
ALL SHEET METAL BEND RADIUS ARE .06"

Ckd by: MW	Init:	Drawn By: BKM	Init:
Next Assy: NA	Scale: 1:2	Material: 1020 STEEL SHEET METAL, 20 GAUGE	
Drawing #: 1002	Units: INCHES	Title: BENT FLAP	
Date: 5/26/09	Tolerance: ±.01	Group: CHIP ASSIST	

Mechanical Engineering CAL POLY