Ultra-Light Bear Canister

by

Naveen Beasley
Eli Rogers
Cory Wilson
Donald Wood

Sponsored By Nick Hellewell

Project Advisor: Christoph Maurer

Instructor’s Comments:

Instructor’s Grade: ____________________

Date: ______________________________

Ultra-Light Bear Canister

by

Naveen Beasley
Eli Rogers
Cory Wilson
Donald Wood

Sponsored By Nick Hellewell

Mechanical Engineering Department

California Polytechnic State University

San Luis Obispo

2016

Statement of Disclaimer

Since this project is a result of a class assignment, it has been graded and accepted as fulfillment of the course requirements. Acceptance does not imply technical accuracy or reliability. Any use of information in this report is done at the risk of the user. These risks may include catastrophic failure of the device or infringement of patent or copyright laws. California Polytechnic State University at San Luis Obispo and its staff cannot be held liable for any use or misuse of the project.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1 - INTRODUCTION

1.0 INTRODUCTION

A bear canister is the primary tool used by outdoor enthusiasts to protect their food from bears while camping or backpacking. There are many effective products currently on the market, however many are not designed with reduced weight in mind. Hardcore backpackers want to have the lightest gear possible to ease the strain of carrying a large pack for sometimes weeks at a time.

Current bear canisters exist that utilize carbon fiber for weight reduction, however they rely on stock carbon tubes and lack engineering analysis, and no competitor has a fully composite bear canister available. Our sponsor, Nick Hellewell, approached our team with a unique challenge to design an ultralight bear canister that could withstand testing requirements set by national parks and weigh under one pound. In a marketplace where niche consumers will pay hundreds of dollars for the lightest backpacking equipment available, an ultra-light bear canister could relieve precious weight, and carry a significant price premium.

To achieve this goal, our team set out to research competitors' products and patents to develop a concept within a set of specified design requirements. Table 1 lists a brief summary of these specifications. The mains requirements set by the sponsor were to create a 650 in^3 canister that would have a maximum weight of one pound. It was also deemed necessary that the canister passes certification testing to be used in the National Parks. The full list of requirements and specifications can be viewed in Appendix A.

Table 1: Critical criteria for final product.

Volume [in^3]	Weight [lbs]	Maximum Deflection from 100 ft-lb impact test [in]
650	1.0	.025

The project's feasibility would be tested by manufacturing molds, which could reproduce bear cans reliably. These canisters would then need to undergo testing similar to that required for certification in order to ensure that the final product is up to the necessary standards. Canisters that passed testing would be sent to agency testing at the conclusion of the project.

With Eli's previous experience as a shop technician and Composites Lead for Cal Poly Supermileage, he would be responsible for carbon fiber manufacturing and analysis. Don would assist with his manufacturing and be responsible for purchasing and scheduling. Naveen would be responsible for testing completed canisters as well as assisting with manufacturing. Cory would be responsible for lid design and design verification using an Abaqus model. The tasks completed during the project are outlined in Appendix F in a Gant Chart.

<u>CHAPTER 2 - BACKGROUND</u>

2.0 BACKGROUND

An important step in developing a list of customer requirements is researching existing solutions and finding ways to optimize our design considerations. These existing solutions were found through current products being used on the market along with patents for different canisters and patents for various subcomponents, such as locking mechanism and lid attachment methods.

Also of importance is any type of standardized testing that these products go through in order to be deemed suitable for their intended applications. It is necessary that our canister be able to pass any inspection that it may need to undergo in order to ensure that it will actually be a viable option to use in the national parks.

2.1 Current Products on the Market

There are a wide variety of products being sold on the market that claim to be suitable for use as bear resistant canisters. For our purposes, the focus of our research was on products of similar carrying capacity to that which was specified by the sponsor as well as those that have been certified for use in the national parks relevant to this project.

2.1.1 Garcia Backpacker Cache

A commonly used bear canister is the Garcia Backpacker Cache shown in Figure 1. It is popular because of its low price of entry and ease of access; however, it is heavier than many of its competitors, making it a burden to carry on short trips where only a few days' worth of food is needed. This particular model is made of an ABS plastic body and lid along with stainless steel quarter turn locks. The overall carrying capacity is 614 in^3 (5-7 days' worth of food) at a weight of 48 oz. [9]. The retail price for the Garcia is around $70 at most locations where sold.

Figure 1: The Garcia Backpacker Cache. *Source: REI*

2.1.2 Bearikade "The Weekender"

At the higher end of the market, Berikade weigh in at 1.9lb, are made of a carbon fiber composite body and a 6061-T6 aircraft-grade aluminum lid. The model referred to as "The Weekender" (shown in Figure 3) weighs approximately 31 ounces and has a 650 in^3 carrying capacity [11]. This particular product currently gives the best weight to volume ratio on the market (0.048 ounces per cubic inch of useable volume) out of all current products of similar size. This low weight to volume ratio also carries a premium price on the market with "The Weekender" is currently being sold for $288 [11].

Figure 2: Bearikade canister "The Weekender". *Source: Wild Ideas*

For our product to be truly competitive, we would need to design a canister that can beat the Scout's weight and volume specifications. All the given specifications for the Bearikade, along with other products, can be seen in Table 2.

Table 2: Specifications list for the products mentioned for competitor products.

Product Name	Material	Capacity [in^3]	Width [in]	Height [in]	Weight [oz]	Price [$]	Weight to Capacity Ratio [oz/in^3]
Garcia Bear Resistant Canister	ABS body; stainless steel locks	614	12	8.8	48	70	0.0782
Bearikade "The Weekender"	Carbon fiber composite housing	650	9	10.5	31	288	0.0477

2.2 PATENTS

An extensive patent search was also conducted in order to ensure that or design did not infringe upon any ideas that others may have already claimed. A wide variety of patents were discovered, ranging from whole bear canisters to individual sub functions, such as locking techniques. *NOTE: The following patents found do not compose an extensive list of our findings. To see the extensive list, please consult the project binder.*

2.2.1 Tamper-Resistant Container and Methods [2]

This particular patent is for an entire bear canister device, including container, lid, and locking mechanism. It claims to include the features of being lightweight, low cost, and easy to use and carry. The model sketches for the design are shown in Figure 3.The body is made from a polycarbonate material and is cylindrical in shape. The lid is also made of a polycarbonate material, and threads onto the body. The way that the lid and housing mate is in such a way to prevent animals from inserting claws and prying off the lid.

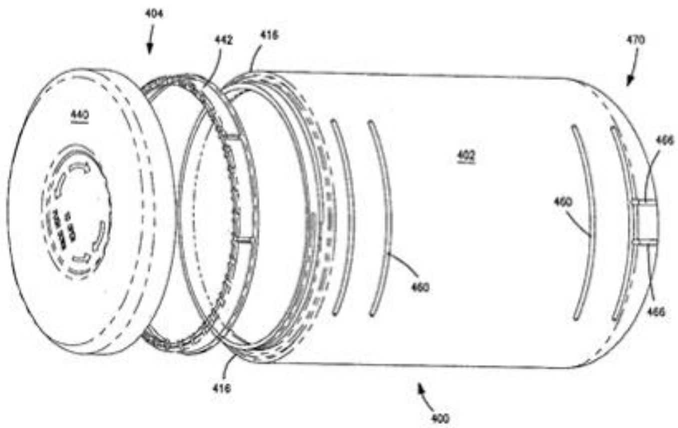


Figure 3: Exploded view the tamper resistant container. *Source: USPTO Patent Full-Text and Image Database.*

2.2.2 Bear Resistant Pannier [4]

The following patent details the design of a particular pannier to be used in keeping bears from accessing food. This method is one that could be applied to a bear resistant storage device. The focus of this particular patent was the latching mechanism, depicted in Figure 4.

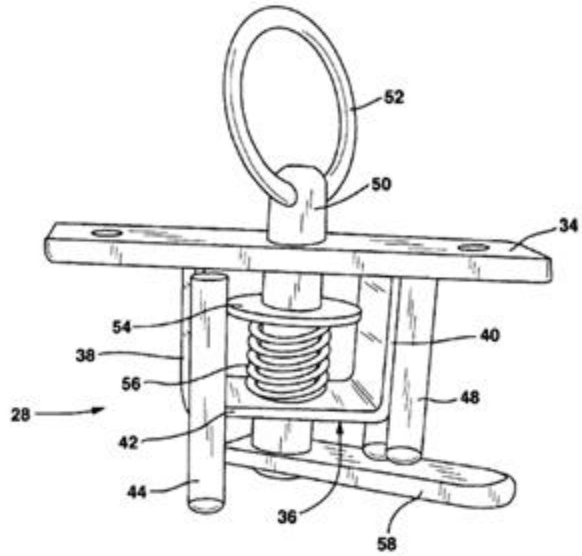


Figure 4: Spring locking mechanism implemented on the bear resistant pannier. *Source: USPTO Patent Full-Text and Image Database.*

This latching mechanism utilizes a spring as a means of engaging and disengaging the latch. The implementation of a handle allows the user extend the latch beyond the locking poles and move it into the locked position. The spring then reengages the latch between the poles and locks the lid into place. The top image depicts the latch in the unlocked position. The user presses down on the latch, using the handle, and moves the latch into the locking position.

2.3 Standard Testing Procedures

Several sources were utilized to determine any standardized criteria that a bear canister would need to meet. One of these sources was Yosemite National Park themselves. While they may or may not test the product themselves, they established that it is essential that any product should be able to pass the test conducted by the Interagency Grizzly Bear Committee (IGBC). Research on existing products showed that all products currently allowed in the national parks under consideration had been tested and approved by this committee as well as some bearing that stamp of approving from another organization called the Sierra Interagency Black Bear Group (SIBBG). Through communications with the Yosemite National Park Staff, it was determined that the SIBBG is no longer in existence, therefore, any testing criteria set by this organization will not be directly applicable to the design of the bear canister.

2.3.1 Interagency Grizzly Bear Committee

The Interagency Grizzly Bear Committee is located in Missoula, Montana and serves as the official word for many national parks on whether food storage devices can meet the challenge of preventing bears of all sizes and levels of intelligence from accessing a person's food. It would be the main focus of this project to ensure that the final product will undergo and pass testing by the IGBC. Testing protocol conducted by the IGBC goes as follows:

Testing is conducted in West Yellowstone, Montana at the Grizzly and Wolf Discovery Center between April 1st and October 31st. First, there is a visual inspection of the product. Product components such as hinges, latches etc. that might allow bears to bend, break, or pry open the container with their claws are visually inspected. Further visual inspection is to ensure that there are no loose parts, hanging debris, or sharp edges, which could potentially cause harm to humans or bears. After passing the visual inspection, the product will then undergo a live bear test. Testing personnel will place food inside the container and will leave the container inside of the bear enclosure. The testing is considered complete once the bear breaches the container or the container has undergone 60 minutes of bear contact (i.e. chewing, clawing, etc.). The container will undergo contact with several bears of various sizes and experience in dealing with bear-resistant devices. Pictures are taken after the testing and a report is made of the areas of the product that may have been subjected to damage. Food containers are allowed gaps, tears, or holes of ¼'' or less to be considered "passed" [3].

Additional standards have been set by the Sierra Interagency Black Bear Group (SIBBG), which states that the canister should also be able to withstand an impact test equivalent to dropping 100 lbs from a distance of 1 foot. The impact test is conducted by dropping the weight on the lid and the side of the container. While the SIBBG has disbanded, these standards will still be adopted into the design of the final product.

Chapter 3 – Design Development

3.0 IDEA SELECTION

Coming up with our final design was a multistep process for the group. Creating the most efficient design was pivotal in order to meet the needs established by the sponsor as well as meeting the criteria necessary to pass inspection and testing. Many ideas were presented, and many were weeded out as not feasible or incapable of fulfilling the objectives set forth in the specifications list (Appendix A). Ideas were continually weeded out until we came to the final design choice of a cylindrical container, consisting of a top lid locked on with quarter turn fasteners.

3.1 Design Concepts

A number of different design options were taken into consideration as potential solutions. A list of the preliminary design considerations can be seen in Table 3. Since the main scope of this project was to create a canister that is both lightweight and strong, the decision was made to use carbon fiber as the primary material from the onset of the project. Many of the design concepts were created based on this material decision.

Table 3: Technological decision matrix

	A	B	C	D	E	F	G	H	I	J
Review Criterion	Pill Shape, Half-Split, Spring Mechanism	Split Shell, 1/4 Turn, Outer/Inner Bond	Cylinder, Outer Lid, Twist Lock	Garcia Shape, Outer/Inner Bond, Twist Lock	Cylinder Shape with Integrated Shovel	Full Composite 3/4 Can with 1/4 Lid, Locking Rings	Garcia Shape, Outer Bond, 1/4 Turn Lid, Locking Rings	Cylinder, Inner Bond, Tongue and Groove	Cylinder, Outer Bond, 3 Groove Actuator	Cylinder with Lid and Quarter Turn Fasteners
Min Surface Area to Volume Ratio	3	3	4	3	4	3	3	4	4	4
Ease of Operation	2	4	3	3	3	4	4	4	4	3
High Mechanism Strength	2	3	3	4	2	4	4	2	2	4
Low Complexity	1	2	2	1	0	2	3	3	0	3
Ease of Packing Food	2	2	3	4	3	3	4	4	4	4
Ease of Storage	2	2	3	2	3	3	2	3	3	3
P_{max}	12	16	18	17	15	19	20	20	17	21
W_t	2.00	2.67	3.00	2.83	2.50	3.17	3.33	3.33	2.83	3.50
Ranking	7	5	3	4	6	5	2	2	4	1

Choosing an appropriate shape of the container was a major aspect of the design; therefore, various shapes were considered and compared against each other. It was important that the shape of the container be such that it would be easily packed into a person's backpack as well as a shape that is optimized to give the maximum storage capacity while needing a minimal amount of material. Specific profiles considered during idea generation sessions included cylindrical, spherical, and pill shaped designs. Also considered was implementing a shape similar to that of the Garcia bear-resistant canister mentioned in the existing products section of the report.

Further design considerations were given for the the lid and corresponding locking mechanism. This would prove to be a crucial aspect of the design as the lid serves multiple purposes, serving as a mechanism to prevent entry by bears as well as a structural member that plays a role in the strength of the overall canister. Potential designs for the lids would also have to take into consideration the regulations set by the IGBC regarding hinges, latches, gaps, etc. It was also crucial that the design not implement excessive amounts of hardware as that would prevent us from meeting the weight requirement of 1 lb. Potential solutions for this problem consisted of lids that were flat plates, recessed flush with the surface of the canister. This types of lids could implement locking mechanisms such as spring latches, tongue-in-groove latches, twist locks, locking rings, or quarter-turn fasteners. Another idea considered was to due away with the lid completely and have the canister split down the its center where it disassembles into two corresponding halves which can filled filled and the reassembled and locked together.

Each of these individual component ideas were pieced together in different combinations to come up with the list of design choices shown in Table 3.

3.2 Concept Decision

Using our finalized concepts, our team went about systematically ranking them in a design evaluation matrix. A design evaluation matrix involves developing six of the most important technological and economic objectives of our product, and ranking each of our proposed concepts on a numbered scale. This allowed our team to weigh each concept in the most objective manner possible, since our team was required to unanimously agree on what ranking each concept received.

For our technological criteria, we selected the following six criteria: minimum surface area to volume ratio, ease of operation, high mechanism strength, low complexity, ease of packing food, and ease of storage. Minimizing surface area to volume assured that the canister shape we would choose hold the largest amount of food while remaining lightweight. We discovered in our research that for many backpackers ease of operation was a top concern, since some mechanisms are frustrating to use or do not work well in colder conditions. High mechanism strength was important to keep bears from opening the container, and low complexity assured that the design would be easy to manufacture and contain a minimal number of parts. It was important that it would be easy to pack the maximum amount of food in our container for the volume we provided, and our canister would need to fit in a wide range of backpacks. The evaluation matrix for technological factors can be seen in Table 3.

Our team also selected five important economic criteria to evaluate low labor and assembly cost, low manufacturing cost, low number of custom parts, cheap purchased materials, and the cost of development. Because the process of making a multiple composite canisters is especially time consuming, we wanted to make sure our final concept had the minimal amount of labor and cost to assemble so that we could spend more time in testing and less time in manufacturing. Low manufacturing cost was important for the composite canister as well as the locking mechanism, and designs that required CNC machining or more custom-made parts would receive a lower ranking. The evaluation matrix for economic factors can be seen in Table 4.

Table 4: Economical decision matrix.

	A	B	C	D	E	F	G	H	I	J
Review Criterion	Pill Shape, Half-Split, Spring Mechanism	Split Shell, 1/4 Turn, Outer/Inner Bond	Cylinder, Outer Lid, Twist Lock	Garcia Shape, Outer/Inner Bond, Twist Lock	Cylinder Shape with Integrated Shovel	Full Composite 3/4 Can with 1/4 Lid, Locking Rings	Garcia Shape, Outer Bond, 1/4 Turn Lid, Locking Rings	Cylinder, Inner Bond, Tongue and Groove	Cylinder, Outer Bond, 3 Groove Actuator	Cylinder with Lid and Quarter Turn Fasteners
Low Labor/Assembly Cost	4	4	3	2	1	3	3	4	3	4
Low Manufacturing Cost	3	3	2	2	1	3	3	4	4	4
Low Number of Custom Parts	3	3	4	4	3	3	3	4	2	3
Cheap Purchased Materials	1	2	1	1	1	1	2	3	1	3
Cost of Development	4	4	2	2	1	3	2	3	2	4
P_{max}	15	16	12	11	7	13	13	18	12	18
W_t	3.00	3.20	2.40	2.20	1.40	2.60	2.60	3.60	2.40	3.60
Ranking	3	2	5	6	7	4	4	1	5	1

3.3 Supporting Preliminary Analysis and Testing

A mostly qualitative approach was used a preliminary analysis tool for each concept under consideration. These qualitative assessments were based on intuition as well as obtaining and testing the Garcia and Bearikade "The Scout" canisters. In order to determine the optimal design, each design idea was analyzed piece-by-piece and evaluated as to whether or not it satisfies several important design criteria.
The overall goal for "The Bear Minimum" is to create the lightest weight bear canister on the market while still being able to keep bears out and humans in. It is also important that this canister be profitable to the sponsor should he decide to turn this into a consumer product. In order to do so, categories for technological and economic factors were evaluated for the initial concepts, as will be discussed in the following sections.

3.3.1 Minimum Surface Area to Volume Ratio

The cylinder was the best chosen fit for having the greatest surface area to volume ratio as opposed to the Garcia Can shape. The split shell is to have the Garcia Can shape once attached together, therefore it was rated the same score as the Garcia Can solid body shape. The pill bottle shape was also considered due to its comparable surface area to volume ratio. By having the lowest amount of surface area to volume ratio allows us to reach the target volume of 600 cubic inches while not compromising on space. A lower surface area allows a lesser amount of material used which will decrease the cost of production for the overall product.

3.3.2 Ease of Operation

The ease of operation corresponds to how easy the canister is opened by humans. Quarter-turn fasteners were given a high score but not as high as the 3-groove actuator. The 3-groove actuator requires one motion to unlock, however, it is definitely the most mechanically complex and requires a large number of custom parts. Due to the large number of custom parts the final product would have an increase in weight which goes against the most important design criteria of having the product weigh less than one pound. The quarter-turn fasteners would also require a simple tool to open such as a spoon or quarter. This opening for the tool would be wide enough to allow the entrance of a quarter or the back end of a spoon but not wide enough to allow a bear claw. Barring the need for a tool, the quarter-turn fasteners on the Bearikade model were shown to be easier to operate in comparison the the Garcia twist-lock.

3.3.3 High Mechanism Strength

The locking mechanism has to be able to be opened by human beings with ease but also be strong enough to endure any force the bear may use. Quarter-turn fasteners were rated highly due to the high shear strength and bending strength associated with them. The final design is to implement quarter-turn fasteners as the method of locking the lid in place. This is to ensure that the potential prying force of the bear will be distributed amongst the multiple fasteners and will therefore be harder to break or open. Quarter-turn fasteners would also allow the canister to be free of any openings or hinges which is a requirement for testing at the Interagency Grizzly Bear Committee. The most important design criteria will be fulfilled with quarter-turn fasteners. Quarter-turn fasteners have a high strength to weight ratio, thus they are very lightweight components. The lighter the locking mechanism the better for the lightweight design, therefore the quarter-turn fasteners were given the highest rating.

3.3.4 Low Complexity

The low complexity of the product is not only important to the manufacturer but, more importantly, to the customer. The quarter-turn locking mechanism provides the user with one motion locking. The ergonomics of the product will heavily influence how well the product does on the market. If the can is too complex to use, customers will not invest in the product. The locking mechanism and use of the bear canister has to be just as simple if not simpler than the products on the market to date.

3.3.5 Ease of Packing

A solid body would be the easiest to pack when considering the ergonomic factors for the product. If a split shell was used it would be harder to pack due to the two halves coming together. The design criteria is to have the length of the canister be less than 1.5 feet, which would mean a diameter of 10 inches or less must be used to maintain the lightweight and volume criteria. Having a diameter of about 10 inches allows ease of packing to fit a hand through the opening with ease. Also by having a lid, the canister can be packed from the top, which allows the most food to be put in.

3.3.6 Ease of Storage

The cylindrical shape was shown to not be as easy to pack in a backpack as originally assumed. The cylindrical shape was proven to be hard to pack other items around when placed within a standard backpack, making packing less efficient. Testing showed that the Garcia can shape was a better fit into the backpack and was easier to pack around once in the backpack when compared to a standard cylindrical shape. The rounded edges of the Garcia canister also put less wear on the backpack material compared to the cylindrical shapes sharper edges.

3.3.7 Labor and Assembly Cost

The low labor and assembly cost is dependent on how difficult the lay up process would be for the proposed shapes. The Garcia Can shape would require a clamshell mold, this requires a layup from the inside out and it may be difficult to reach certain places within the can. The cylinder would take the least time to lay-up. However, the proven benefits of the Garcia canister proved that the extra difficulty in manufacturing could be worth the benefits that the final product would provide.

3.3.8 Manufacturing Cost

As far as manufacturing cost, tooling for the cylindrical shape would be the easiest due to the simple shape. CNC Machining or water-jet cutting would be used for the lid and connections of the bear canister which would save a large amount of time which is the main cost issue. The longer the manufacturing time, the more the manufacturing cost will be. The tongue and groove would be another manufacturing addition which would cost more money, whereas the quarter turn fasteners can be bought at a low price. Buying the quarter turn fasteners would cost substantially less than manufacturing it in house. The 3-groove actuator contains a locking mechanism that would require a significant amount of tooling and manufacturing time. The split shell would require complicated molds and therefore would take a longer amount of time to manufacture.

3.3.9 Number of Custom Parts

The 3-groove actuator would require a significant amount of custom parts due to it being the most mechanically complex for a locking mechanism. The twist lock and tongue-and-groove were rated the highest for number of custom parts because the design of the locking mechanism doesn't require parts to be purchased. The tongue and groove locking mechanism would be designed into the can itself. The twist lock works in a similar way in which the locking mechanism would be designed into the can itself therefore eliminating the need for extra custom parts. Although this requires a lower number of custom parts, the extended amount of time to design and manufacture would increase the overall cost of constructing the final product. Quarter-turn fasteners can be bought off the shelf and would not be a custom part to be used; therefore it was given a relatively high score but not as high as the twist lock and tongue and groove. The rest of the bear canister would require custom parts, however, when weighing the time needed to make the custom parts, the cylinder with a lid and quarter turn fasteners wins out. Based on the requirements list, the goal was to have 3 or less parts for the final product, thus, a lid and quarter-turn fasteners would fulfill these criteria.

3.3.10 Cost of Purchased Materials

Having quarter-turn fasteners as the locking mechanism allows the ability to purchase cheap materials. The locking mechanism can therefore be bought at a low price as opposed to designing a complicated locking mechanism that would require longer hours of manufacturing and labor. This is definitely a plus due to the amount of material cost goes into each prospective design. Some of the materials to be used are epoxy resin, carbon fiber, kevlar, fabric, balsa and syncore for core material, and MDF and foam for tooling. As shown all of this material will cost a significant amount of money and will be used on each concept design, therefore by having a locking mechanism that can be bought greatly reduces the overall price of the product.

3.3.11 Cost of Development

The cost of development takes into account the previous categories and places a score based on the overall scope. The cylindrical shape with a lid and quarter-turn fasteners would take the least amount of time to manufacture due to the symmetrical and simple shape of the cylinder. Lay ups would not be as complicated for a cylindrical shape as it would be for a Garcia Can shape or split shell shape. However, the outcome of producing the cylindrical canister may not result in as marketable a product as originally assumed due some of the shortcomings mentioned previously. Overall the cost of developing a more difficult concept could prove more beneficial in the end if it helps to meet all of the requirements a gives a more marketable product.

CHAPTER 4 – THE FINAL DESIGN

4.0 FINAL DESIGN

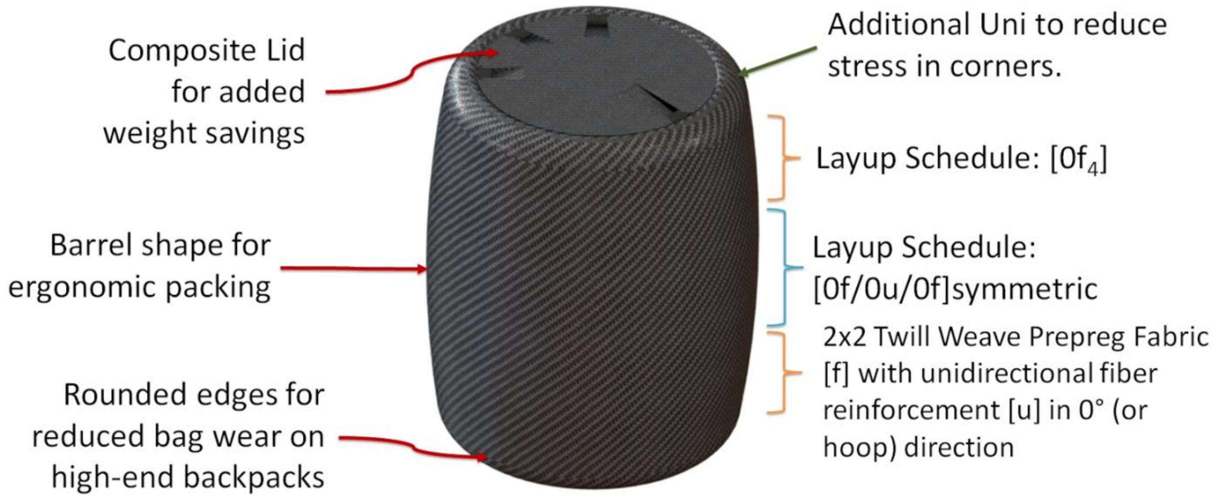


Figure 5: Model and general lay out of the final design.

Figure 5 shows the design chosen for the final product. From testing different shapes, it was decided that a "Garcia" shape would be implemented in the final model. This shape proved to utilize space most efficiently within the common backpacking backpack, allowing the user to more effectively fill up the negative space around the container with other backpacking equipment. This shape has allowed for a carrying capacity of 630 in^3 at a weight of 1.2 lbs, lid included. This weight is 20% higher than our intended goal of 1 lb., but it is still well below the weight of other products on the market that are of comparable size. The most competitive product currently on the market, the Bearikade Weekender, runs about 1.94 lbs. for 650 in^3 of carrying capacity, or 0.048 oz. per in^3 of carrying capacity [11]. Our product provides a ratio of 0.030 oz. per in^3 of carrying capacity. This is an approximate 36% reduction from the currently best product on the market.

For the canister lid, the flat shape recessed into the can surface was chosen. The material used for the lid will also be carbon fiber in order to meet the low weight requirement. This lid will consist of a tabbed locking mechanism. This mechanism works by guiding the three back tabs of the lid under the lip of the canister, depressing the front tab to lay the lid flush, and then releasing the front tab to lock the lid in place. This lid design means that no tools will be required to open the canister.

4.1 Detailed Description

The canister consists of two main components: the actual container and the lid. The detailed design of each of these components has been has been carefully considered to ensure that the final product meets all of the necessary requirements to be a marketable product. The following sections will give a detailed description of the specific details of each component structure.

4.1.1 Bear Canister Body

The main body of the canister will utilize what the team has termed a barrel shape. This shape was inspired by the layout of one of the more common canisters on the market; the Garcia Bear Resistant Canister. This shape showed to be the most efficient of the shapes tested in terms of utilizing backpack space and having a low weight to carrying capacity ratio. The thickness of the canister body will be a constant 0.048" throughout most of the canister. This thickness corresponds to four layers 0.012" carbon fiber fabric. The layup schedule has each layer of carbon fiber fabric orientated at 0 degrees with respect to the circumferential aspect of the canister. The top of the canister as well as the middle of the canister will be slightly thicker due to added layers of unidirectional carbon fiber. These additional layers are implemented in order to reduce the stresses produced during a sudden impact.

This shape is partly cylindrical, however the cross-sectional area changes as you move from the center of the canister to either top or bottom. The canister shape transitions from 9" outer diameter in the center and tapers off to an 8.23" outer diameter at top and bottom. The canister height, from the bottommost to topmost surface, is 11". This height will allow for the canister to be placed in most backpacks in either a horizontal or vertical orientation while putting minimal strain on the backpack material. The transition from the sides to the bottom and top edges of the body is curved surfaces, with a radius of 0.80", eliminating any sharp edges. This will minimize the wear to the user's backpack should the canister be placed in the backpack in such a way that it would be rubbing or pressing into the user's backpack. This is most important in high-end backpacks where the material is thin and easily worn through should there be any sharp edges present.

The bottom of the canister is a flat surface so that the canister can be set down on a flat surface without the user having to worry about it rolling away. The top of the canister will consist of a 5.90" opening that will be used to place items into the container. This opening is recessed 0.12" below the topmost surface of the canister by a downward sloped surface that transitions to a flattened lip with a width of 0.30". This recessed lip will give the lid a surface to rest on while allowing the lid to be flush with the top of the canister when locked into place. It was determined that the thin edge of this lip could pose a potential risk of the user cutting themselves while reaching into the canister. In order to mitigate this risk, rubber trim will be placed along the opening edges to serve as a barrier between the user's hand and any sharp edges. Figure 6 shows the final SolidWorks model of the canister body and points out the main features of the design.

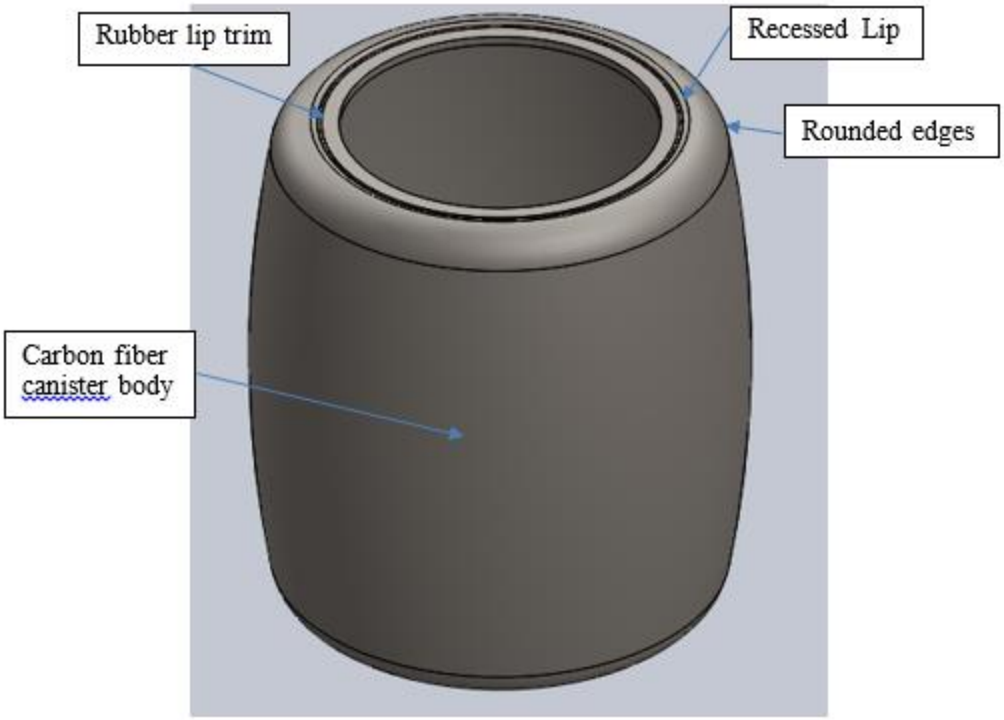


Figure 6: SolidWorks model of the bear canister body. The material used for the canister will be made from 2x2 twill weave carbon-fiber prepreg cloth. The twill weave was chosen based on the fact that it is more capable of conforming to the curves and contours that our present in the canister shape design. This choice will make laying up the carbon-fiber into the canister molds an easier and more efficient process during the production phase.

4.1.2 Bear Canister Lid

The general design for the lid consists of 6.5" circular plate which will rest atop the recessed surface of the canister body (Figure 7). The lid will be composed of carbon fiber, the same as the body of the canister, and consist of three set tabs and a single depressible tab. These tabs are used to lock the lid in place on the canister. The way in which they work is that the three set tabs will first be slid underneath the lip of the top surface of the can. The single depressible tab will then be pushed down by the user and the lid placed in its final flush position. Upon the user's disengagement, the depressed tab will release a place itself underneath the top surface lip. This will, in effect, lock the lid. To remove the lid, the user once again depresses the tab and lifts the lid up and out to clear the set tabs from the lip.

The material used for the lid itself is carbon-fiber and will be layered such that the lid will have a thickness of 0.036", which will make it flush with the top of the container. This will prevent bears from being able to get leverage on the lid and effectively use their strength to in a way that could put an excess amount of shearing stress on the latches. This greatly reduces the risk for potential failure of the lid and its components.

Figure 7: Implementation of the canister lid and locking mechanism.

4.2 Bear Can Analysis

Strength analysis was done on the bear canister in order to defend our designs capability to withstand the loadings it may be subjected to during a potential bear encounter. This analysis was based around the test criteria it would need to meet in order to become a certifiable product. In order for the bear can to meet specifications, it must pass the requirement set by the Sierra Interagency Black Bear Committee of withstanding a 100 lb. weight dropped from one foot. Under these specific conditions, the bear can could be analyzed quite well. However, when designing the strength of the bear can, loading conditions not specified by testing are likely to occur in normal use. When observing bear behavior, they frequently picked the bear can up over their head, dropping it to the ground. Therefore, our bear can should have sufficient strength to withstand any bear attack in order to protect the bears.

4.2.1 Loading Calculations

Two loading cases were taken into consideration when analyzing the laminate. These consisted of a side loading and a top loading (Figure 8). Initial analysis considered included the use of shell theory in order to model the effects of the canister as effectively as possible. However, after researching the application it was determined to be too difficult of an analysis to be done easily. So, Classic Lamination Theory (CLT) with a static loading was used as an approximate answer with an in depth Finite Element Analysis (FEA) to calculate the appropriate impact response.

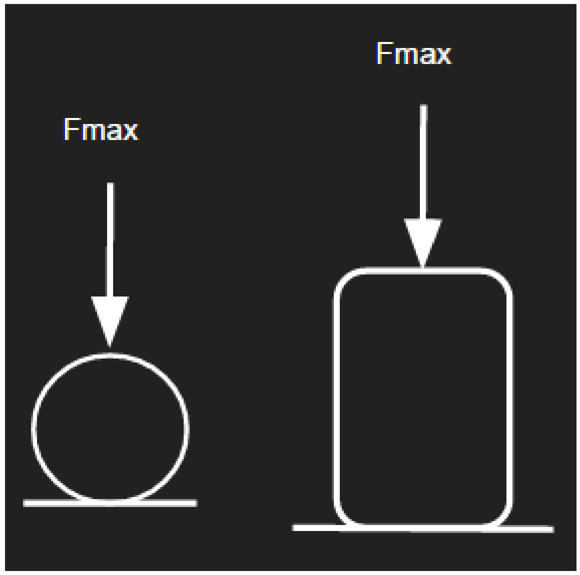


Figure 8: Free Body Diagrams of bear canister for the required loading conditions.

By analyzing the stress with a static loading, the analysis became very simple with the appropriate free-body diagrams. Using CLT, the designed laminates were analyzed to see which one is best. Through this analysis it was found that the best layup would be 4 plies of 45 degree fabric, as shown in Figure 9. This is better than the other theorized layups because it allows the matrix to flex and shear instead of breaking the fibers which would results in failure of the can. Results from the analysis can be seen in Table 5. This layup is also very easy to layup since it can flex in the hoop direction it laminates most easily to the molds. With this much flexibility in the laminate, it may survive the loading, however, it probably will not pass the deflection requirement since this is the most flexible laminate in the hoop direction. Matlab code can be found in Appendix H.

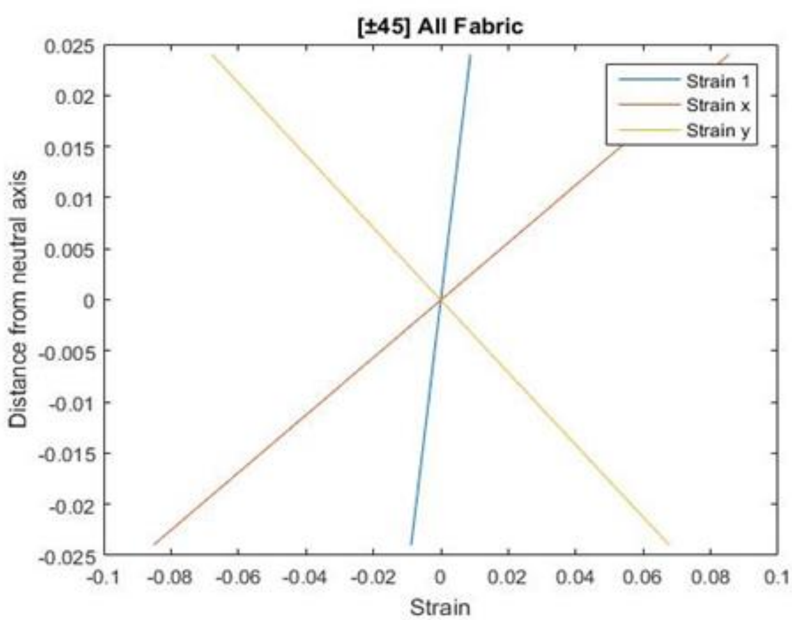


Figure 9: Strain analysis of the 4 layer, +/-45 degree fabric layup displaying a strain of less than 1% for a 1000lb load from the side.

Table 5: Results from CLT showing the 45 all fabric option is the strongest for the given loading conditions.

Laminate	Weight [lb]	Max Index for 1000 lb. side load
[±45_4] All Fabric	1.17	0.91
[$45_f/0_{3u}/45_f$]	1.0	3.43
[$45_f/0_u/90_u/0_u/45_f$]	1.0	3.45

4.2.2 Abaqus Model

A finite element method was used as an additional tool to predict the results of a dynamic impact on the canister. This model would also have the potential to be used to analyze other layup schedules prior to creating the actual canister. This would help in minimizing the number of iterations needed to reach a successful layup that meets the strength requirements that have been set for the container. Figures 10 and 111 show the Abaqus model results.

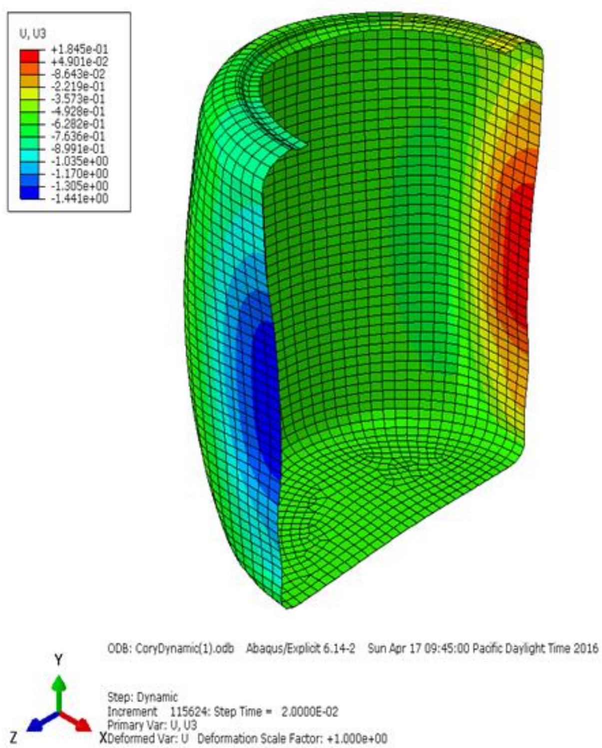


Figure 10: Abaqus model results for the side impact loading equivalent to 100 ft-lb.

The Abaqus model was set up to analyze the the [±45_4] layup schedule as a means to back up the hand calculations conducted. A load was created equivalent to a 100 pound plate impacting the container by being dropped from a height of one foot above the canister. The resulting FEA resulted in a maximum deflection of 1.44 inches during the side impact test and .664 inches during top impact. These are far greater than our maximum allowable deflections, with the greatest deflection caused by side impact being almost six times greater. In order to verify the accuracy of this model, an actual drop test was conducted similar to the modeled, and each of the results compared. This will be discussed further in the testing section. Testing will give a better idea of how the can will fail so that the appropriate adjustments can be made.

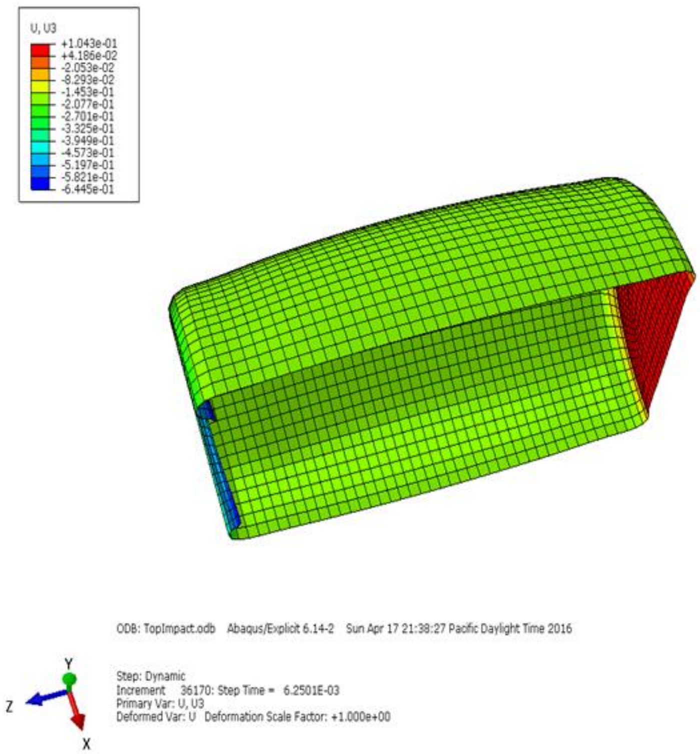


Figure 11: Abaqus model results for a top impact loading equivalent to 100 ft-lb.

Additional layup simulations were conducted in correspondence with further attempts to create a more structurally sound product. A model was created based on a can consisting of four layers of unidirectional carbon-fiber oriented 0° in reference to the global x-axis. Additional layers were added to the top and middle sections of the modeled can. The resulting analysis yielded a maximum deflection equal to approximately 1.5" from the side-impact test. These results would later be verified for accuracy based on an actual drop test conducted on the manufactured canister.

4.3 Mold Analysis

In order to make the canister body and lid, it will be first be necessary to manufacture a proper mold that will be used to lay up the structures. Before beginning manufacturing of the molds, it was first necessary to calculate certain parameters of the mold in order to ensure a design that could withstand the temperatures and pressure it will be subjected to once manufacturing of the carbon fiber body and lid begins. Calculations determined that a total of 12 3/8" bolts should be incorporated into the middle flange and 6 5/16" bolts used to fasten the top plate to the mold.

The analysis of the final mold design was broken up into two sections: the middle-section and the top-section, shown in Figures 13 and 14, respectively. The middle section involves a flange consisting of two carbon fiber plates bolted together. In considering the mold's operating conditions, the mold will be cooked in an oven at about 300 ° F and pressurized to 50 psi. It should be noted that the mold was designed to withstand a pressure of 100 psi to keep a factor of safety of 2. The process for bolt selection is shown in Appendix E as well as equations and tables used.

Figure 12: Middle-section of carbon mold with circular bolt pattern.

The bolt calculations for the top section were done in a similar manner to those done in the middle section An aluminum plate will be bolted to the top of the carbon fiber mold. This is to accommodate the pressure given off by the vacuum bag inserted inside of the canister. The hole at the top of the aluminum plate is where the pressure hose will be inserted to pressurize the vacuum bag. As mentioned earlier, the calculations for the top section bolts followed the same procedure and used the same equations as the middle section from Shigley's Design book. The only difference between the middle section and the top section is that the top section's total force exerted value will incorporate thermal stresses.

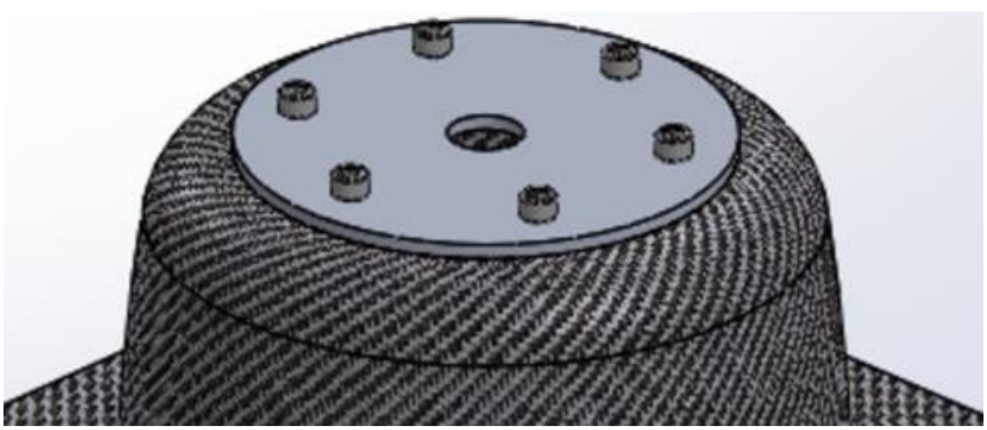


Figure 13: Top-section of the carbon mold with the circular bolt pattern.

4.4 Cost Breakdown

Once our design was finalized, our team researched online suppliers to find materials. All of the of the required supplies were then order and the resulting costs for each item can be seen in Appendix C. Note that the spring cam latches were not incorporated during manufacturing in an attempt to create a lid that does not require tools to open. It may be beneficial to go back and explore incorporation of the spring locks as the tool-less lid was not sufficient to meet the requirements of the project. The overall budget for this project was $1858.61. The main cost driver for this design was the carbon fiber fabric, accounting for almost 40% of the total expenditures. Additional costs were also added on due to an unforeseen malfunction with the ShopBot used to machine out the molds. This resulted in an additional $139 worth of expenses so that the collate on the machine could be replaced and production continued. Additionally, another $166 was spent on spring cam latches that went unused. These were purchased for the first iteration of our lid design, which was then changed towards the end of production in an attempt to make a more efficient, and lightweight lid since the can itself had already exceeded the one-pound weight goal.

To find which carbon fabric we should use, we did a cost benefit analysis between using prepreg carbon fabric and doing a wet layup. In large quantities, wet layups can be significantly cheaper than prepregs since the resin isn't already baked into the material. However, we decided to purchase a twill weave carbon prepreg for some critical reasons. Weight is a major concern in our design, and it is difficult to produce consistent results in wet layups since the resin is applied by hand. In a manufacturing process such as ours where the carbon will be placed by hand in tight quarters, it would be difficult to apply wet resin in a consistent thickness. Using a prepreg fabric would allow us to keep weight down and produce a more consistent product. Prepreg also is not cost prohibitive in our case since we are producing only five prototypes.

When looking for a suitable latch for the locking mechanism, we needed something mass-produced, lightweight and reliable. The stainless steel fasteners we chose are expensive, but they fit our criteria perfectly. The stainless steel construction will prevent rusting over long periods of use, and the weight of 0.07 lbs is the lowest we could find. It also has a low profile, less than 1/8", which will deter a bear from removing the mechanism with its claws. We designed our canister to have minimal outside manufacturing costs. By designing the lid to be carbon fiber we eliminated the need of expensive and time-consuming CNC machining.

Overall, our total cost for the mold and the five prototypes came to $1858. This is within our given budget of $2000. A structured bill of materials can be viewed in Appendix B, which includes costs, lead times, and a list of suppliers. Specification sheets for purchased parts can be found in Appendix D.

CHAPTER 5 – MANUFACTURING

5.0 MANUFACTURING PLAN

The manufacturing process for this project can be summarized in two main parts: the manufacture and assembly of the carbon fiber molds and the manufacture and assembly of the bear canisters themselves.

5.1 Mold Manufacturing

For our team to construct the final carbon fiber mold, we built a sequence of two prior molds that would be used to make our final mold. The first of these was an MDF mold, into which a negative of our final molds shape was machined. Pouring plaster into the MDF mold allowed us to produce a positive shaped mold that was smooth and could be repaired before making the prepreg mold. Finally, carbon fiber was laid onto the surface of the plaster mold to create the final pieces. There were also other pieces to be machined and jigs used to aid in mold assembly, which will be discussed in the following sections.

5.1.1 MDF Mold

The first step in our mold manufacturing process was to machine a negative mold that we could cast a second material into and make a positive mold. We chose to use Medium Density Fiberboard (MDF) as our mold material because of its machinability, durability and cost. Because of the depth of the mold cavity and the length of ten-inch ball end mill we decided to machine the mold in two pieces, which would be joined together and located with four pins. These molds were machined on the ShopBot in the Hangar.

Several 0.75” thick MDF sheets were cut to size and glued together using wood glue to create the workpiece for the machining operation, as shown in Figure 14. Eli used computer-aided manufacturing software to model each of the mold pieces and developed a machining sequence in HSMWorks that could be carried out on the ShopBot. The run time for each half of the mold was six hours due to the low depth of cut required for the ShopBot. Once the molds were removed from the ShopBot they were sanded smooth and treated with Duratec EZ sanding primer, as shown in Figure 15 (left).

To create the recessed lip feature we also made a removable disk shaped insert. This insert was made by milling the disk shape into a sheet of MDF, sanding the surface to a wet finish and filling the recess with Bondo filler. The insert was then centered and glued to the bottom of the MDF mold, as seen in Figure 15 (right).

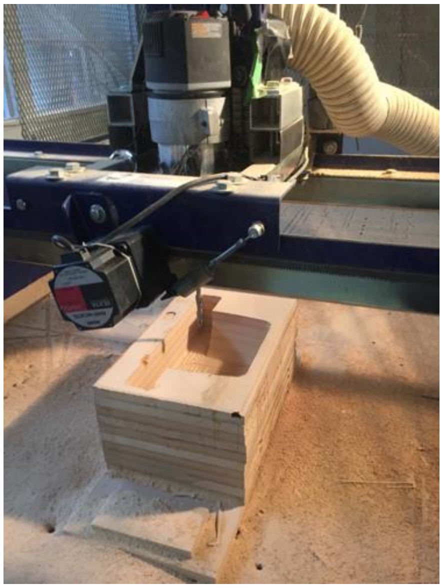


Figure 14: MDF Mold during the milling operation on the ShopBot.

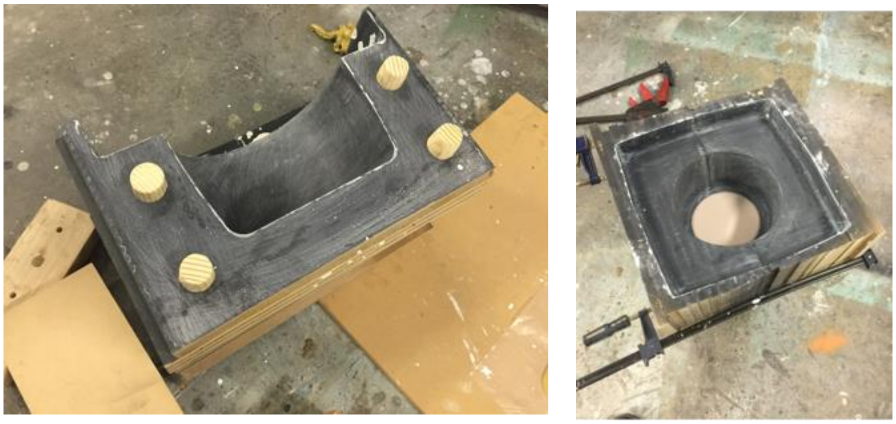


Figure 15: MDF mold after sanding and post processing (left) and joined MDF mold halves with the Bondo insert glued at the bottom (right)

5.1.2 Plaster Molds

To achieve a positive surface onto which our team could layup our final carbon mold, we decided to make a mold from Plaster of Paris and fiberglass. Plaster of Paris is an excellent material for inexpensive molds because it is easy to work with, however it is not a strong material and is typically used in housing drywall applications. To add strength to our mold we added strands of fiberglass, which helped the plaster, hold together during manufacturing.

The plaster was poured into the MDF mold and groups of fiberglass strands were stirred in by hand. It was important for the person mixing the plaster fiberglass mixture to make sure fiberglass strands did not set at the surface of the mold. This would make it difficult to post process the molds and achieve a smooth surface. After a fifteen minute setting period and an hour of curing, the MDF mold was wedged apart from the new plaster mold. The plaster mold process can be viewed in Figure 16.

Figure 16: Strands of fiberglass placed into the mold cavity (left), the post cured mold with one half of the MDF mold removed (middle) and the resulting plaster mold (right).

The resulting plaster pieces were then heated in an oven to remove moisture. This must be done to ensure proper curing when done with the tooling prepreg. To prepare the plaster molds for the carbon fiber layup, our team used a putty filler to fill any depressions in the plaster and sanded the surface to a wet finish. The surface of each mold was also coated with High Gloss Duratec tooling paint to create separation between the laminate and the mold. Our plaster mold was then prepared by applying Frekote, a release agent, to ensure release. The finished plaster mold can be seen in Figure 17

Figure 17: Plaster mold with depressions filled and imperfections sanded to a wet finish.

5.1.3 Carbon Fiber Molds

The layup for our carbon fiber mold pieces consisted of 9 layers of tooling prepreg fabric with a quasi isotropic layup schedule. To keep the final thickness consistent, we used three stencils to cut out reproducible pieces of carbon: a bottom piece for the flange, a rectangular piece for the walls, and a circular piece for the top of the mold. The pieces were applied in the order shown in Figure 18. Also, small pieces of carbon were chopped up and distributed evenly around the inside edge of the mold so that the carbon would take to the shape of the sharp corner easier. To make it easier for the carbon mold to break away from the plaster we also added a layer of PTFE coated fiberglass release film between the carbon and the plaster on the flange.

Figure 18: Application of prepreg to the plaster mold. Stencils were applied in the order shown, from left to right.

The mold needed to be debulked after the first layer was applied to the mold and every few layers afterward. We covered the mold in bleeder and breather, and wrapped the assembly in Stretchlon bagging film, as shown in Figure 19. The edges of the bagging film were sealed with tacky tape and a vacuum connector was placed between the bagging film and the breather material. Using a vacuum pump, we then debulked the mold for ten minutes.

Figure 19: Debulking the mold

With the layup process complete we put each mold into the autoclave and cured at 160F for 2 hours, 200F for 1 hour, and 250F for 2 hours with 3 degree/minute ramps. The molds were removed and a post cure was done at 250F for 1 hour, 300F for 1 hour, 350F for 1 hour, 385F for 2 hour The final result is shown in Figure 20.

Figure 20: Carbon molds after cure cycle in autoclave.

In order to use the carbon fiber prepreg molds, they first had to be removed from their plaster molds. This process is usually fairly easy and involves using a wedge to leverage to the part off. However, since the plaster and prepreg adhered to each other and the release did not act properly, the plaster had to be removed with destructive practices, as shown in Figure 21.

Figure 21: Removal of the plaster from the carbon molds post cure with destructive practices.

5.1.4 Mold Components and Jigs

To manufacture the top plate for the mold a circular hole pattern was milled into a quarter-inch thick aluminum plate, as seen in Figure 22 (left). We then used the vertical band saw to cut the plate into a circular shape and the disc sander to smooth the edges and make the plate have the proper diameter. We also made custom blind bolts by grinding small slots into our bolts so that they could be tightened from the outside of the mold with a flathead screwdriver.

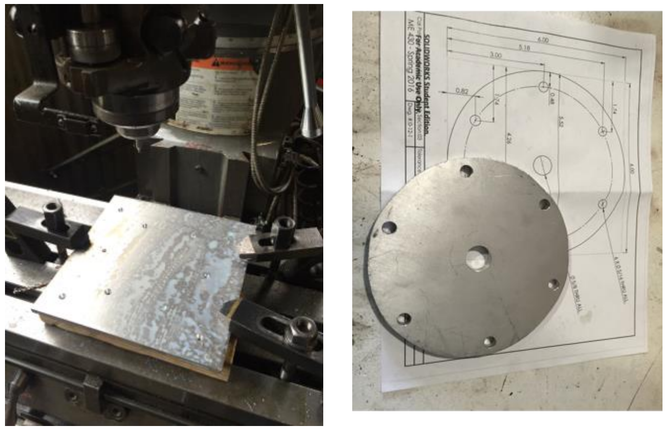


Figure 22: Milling operation for the bolt pattern (left) and the finished top plate (right).

To locate the bolt patterns on the carbon mold we made two jigs from sheets of MDF and milled the pattern on the ShopBot. Because the ShopBot's end mill diameter is larger than the bolt holes we also used the lathes to turn and drill Delrin inserts. The Delrin inserts were pressed into the holes in the MDF jig as shown in Figure 23.

Figure 23: MDF jigs with delrin inserts used in drilling bolt patterns into the carbon fiber molds

Bolt patterns were drilled into the mold pieces using the jigs described and an opening was cut to insert the bladder shown below in Figure 24 (right). Once all the holes were drilled, molds could be assembled accordingly to create the clamshell mold shown below in Figure 26. By using a vacuum to suck up debris from the dremel, airborne carbon fiber particulate was minimized to increase safety. In addition, masks were worn to inhibit inhalation. The edges were also trimmed to remove and sharp points and two "locating holes" were added to ensure proper alignment of the mold halves.

Figure 24: The access hole for the vacuum connector was cut into the top of the mold using a handheld router with a cutting wheel (left). The flange contained sharp edges, which were trimmed for safe handling (right).

5.1.5 Bladder Manufacturing

Before the molds could be used, one more product had to be manufactured in order to pressurize the laminate against the mold walls. To manufacture the bladder, EZ Brush Silicone was applied to the MDF mold, as shown in Figure 25 to create one half of the bladder. One half was then be removed, applied to the carbon fiber molds, and additional silicon was brushed on (shown below in Figure 25). It turned out to be fairly difficult to evenly apply silicone on the female MDF mold, and it was easier to apply extra silicon to the male mold. Once each half had cured, they were then trimmed and then glued together at the center using additional EZ Brush Silicone.

Figure 25: Silicone bladder in the middle of manufacturing. In the background, the MDF mold can be seen which was originally used to brush on the silicone.

Figure 26: Assembled bear canister mold with all accessory components installed.

5.2 Bear Canister Manufacturing Process

By following a process for each bear canister, the manufacturing quality can stay consistent. This is integral to the strength of the can. Throughout this process, different layup techniques were used to improve the end product. Since composite performance is largely dependent on manufacturing quality, defects in manufacturing would degrade the ultimate strength of the canister.

5.2.1 Mold Preparation

The mold must be cleaned of any debris before a release agent must be applied to the mold. First, Frekote NC-700 was used, however, it resulted in our first canister becoming stuck. Choosing the correct release agent and applying it correctly are of utter importance when manufacturing composites. A stuck part can ruin a mold and halt manufacturing. Instead, Chem Trend Chem-release 41-90 EZ was used. This resulted in a very easy release from the mold. Every release agent has different application directions and should be followed explicitly.

5.2.2 Laminate Process

Parts were manufactured according to the layup process shown in Figure 27 (left). By printing a ply stencil on the plotter in Engineering IV, we were able to quickly cut out laminate shapes which fit the mold effectively. Once all the plies were cut, they were laid into the cans as shown in Figure 27 (right).

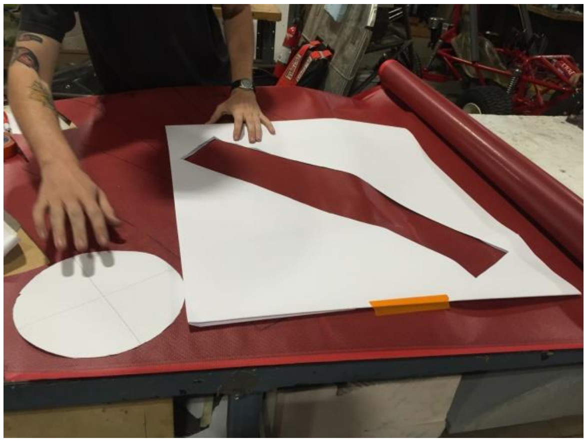



Figure 27: Stencils were utilized to cut accurate shapes at the proper angles required by the layup schedule (left). The carbon plies were applied to the inside of the carbon molds as shown (right).

Each can was laid up individually with an overlap of one inch protruding from either the top or bottom mold. This one inch overlap creates a seam between the two pieces and creates strong bond at the centerline for the can. Each layer was inserted into the can using a heat gun to soften the resin, then was compressed against the mold using a squeegee. Figure 27 (right) shows both top and bottom cans with layups.

5.2.3 Pressurization and cure

Once the laminate was inserted in the can, the clamshell was brought together and secured using bolts around the center flange. First, the locating bolts located on the outer edge of the flange were tightened. These locate the concentricity of the molds and ensure a continuous surface. Next, the rest of the bolts were tightened using a star pattern. In order to ensure proper lamination at the centerline, the overlap was compacted by hand at the seam. Next, the top plate was installed along with the bladder and valve using the blind bolts manufactured previously.

The fully assembled mold was placed into the large oven in the composites lab and connected to an external pressure line. Before the cure cycle the mold was pressure checked with the oven doors shut to avoid injury in the case of the mold breaking.

Once all preparation was done, we began the cure cycle. With our product ACP Room Temperature Storage PrePreg, it calls out several different cure cycles. Our cycle was a soak of 2 hours at 290F, with 4F/min ramps. Total cure time was approximately 3.5 hours.

5.2.4 Removal

The canisters are removed by first removing the top plate seen in Figure 28 (left). Now, the bladder can be seenin Figure 28 (middle) to it shows the inside of the bladder which exhibits wrinkling. The smoother the bag, the more even pressure will be distributed and the end product will be better.

Figure 28: Top portion of the mold post cure with the aluminum plate removed (left). The bag exhibited wrinkling in certain portions of the canister (middle). This lead to wrinkled carbon on the interior of the canister (right).

Figure 29: Wedge inserted between flanges to remove one half of the mold from the bear canister.

Next, a wedge was used to split the two halves shown in Figure 29. This removes one of the two halves and depending on which side comes off, the removal process is different. If they top half of the mold comes off first, return the mold back on top of the can, and insert the bolts for the top plate using wide washers. This will clamp the mold and part together using the top bolts. Next, inserting a wedge will remove the bottom half of the mold and release the canister.

If the bottom half comes off first, a more complicated procedure must be done to remove the top mold. Replace the bottom mold and place onto a table such as shown below in Figure 30. Using two clamps, and two pieces of wood, apply pressure to the bottom mold clamping it to the table. Then, a wedge can be inserted between the flange to remove the top mold.

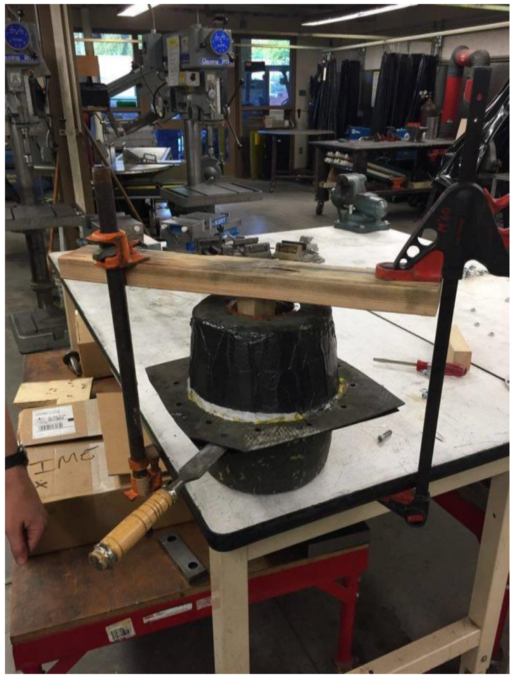


Figure 30: Jig used to remove the top half of the mold from the canister.

5.2.5 Lid Manufacturing

The lids were manufactured using a wet layup technique, shown in Figure 31. By making an MDF mold (Figure 32), lips were integrated in the design to sandwich the silicone lip of the bear canister. Only one was manufactured for this test to display the functionality. The lid consisted of 4 layers of carbon fiber woven twill in a [0/45]s layup. Once the lid was cured, excess was trimmed in order for it to fit on the can. This lid design does not meet requirements of the IGBC, however, it is representative of the lightest weight the lid could be.

Figure 31: Vacuum bagging process to cure wet layup of carbon fiber lids.

Figure 32: MDF mold for creating lids with integrated tabs.

5.2.6 Post Processing

Once the bear canister was removed from the mold, rough edges were cleaned up using sand paper, as well as a dremel tool. The raw bear can fresh from the mold had excess carbon on the top shown in Figure 33 (left) and some flash at the centerline. Excess carbon fiber was trimmed away using a composite cutting disk to the shape shown below in Figure 33 (right). Rubber edge trim was then added to the lip to eliminate the risk of contacting sharp edges while reaching in and out of the can.

Figure 33: Excess carbon at the inner lip of the canister (left) was trimmed to the proper diameter shown (right).

5.3 Results

Figure 34: Three of the four manufactured canisters. On the left: the first, middle: third, right: fourth. Using varying layups and lamination techniques, the cans had differing lamination qualities. Only the First

canister laminated properly while the third and fourth had signed of delamination.

Our team successfully pulled four canisters from the mold, which were then subjected to testing. Varying layup schedules and application techniques were applied from canister to canister with differing results. The first successful canister with 4 layers of +/-45 fabric came our looking the best due to the fabric orientation, however it deflected the most and was also the most damaged by testing. Other laminates which incorporated hoop direction laminates were more difficult to manufacture and resulted in defective bear canisters which would not pass visual inspection.

5.3 Manufacturing Issues and Recommendations

Throughout the manufacturing process our team experienced a number of issues that caused defects in our end products or delays in our project timeline. These issues are detailed in the paragraphs below in the order in which they occurred. It is recommended that these issues be reviewed by any future teams that continue this project to avoid costly mistakes in the future.

During the machining operation of the MDF molds on the ShopBot there was significant buildup of dust in the mold cavity and in the end mill itself, so we made sure to stop the operation intermittently and clear it out to avoid overheating the end mill and to keep the ways clear.

During the first attempt at machining the molds, the ShopBot was run with a 0.15-inch depth of cut and a feed rate of 100 ipm. Two minutes into our first operation, the end mill started to show significant vibrations, proceeded to break from the router and was thrown into the protective glass. After halting the operation and inspecting the router, we determined that the issue was either our feed rate or the collet holding the end mill. To remedy the issue, a new machine-ground collet was installed, the feed-rate was increased to 150 ipm and the depth of cut was lowered to 0.06 inches. This introduced a delay of three weeks to the production schedule.

In our first attempt to remove moisture from the plaster molds, we placed the plaster molds in the autoclave oven. However, this should NOT be repeated, moisture from the molds does not vent from the autoclave and accumulates during cure until condensing at the end of the cure. This process should be done in a more common oven.

Our team decided to use a combination of plaster of paris and fiberglass to make the male molds for our female carbon molds. Although the plaster molds were cost effective they required significant rework to fix defects before the carbon plies could be applied. When our team attempted to pull the molds from the carbon shells the plaster was extremely brittle and needed to be removed by destructive methods. This added delays to our schedule and the removal caused damage to the carbon shells that needed to be repaired before we could use them. Future teams should consider an alternate material for these molds such as aluminum which could be used repeatedly to make multiple molds.

While using the jigs to drill the bolt patterns in the carbon molds we discovered that the fitment between the two mold halves was not centered and left a ridge on the seam. This was an issue because it would make it impossible to have a smooth canister where the mold halves joined. To fix this issue we clamped the two halves at the centered position and drilled two locating holes at opposite corners of the flange. After reassembling the mold pieces multiple times we confirmed that the locating holes were correct and the pieces fit as designed.

To cut the carbon plies to fit the shape of our canister we unwrapped the surface of the can in Solidworks and printed stencils on the plotter in Engineering IV. The stencils were then cut with a X-Acto knife by hand and then applied to the inside of the carbon molds with a one inch overlap between plies. In future projects this process could be expedited much more effectively if a fabric plotter was implemented to cut the laminates. This would eliminate the time required to cut stencils before every layup and ensure a more consistent product.

Debulking within the final molds became a huge issue while manufacturing. Because it was difficult to debulk the molds, two of the cans exhibited inadequate resin bleed out because the cloth could not laminate against the walls of the mold. This problem was reduced by using a heat gun to apply the laminates to the can, however, it did not remove the problem. Debulking could be done by using a press with a mold in the shape of the can. This device could apply pressure to each layer making the end product laminate better.

For our first attempt at making the bladder we tried a lost foam technique for the foam shape shown in Figure 35. This would be the optimal method since the bag would come out as one piece. This method consisted of making a model of our canister from closed-cell insulation foam, and applying the EZ-Brush Silicone to the outside of the foam. We would then melt the foam out of the surrounding bag by using acetone. However when we built our foam model we sealed gaps by using a foam filler spray which was supposed to be dissolvable. When we attempted to melt out the foam with acetone, the filler material remained attached to the bag, which was an issue since the material is not high temperature safe and could not be used in an oven. Therefore, we used the MDF molds from the beginning of our process to make the bladder in two pieces and assemble them at the seam. This caused a few days of delay in our project timeline.

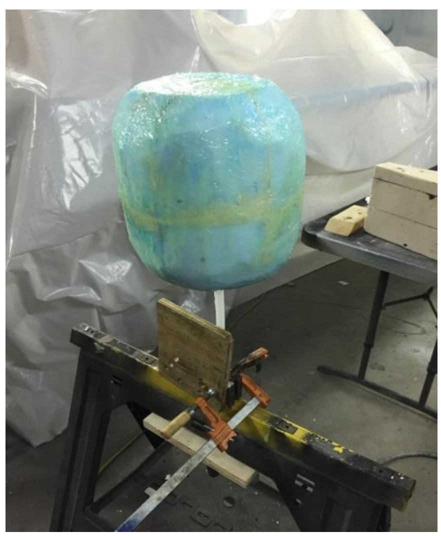


Figure 35: Application of the silicone material to the mold, which would be melted out through the white tube protruding from the bottom of the foam.

Another problem, which persisted throughout manufacturing, was the air attachment to the bladder. Since the bladder had an inconsistent surface, it did not easily create an airtight seal with the through bag connector. This created inconsistent pressure within the mold and inadequate quality control.

CHAPTER 6 – DESIGN VERIFICATION

6.0 DESIGN VERIFICATION PLAN

In order to verify that our design would meet the requirements listed in our original specification agreement, we performed a "Failure Mode and Effects Analysis" on our canister design. This can be viewed in Appendix A. The two major design specifications that require testing are the weight of the canister and the canister's resistance to an impact load. These specifications will need to be verified by quality inspection in the post manufacturing stage and by impact testing as described further on.

6.1 Qualitative Inspection

Our original specification called for a 1.0 pound canister. However, after performing analysis on various layup schedules it was determined that four layers of prepreg fabric were necessary to withstand the 100 pound impact testing. This brought our weight for the carbon portion of the container to 1.17 lbs. This analysis also took into consideration the variability of the weight of prepreg fabric per yard, so our total weight is a conservative estimate. Because each of our canisters are constructed by hand, we will need to weigh each canister after it is removed from the mold to verify it remains under our target weight redefined target weight of 1.3 lbs. We will also visually inspect each canister for defects in the carbon from the manufacturing process, such as delamination, matrix cracking or in the worst case, fiber failure. There is also the issue of tolerances, which are difficult to adhere to in low cost composites manufacturing. We have determined that a 0.050" general tolerance is acceptable for the mold and the lid dimensions, and while it will be difficult to keep those tolerances in the canister itself, we can compensate in the manufacture of the lids by sizing the diameter to each canister individually.

6.2 Impact Testing Procedure

With all of the necessary dimensions acquired and potential defects catalogued, the testing will proceed into the next phase. Phase two will consist of measuring the deformation of the canister under two specific loading conditions. The two loading conditions are as follows:

1. An impact on the side of the canister equivalent to the free fall impact of a weight equal to 100 lb dropped from a distance of 1 ft.

2. An impact on the top of the canister equivalent to the free fall impact of a weight equal to 100 lb dropped from a distance of 1 ft.

Note: Impact testing was done on multiple canisters, one of which was tested without the lid cutout and integration. Testing one of the canisters without the lid integration may have affected the final testing results. Testing results are found in further detail in the individual results section. Shown below is a list of the equipment needed to perform the preliminary impact test.

1. 100 lb weight
2. A high speed camera
3. Camera stand
4. Tape measure
5. Weighted plates
6. Flat Force Distribution Plate

Shown below are the steps to carry out the impact test in its entirety.

1. Tape down ruler or measuring tape to solid wall or beam, ensure the ruler is vertical.
2. Position the canister standing vertically next to the taped ruler so that the numbers are visible.
3. Use the weighted plates to wedge the canister on 4 sides to keep it from moving upon impact.
4. Place the flat force distribution plate on top of the canister such that it is horizontal.
5. Position the high speed camera one foot away from the canister and at the same height level as the force distribution plate.
6. Measure 12 inches from the force distribution plate vertically upward and mark it on the ruler.
7. Hoist 100 pound weight directly above force plate and position it to hit the plate evenly.
8. Begin filming and adjust the height of the 100 pound weight to start at mark 1 foot above.
9. Drop the 100 pound weight and stop filming.
10. Turn the canister horizontally on its side and repeat steps 2-9.

It is important to note that testing for the first canister had skewed data due to an inaccurate dropping of the weight. A force distribution plate was placed on the canister during impact testing. During the case of the first impact test on the first canister, a wooden flat plate with dimensions of 8x11 inches was used. This plate was placed on the canister for both top and side canister testing. The canister was wedged into place on the ground using weighted plates and the 100-pound weight was placed on a chair one foot above the canister. For the first testing procedure the weight was rolled off the chair in order to land squarely on the wooden plate on top of the canister. The weight was rolled off inaccurately and therefore did not land evenly on the plate. This uneven landing caused the plate to tilt and not fully contact the bear canister causing inaccurate data. Based on the results of the inaccurate drop test, the testing procedure was altered.

For the next canister testing the weight was hoisted directly above the impact plate instead of rolling off an object. This alteration was proposed in order to obtain more accurate results for testing by having the weight land evenly on the plate. Following the test results for the second and third canisters, the alteration of positioning the weight directly above the plate proved to be successful. It is also important to note that the second bear canister testing did not use an impact plate. This was done by mistake of the group and was not intended, therefore testing results may have been affected by the lack of an impact plate placed on the canister. Testing for the third and fourth canisters involved an impact plate to ensure the most accurate testing results. A textbook was used as the flat impact plate for the rest of the testing procedures instead of the wooden flat plate used on the first canister testing.

6.3 Data Analysis

With both trials recorded, the next phase in the testing will be to extrapolate the necessary data from the video capture. The initial height of the center of the canister will be recorded and used as the value from which the deflection will be based off of. The videos will be played back frame by frame in order to pinpoint the time at which the maximum deflection occurs. Using the tape measure captured in the video, the testing team will be able to extrapolate the amount the canister deflects. If necessary, a printout of the necessary frame can be made in order to more easily measure the deflection. The deflections obtained from this video will then be compared to the ¼" maximum deflection requirement established for the design. The deflection obtained from the experiment will also be compared to the Abaqus values in order to determine the validity of the model.

6.3.1 Further Testing

Should the canister not hold up during initial testing, then it will be necessary to modify the design of the canister. The strength of the canister can be increased by increasing the thickness of the container walls. It will be necessary to conduct the same test on the modified designs in order to determine whether the sufficiently meet the strength requirements.

Should the canister pass testing, then it may be beneficial to perform a test involving repeated loading. It would be useful to know at which point the product is compromised to the point where it should no longer be used by the consumer. Also, it is likely that it will see this repeated loading should it ever be subjected to actual bear testing. Knowing whether the product will become compromised after a single impact or if it can withstand multiple impacts and stay intact will allow for the team to convey the necessary information to the consumer for safety purposes. If the canister is only strong enough to survive a single impact, then the consumer should be aware that they need to replace their product as it is no longer useable and could be a safety hazard to both the user and any wildlife that may encounter the container.

If the preliminary impact tests are passed with less than ¼" deflection and no visible cracks greater than 0.125", then the canister is eligible for live bear testing. Live bear testing is conducted by the Interagency Grizzly Bear Committee in Montana. "Live bear" testing involves the canister being filled with food and placed in an enclosed environment with the bear. The canister must survive one hour of "live bear" time in order to pass. If the canister has not been broken or opened after one hour, the canister is eligible to be placed on the market. The cost of sending one canister in for testing is $500, therefore it is crucial to have confidence that the canister will be able to pass the one-hour live bear testing as it will become costly to send multiple designs for testing. The Interagency Grizzly Bear Committee sets the preliminary impact testing requirements in order to filter designs that may cause harm to the bear in captivity. The ¼" deflection maximum and 0.125" crack width requirements are arbitrary values selected by the committee based on past live bear testing procedures. Canisters that passed the preliminary impact testing requirements often passed the live bear testing as well. The following section outlines the results of the four testing procedures conducted on each canister manufactured.

6.4 Individual Testing Results

The following sections will outline the major results obtained from testing of the four manufactured bear canisters.

6.4.1 Test of the first canister

Table 8 lists the important parameters recorded during the testing procedure. Getting the dimensions of the canister was obtained as well as the weight. Values for the deflection caused during impact were also recorded.

Table 6: List of recorded data for impact test of first canister.

Original Dimension			
Lid Inner Diameter [in]	Bottom of Curved Flange [in]	Length of Can [in]	Middle Diameter [in]
5.72-5.9	6.21	11.00	8.5
Deflections of Canister Post Impact Test			
Deflection of Length of Can [in]		Deflection of Middle Diameter [in]	
0.5		2.25	

In addition, Figures 15 through 19 show images captured during the testing procedures. These images consist of the before and after canister heights used to determine the total deflections. Also shown are images of the damage done to the canister during impact. This first canister suffer catastrophic failure as several cracks developed along the top half of the canister that managed to propagate through the entire thickness of the wall.

Figure 36: Top before (left) and after (right) deflections for canister #1

Note that the initial height measured for the canister was approximately 11 inches. During the impact test, the weight was dropped on one end of the distribution plate as shown instead of in the middle of the plate. This caused measurements in the deflection due to the plate tilting at an angle as shown above. On further tests we will more accurately drop the weight on the plate to prevent more errors in deflection measurements. The actual deflection was approximated to be about 0.5 inches in which the length of the can was approximately 10.5 inches following maximum deflection. Before and after deflection pictures can be found in Figure 36. Following the impact test on the length of the can a crack formed on the top side view of the can.

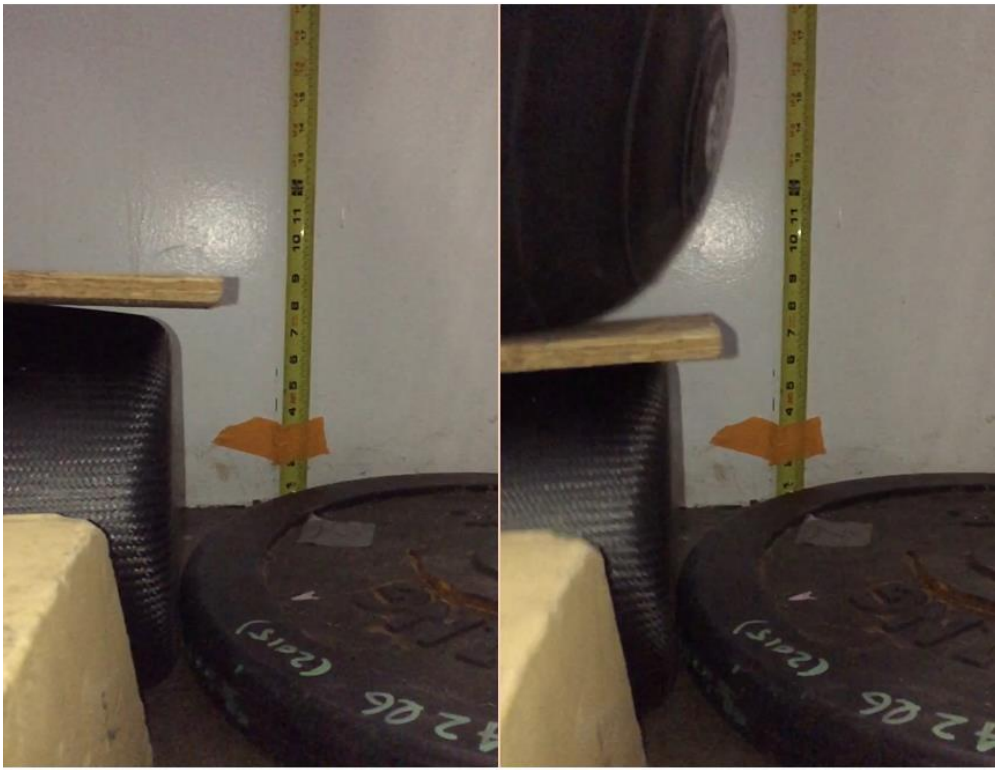


Figure 37: Side before and after deflections for canister #1

Notes:

The initial middle diameter was 8.5 inches and was then deflected 2.25 inches to a final middle diameter of 6.25 inches. Following this impact test the canister cracked and completely broke in 3-4 places. In the previous impact test the canister had cracked but not broken. Before and after deflection pictures can be found above in Figure X. Had the canister not broken it still would not have passed the deflection test: no more than ¼” deflection. The photos of the damage post impact test can be seen in Figures 38-41.

<u>Photos of Bear Canister Post Impact Testing</u>

Figure 38: Canister #1 top view post-impact

Figure 39: Canister #1 top close-up view post-impact

Figure 40: Canister #1 additional top view post-impact

6.4.2 Testing of the second canister

Table 7: List of recorded data for impact test of second canister.

<table>
<tr><th colspan="4">Original Dimension</th></tr>
<tr><td>Lid Inner Diameter
[in]</td><td>Bottom of Curved Flange
[in]</td><td>Length of Can
[in]</td><td>Middle Diameter
[in]</td></tr>
<tr><td>6</td><td>6.17</td><td>10.5</td><td>9</td></tr>
<tr><th colspan="4">Deflections of Canister Post Impact Test</th></tr>
<tr><td colspan="2">Deflection of Length of Can
[in]</td><td colspan="2">Deflection of Middle Diameter
[in]</td></tr>
<tr><td colspan="2">0.2</td><td colspan="2">0.75</td></tr>
</table>

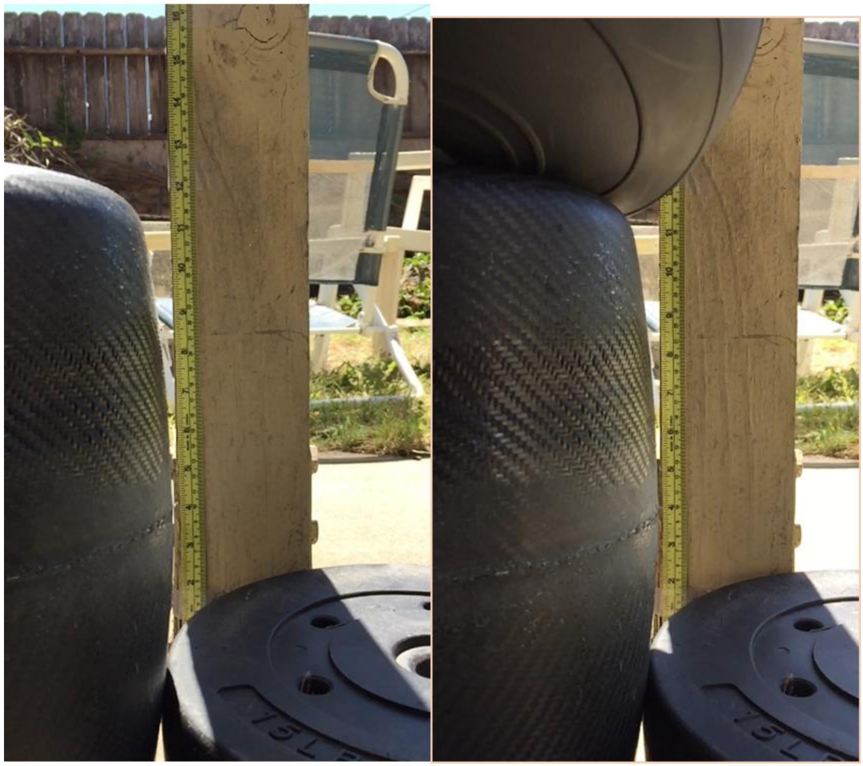


Figure 41: Top before and after deflections for canister #2

Notes:

The initial height measured for the canister was approximately 10.5 inches. The 100-pound weight directly impacted the top of the canister. It is important to note however, that for this canister the lid was not cut out like the first tested canister. This may have impacted the testing for the canister length wise. For the next can, we will make sure to cut out the lid portion to ensure more accuracy for the testing lengthwise. Figure 41 shows the before and after deflection images. Based on the current test with the lid not cut out, there was a deflection of less than 0.2 inches. An audible crack was heard upon contact, a picture of this crack is shown in Figure 46. This crack was only surface level and did not extend through the entire thickness of the can.

Figure 42: Side before and after deflections for canister #2

Notes:

The initial middle diameter was 9 inches and was then deflected approximately 0.75 inches to a final middle diameter of 8.25 inches. There was no damage following the impact test when the can was on its side. The crack caused by testing the can in the longitudinal direction did not change. There were also no other cracks visible on the can following the impact test on its side. Shown below are pictures of the can following the 2 impact tests as well as a close up of the single crack caused by the longitudinal testing. Before and after deflection pictures can be found in Figure 42. The photos of the canister condition prior to and following the impact test can be seen in the next section in Figures 43-46.

Photos of Bear Canister Before Impact Testing

Figure 43: Main body of canister #2 before impact

Figure 44: Close-up view of main body of canister #2 before impact

Photos of Bear Canister After Impact Testing

Figure 45: Top view of canister #2

Figure 46: Close-up view of crack on canister #2

6.4.3 Impact Test of Third Canister

Table 8: List of recorded data for impact testing of the third canister.

Original Dimension			
Lid Inner Diameter [in]	Bottom of Curved Flange [in]	Length of Can [in]	Middle Diameter [in]
6.5	6.37	11	8
Deflections of Canister Post Impact Test			
Deflection of Length of Can [in]		Deflection of Middle Diameter [in]	
<0.1		1.25-1.5	

Figure 47: Top before and after deflections of canister #3

Notes:

The initial height measured for the canister was approximately 11 inches. The 100-pound weight directly impacted the top of the canister. On this particular testing the lid opening was cut out and the carbon-fiber lid was attached to the can along with the rubber trim. Essentially this was a completely manufactured can testing. There were no audible cracking noises and the canister did not appear to deflect at all. Before and after deflection pictures can be found above in Figure 47. No visible cracks were seen.

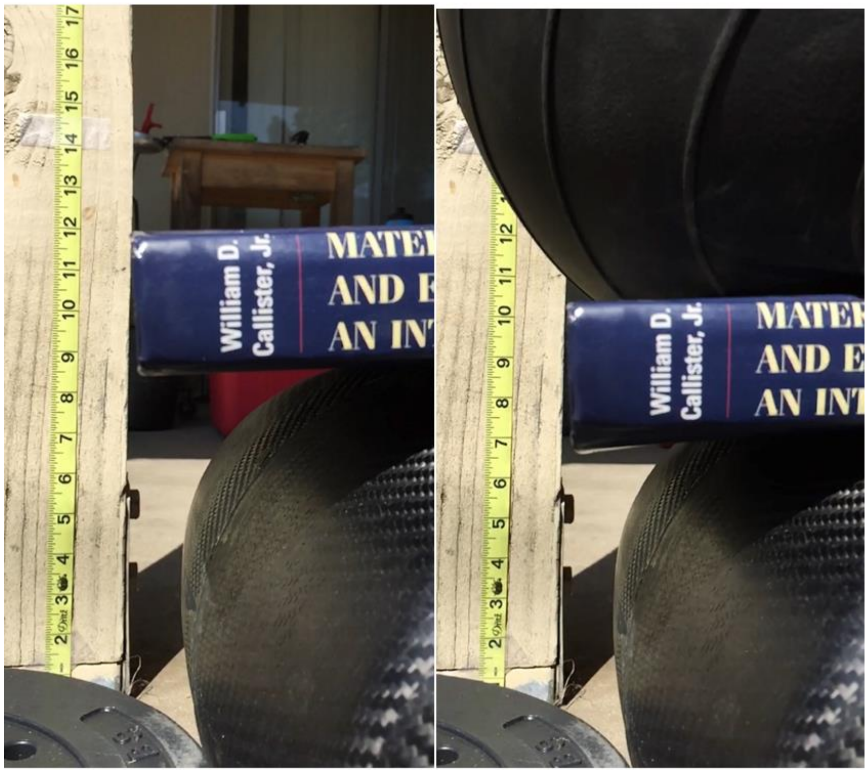


Figure 48: Side before and after deflections of canister #3

Notes:

The initial middle diameter was 8 inches and was then deflected approximately 1.25-1.5 inches to a final middle diameter of approximately 6.75 inches. There was an audible cracking noise upon impact of the weight. There were however no visible cracks shown. Before and after deflection pictures can be found in Figure 48. The can deflected slightly more than previous testing but reformed to its original diameter following the impact. The condition of the can prior and following impact testing can be seen in Figures 49-52.

Photos of Bear Canister Before Impact Testing

Figure 49: Top view of canister #3 before impact with lid

Figure 50: Side view of canister #3 before impact

Photos of Bear Canister After Impact Testing

Figure 51: Close-up side view of canister #3 post impact

Figure 52: Close-up top view of canister #3 post impact

6.4.4 Impact Test of Fourth Canister

Table 9: List of recorded data for impact testing of the third canister.

Original Dimension			
Lid Inner Diameter [in]	Bottom of Curved Flange [in]	Length of Can [in]	Middle Diameter [in]
6	6.30	11	8
Deflections of Canister Post Impact Test			
Deflection of Length of Can [in]		Deflection of Middle Diameter [in]	
<0.1		4	

Figure 53: Top before and after deflections of canister #4

<u>Notes:</u>

The initial height measured for the canister was approximately 11 inches. The 100-pound weight directly impacted the top of the canister. Following the impact an audible cracking noise was heard. Upon investigation, the top upper portion along the rim had separated slightly. There was no apparent deflection on the top section. The bottom of the canister contained visible points of light after the first impact. This means that fibers on the bottom of the canister had separated as well. Before and after deflection pictures can be found in Figure 53.

Figure 54: Side before and after deflections of canister #4

Notes:

The initial middle diameter was 8 inches and was then deflected 4-5 inches to a final middle diameter of approximately 3 inches. A very loud audible cracking noise was heard. Upon further investigation there was about a 2/3 detachment of the top surface from the main body of the canister. This was the most a canister has deflected following an impact test, as shown in the before and after photos, the canister was completely crushed under the weight. Before and after deflection pictures can be found in Figure 54. The photos of the damage prior and post impact test can be seen in the next section in Figures 55-57.

Photos of Bear Canister Before and After Impact Testing

Figure 55: Close-up view of canister #4 before impact

Figure 56: Close-up top view of canister #4 post impact

Figure 57: Top-side view of canister #4 post impact

6.5 Testing Results

Based on the four different testing of the canisters, the third canister performed the best when looking at a post-impact damage perspective. The third canister was fully manufactured including the lid opening cutout, rubber trimming, and lid attached to the top. In other words, the canister was completed from a manufacturing point of view. There were a few issues when comparing the test of the canisters accurately. The second canister tested was not completed from a manufacturing point of view as the lid was not cut out. The third canister testing includes the use of a flat force distribution plate (the textbook) whereas the second canister did not have one. These two testing differences may have affected the deflection rates shown in Table X. in the Appendix G. The second canister deflected only 0.75 inches but also sustained significant damage in cracks. The third canister however deflected between 1.25 and 1.5 inches and did not sustain any damage with cracking or broken fibers. These large differences in deflection may have been due to the fact that a force distribution plate was used in the third canister testing.

Following is a list of potential improvements in testing to gather more reliable data consistently.

1. Use a Force Distribution Plate on every test.
2. Secure the Force Distribution Plate to the Canister so that it is completely horizontal.
3. Construct a reliable test rig that contains an accurate dropping mechanism so that the 100 pound weight is dropped evenly on the plate repeatedly.
4. Use the highest quality high speed camera possible.
5. Use a Force Distribution Plate that is lightweight and also sturdy such as wood.
6. Ensure each canister is at the same stage of manufacturing before testing.
7. Ensure the test rig's dropping mechanism is hoisted to the correct drop height.

Chapter 7 Conclusions and Recommendations

Early on in our design process our team neglected to consider using a geometry for the structure of the laminate which would provide sufficient bending flexural stiffness. Manufactured cans were only a single laminate with no core material, which would increase flexural stiffness. In order to pass the side impact test, it is recommended that an additional skin stiffener is placed near the centerline of the canister. Using a skin stiffener such as the one shown in Figure 58 would result in the stiffest shear deflection. Other commercially available products require similar geometric features to pass the testing such as the BearVault and the Garcia.

Figure 58: The Garcia (left) and Bear Vault (right) both exhibit geometric features which make the middle hoop section the stiffest section of the canister. By applying more ABS plastic on the garcia the bending stiffness is greater. The BV has a ridge feature at the center increasing the moment of inertia of the cross section in the hoop direction.

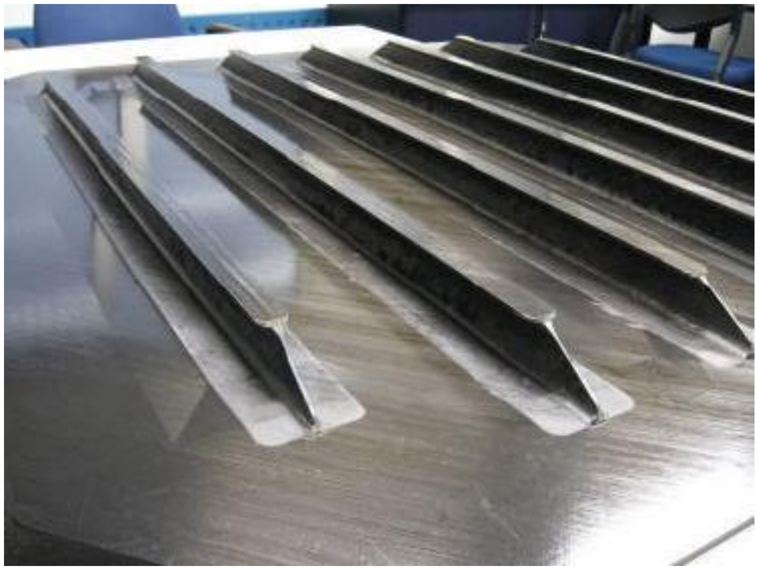


Figure 59: Skin stiffeners used on a flat panel which utilizes a shear web similar to an I-Beam.

Another feature that could be enhanced is using the lid as a structural element in our design. This issue was immediately apparent after our first test as we recognized that failure was occurring not only in the center of the can but through the flange near the top of the can. We would recommend that the next team to continue this project develop a lid utilizing an insert that is co-cured into the body of the canister during the oven cure. By using an insert in this way, post processing can be reduced and more lid options would be available.

Due to the variability of this project, it would be worthwhile to increase the reliability of manufacturing and testing. Two cans with the same layup schedule had a measured deflection of 0.5" and 1.5" respectively. This skew in the data could be due to the inconsistency of the test, incorrect can preparation, or variability within the layup. However, the testing procedures need to be improved to ensure accurately measured results, which reflect more closely to the IGBC testing method. To ensure product quality, improved manufacturing methods must be used to ensure proper lamination as discussed in the results section.

Our team succeeded in manufacturing five canisters; however our best canister deflected 0.5 inches during the side impact test and therefore did not pass the criteria set by the IGBC. With design changes to the laminate structure, we are confident that a canister could be produced within weight specifications that would pass impact testing. This industry always has its risks and testing should be expanded to avoid destructive failure such as the Bearikade shown below which broke at the hands of a brown bear.

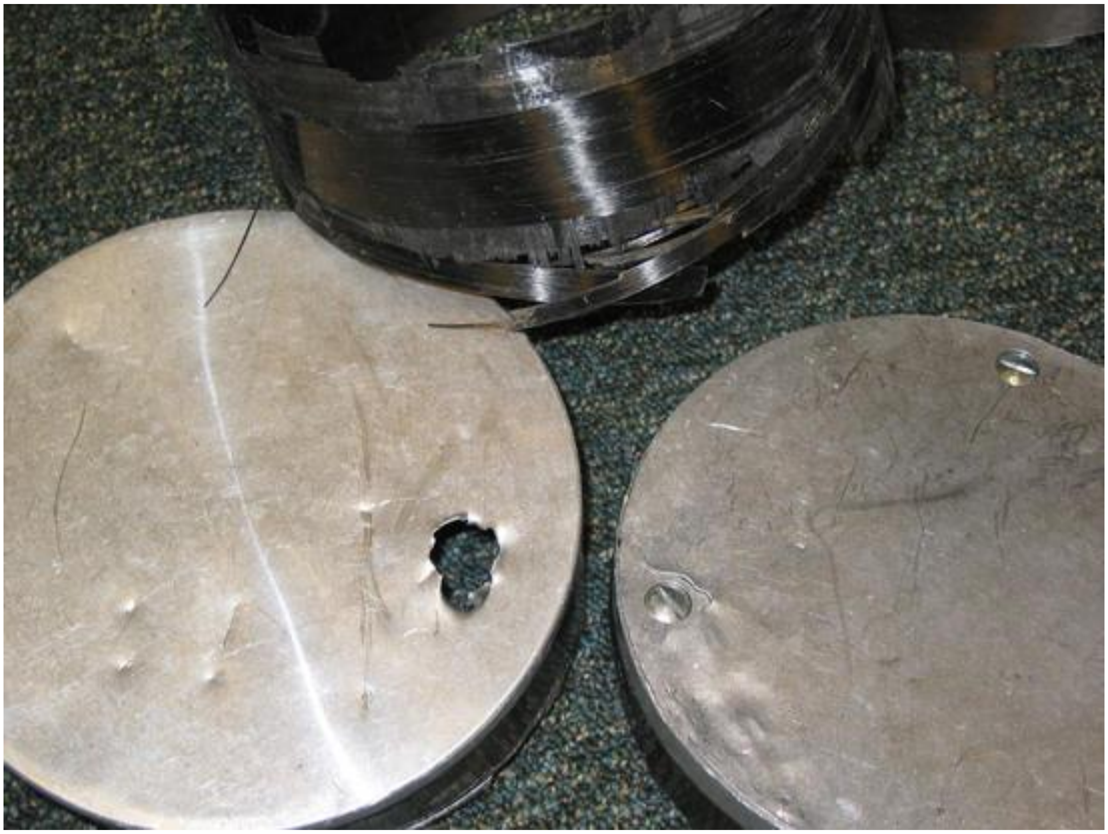


Figure 60: Bearikade which broke from an encounter with a brown bear.

APPENDIX A: DESIGN SPECIFICATIONS

No.		Feature	Measured Value	Unit	Tolerance	Risk	Compliance	Demand/ Wish	Source	Remarks
1	**Geometry**									
	1.1	Volume	450	in^3	Min	High	Measure	D	Sponsor	5-7 Days of Food
	1.2	Straps onto backpack or fits inside of backpack, Loops for Straps	<10	inch (diameter)	Max	Low	Measure	D		To Make Easily Carried
	1.3	Corner radii	>0.125	inch	Min	Low	Measure	D	http://www.sierranaturenotes.com/naturenotes/Bears.htm	not pose a threat of injury to bears or humans
	1.4	Container gaps	<0.125	inch	Min	Moderate	Measure	D	http://www.sierranaturenotes.com/naturenotes/Bears.htm	This applies to after undergoing 100 ft-lb drop test
	1.5	lid must be recessed	N/A	N/A	N/A	Moderate	Inspection	D	http://www.sierranaturenotes.com/naturenotes/Bears.htm	To keep animals from gaining leverage on container
	1.6	No Openings or external hinges	N/A	N/A	N/A	Low	Inspection	D	http://www.sierranaturenotes.com/naturenotes/Bears.htm	This applies to when container is fully closed
	1.7	Length (Standard Backpack width???)	1.5	feet	Max	Moderate	Measure	W		Test different configurations to determine best design for fit
2	**Kinematics**									
3	**Forces**									
	3.1	Force used to unlock (if using twist off lid)	10	in-lb	Max	Moderate	Test	D		Can be opened in the conditions where maximum strength may be compromised
	3.2	100 pound cartridge dropped from one foot on side and top	100	ft-lbs	Min	High	Test	D	http://www.sierranaturenotes.com/naturenotes/Bears.htm	Testing occurs with weight dropped onto lid along with weight dropped onto side of canister
	3.3	What's the allowable deflection/destruction?	<=0.125	in	Max	High	Test	D	igbc.com	This includes, gaps/openings that may develop after drop test

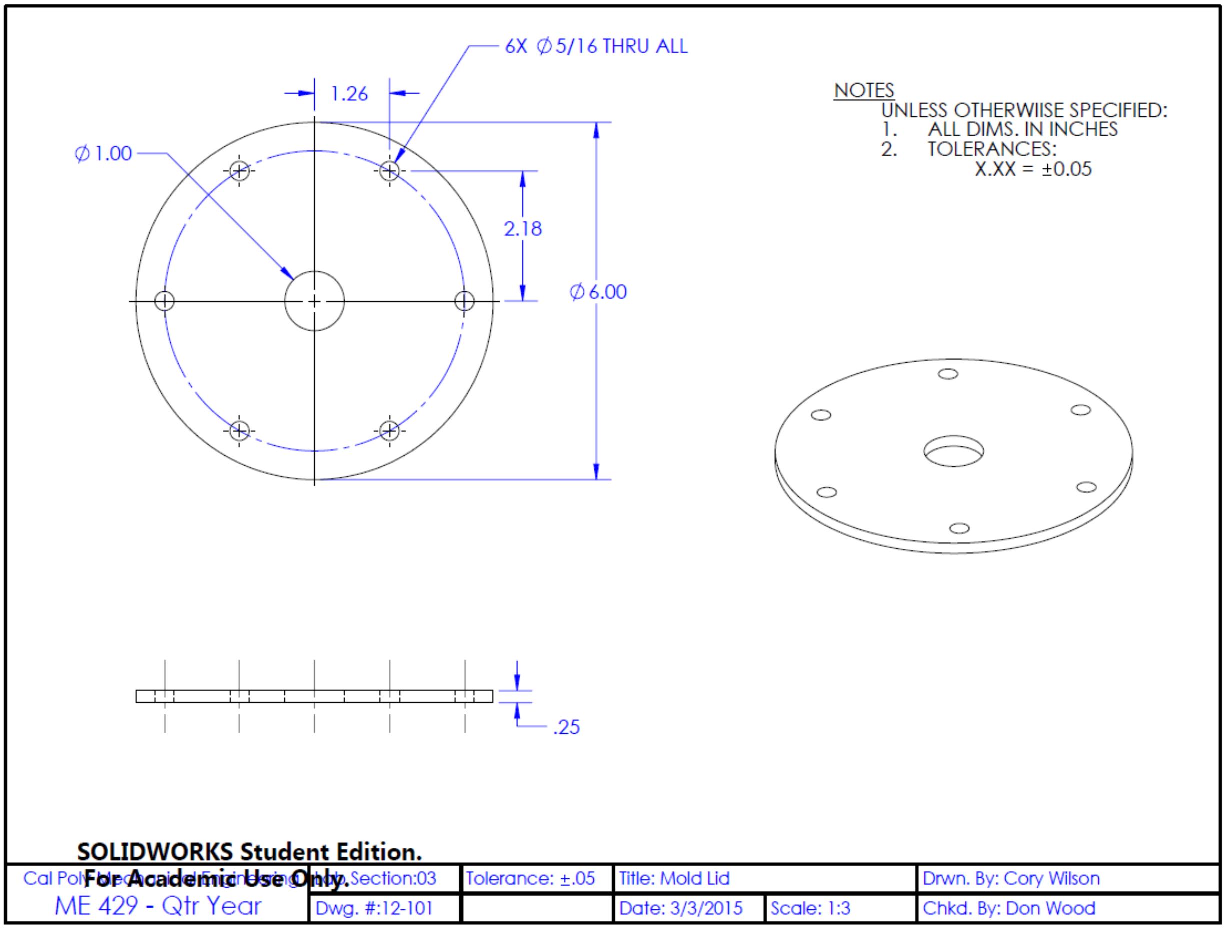
No.		Feature	Measured Value	Unit	Tolerance	Risk	Compliance	Demand/ Wish	Source	Remarks
4	**Energy**									
	4.1	Operating pressures	<=29000	ft	Max	Moderate	Test	W		High Altitude Safe
	4.2	Operating temperatures	0-140	F	Max	Low	Test	D		Varying Temp Safe
5	**Material**									
	5.1	FDA approved interior material	N/A	N/A	N/A	Low	Similarity	W		Food safe
	5.2	Carbon fiber / Specific Plastics	N/A	N/A	N/A	Low	Similarity	D	http://www.sierranaturenotes.com/naturenotes/Bears.htm	Bear Can Approved Materials
	5.3	UV resistance				Low	Similarity	D		Outer coating to protect canister from prolonged UV exposure
	5.4	Proper insulation/coating to prevent leakage of odors	Go/ No Go	N/A	N/A	Moderate	Inspection	W		In order to reduce the risk of bears coming into contact with canister
6	**Signals**									
	6.1	Audible locking	N/A	N/A	N/A	Low	Test	W		Can hear the canister locking mechanism engage
7	**Safety**									
	7.1	Radius	0.125"		Min	Low	Measure	D	http://www.sierranaturenotes.com/naturenotes/Bears.htm	No sharp edges to prevent injury to animals and user
	7.2	Surface roughness	500 grit sandpaper		Min	Low	Inspection	W		

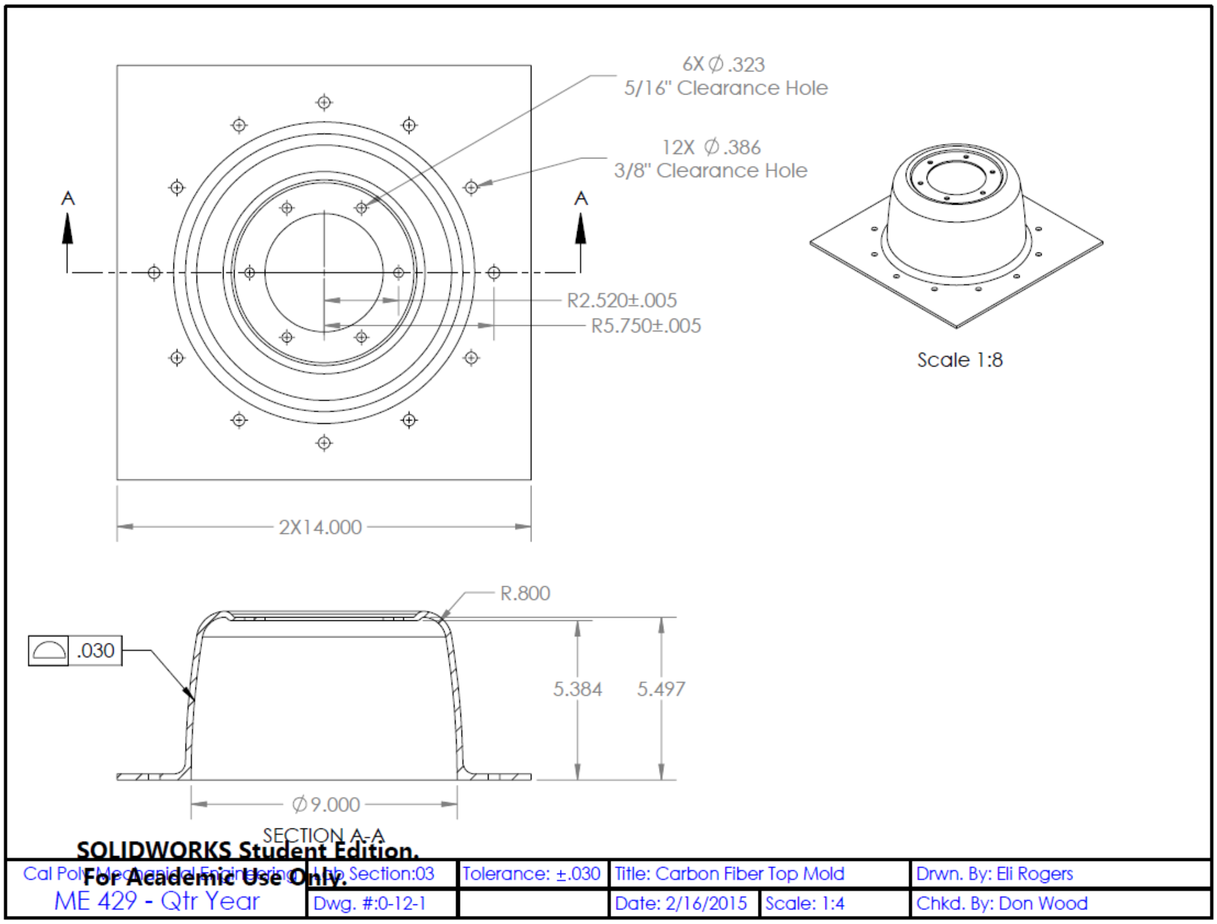
No.		Feature	Measured Value	Unit	Tolerance	Risk	Compliance	Demand/ Wish	Source	Remarks
8	**Ergonomics**									
	8.1	Weight	1	lbs	Max	High		D		<1.5 lbs to beat competitor
	8.2	Unlocking Mechanism uses a common tool (i.e. a quarter, spoon etc)/ or no tool						W		Opened Easily
	8.3	Appropriate shape for backpack	N/A	N/A	N/A	Moderate	Test	D		Easily Carried. Determine by field testing different shapes and getting user feedback
	8.4	Opening size	8 to 10	in	Min	Moderate	Measure	W		Provide easy access to food within container
9	**Production**									
	9.1	Lead Time	3	days	Max					
	9.2	Manufactureable (accurately reproduce multiple units of final design)	Go/No Go	N/A	N/A	High	Test	D	Sponser	Build commercial quality mold
10	**Quality Control**									
	10.1	Tolerances of weight and strength	0.1	%	(+/-) 1%	Moderate	Test	D		Minimum variations in bear cans
	10.2	Nominal Safety Factor	1.15	N/A	Min	Low	Test	W		
	10.3	No Visual Imperfections in Carbon Shell / Machining Defects	Go/ No Go	N/A	Min	Moderate	Inspection	W		
11	**Assembly**									
	11.1	Part count	<=3	parts	Max	Low	Inspection	D		Only assembly required should be putting on/taking off lid
12	**Transport**									
	12.1	Packaging Resistance Crushing Force	50	lbs	Min	Low	Test	D		Withstand shipping loads out of plane from design load requirements
13	**Operation**									
	13.1	Last the lifetime of the user	50	years	Min	Moderate	Inspection	W		
14	**Maintanence**									
	14.1	Simple clean up using basic cleaning supplies	Go/ No Go	N/A	N/A	Low	Test	D		Can be cleaned with just water and/or cloth

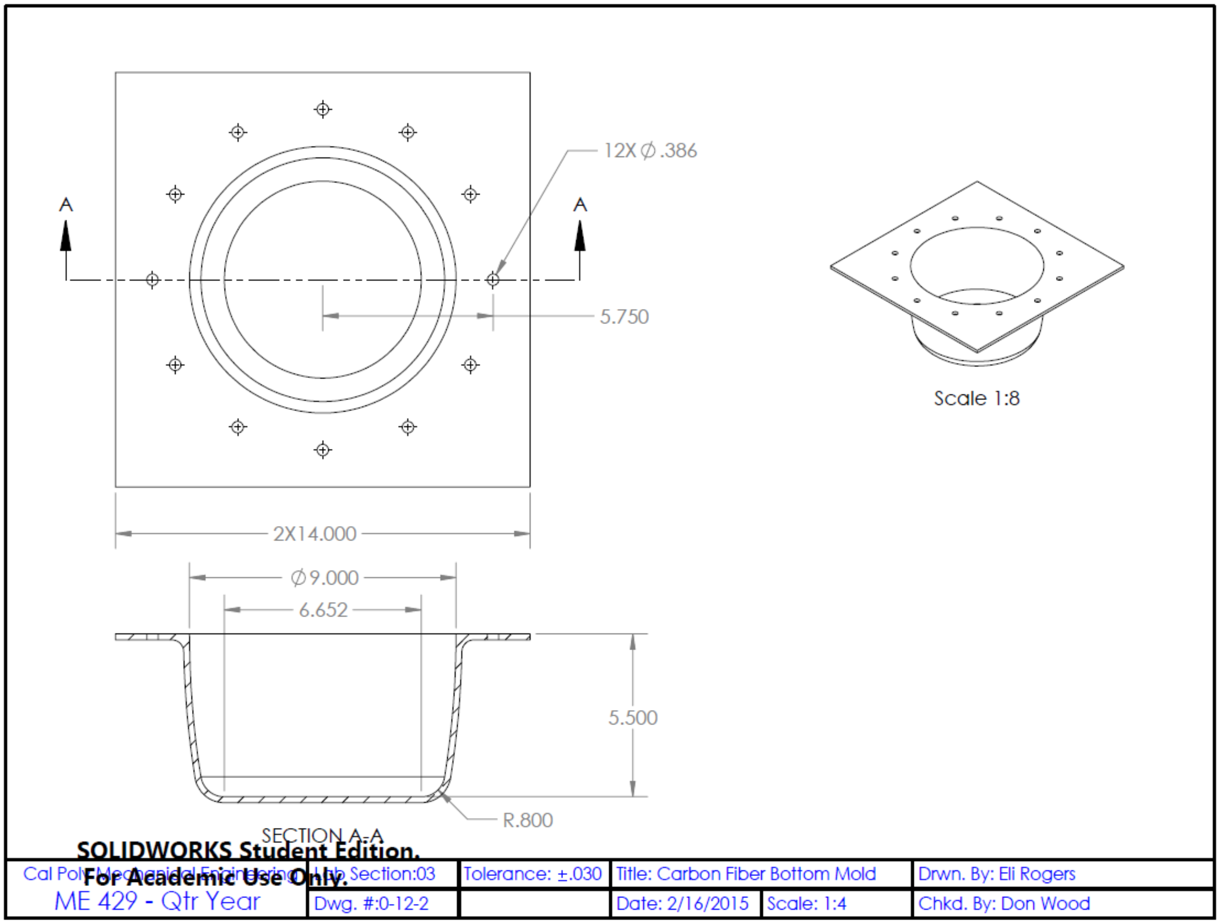
No.		Feature	Measured Value	Unit	Tolerance	Risk	Compliance	Demand/ Wish	Source	Remarks
15	**Costs**									
	15.1	Pricing	<=500	$	Mad	Moderate	Inspection	W		In order to be competitive in commericial market
16	**Schedule**									
	16.1	Delivery Date	May-15							

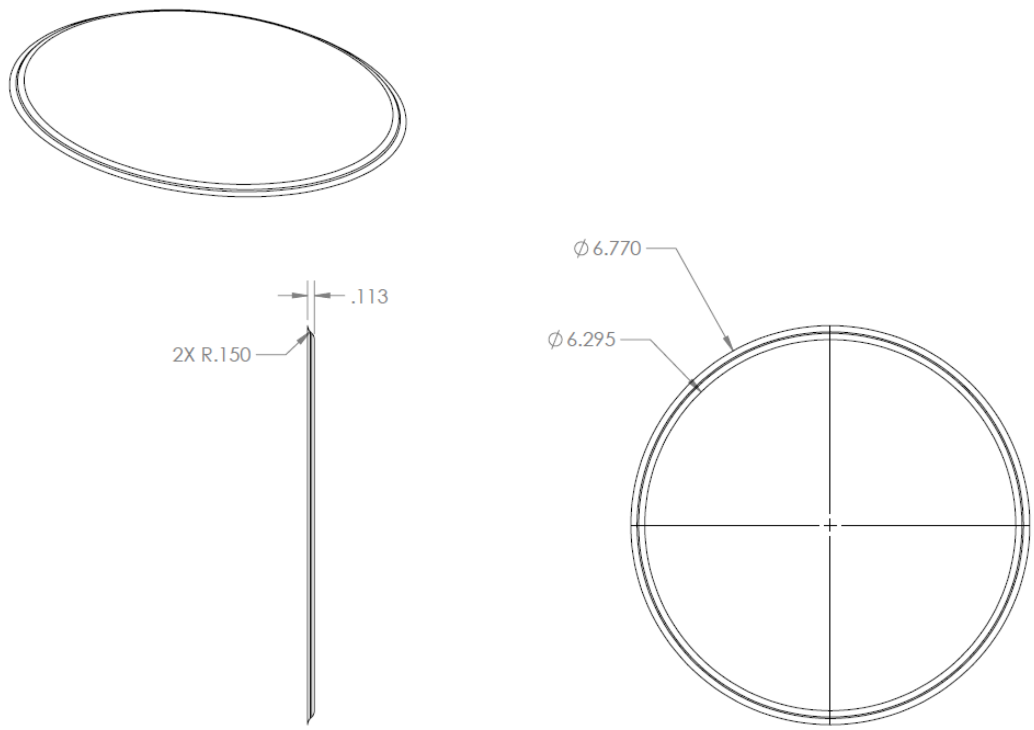
APPENDIX B: DRAWING PACKET

Structured Bill of Materials											
Level 0	Level 1	Level 2	Part #	Quantity	Name	Function	Drawing #	Supplier	Supp. Part #	Price	Shipping [Days]
X			0	1	Mold	Make Bear Canisters	DWG 0				
	X		10	1	Mold Tooling	Tooling to make carbon mold.	N/A				
		X	100	1	1" Ball End Mill, 12" 4 Flute	Machine MDF molds	N/A	Carbon End Mill Store	755-4110	$335.69	14
		X	101	1	Airtech TMGP-4100 Tooling Pre-Preg	Material for carbon mold	N/A	192 Composites Lab	N/A	$0.00	0
		X	102	1	Stretchlon 800 Bagging Film, 60" Wide Sheet	Applies pressure to mold while curing	App. D	Fibre Glast	1688 & 1788	$29.95	7
		X	103	1	Yellow Sealant Tape, 25' Roll	Seal vacuum bagging film	App. D	Fibre Glast	580	$7.95	7
		X	104	2	Medium Density Fiber Board Panel	Material for MDF mold	N/A	Home Depot	202332600	$63.90	1
		X	105	2	Gorilla Wood Glue, 18 fl. oz. bottle	Glue for MDF Panels	N/A	Home Depot	100662003	$11.94	1
		X	106	4	White Plaster of Paris Dry Mix, 8lb Tub	Material for Plaster Molds	App. D	DAP - Amazon	10310	$43.16	1
		X	107	1	High Density Poly Foam 22in. X 22in. X 1in. - (2-Pack)	Material for Bladder Mold	N/A	Home Depot	206610631	$33.95	1
		X	108	1	Duratec Vinyl Ester Hi-Gloss Top Coat, 1 Gallon	Mold top coat	App. D	Revchem Composites	30F010TB55	$140.00	2
		X	109	1	Breather and Bleeder, 4 oz - 5 yd Roll	Mold breather	App. D	Fibre Glast	579-C	$24.95	7
		X	110	1	Polyester Peel Ply, 3 yd Package	Mold Peel Ply	App. D	Fibre Glast	583-B	$29.95	7
		X	111	1	Loktite NC 700 Frekote, 1 Pint	Mold release	App. D	Ellsworth Adhesives	83465	$24.32	7
	X		11	1	Top Mold Insert	Filler between carbon and al plate	DWG 0-11	N/A	N/A	$20.00	1
	X		12	1	Carbon Mold	Final Mold	DWG 0-12		N/A		
		X	100	3	EZ-Brush Vacuum Bagging Silicone, 2.0lb Trial Unit	Vacuum bag for carbon mold	App. D	Smooth-On	75647	$159.03	7
		X	101	1	0.25" Aluminum Bare Plate 6061 T651, 8" x 8" Plate	Lid for carbon mold	App. D	Online Metals	T651	$15.60	5
		X	102	1	Socket Head Cap Screw, 5/16"-18 Thread, 1-1/4" Length, Pack of 25	Fastens two halves of carbon mold	App. D	McMaster-Carr	90128A586	$9.32	2
		X	103	1	Socket Head Cap Screw, 3/8"-16 Thread, 1-1/4" Length, Pack of 25	Fastens Al lid to mold	App. D	McMaster-Carr	90218A627	$14.55	2
		X	104	1	Low-Strength Steel Hex Nut, 5/16"-18, Pack of 50	Hardware for Socket Head Cap Screw	App. D	McMaster-Carr	90473A030	$4.05	2
		X	105	1	Low-Strength Steel Hex Nut, 3/8"-16, Pack of 50	Hardware for Socket Head Cap Screw	App. D	McMaster-Carr	90473A031	$5.58	2
		X	106	1	Oversized Flat Washer, 5/16" Screw Size, Pack of 100	Hardware for Socket Head Cap Screw	App. D	McMaster-Carr	91090A110	$4.92	2
		X	107	1	Oversized Flat Washer, 3/8" Screw Size, Pack of 100	Hardware for Socket Head Cap Screw	App. D	McMaster-Carr	91090A112	$7.62	2
		X	108	1	High Temp Vacuum Bag Connector Locking Ring	Pressure port connection	App. D	ACP Composites	V-13C	$59.00	0
X			1	5	Bear Canister	Protects food from bear	DWG 1	N/A	N/A		N/A
	X		10	5	Container		DWG 1-10		N/A		N/A
		X	100	7	3k 2x2 Twill Weave Fabric, 5.9 oz	Prepreg for canisters	App. D	ACP Composites	14033-D	$660.00	14
	X		11		Lid		DWG 1-11				N/A
		X	100	1	Aluminum Blind Rivet, 1/8" Diameter, Pack of 250	Rivet Latch to Lid	N/A	McMaster-Carr	97447A010	$7.73	2
		X	101	5	Spring Cam Latch, Nonlocking, Slotted Head	Locking Mechanism	App. D	Grainger	4RPY3	$166.54	5
		X	100	7	3k 2x2 Twill Weave Fabric, 5.9 oz	Prepreg for lid	App. D	ACP Composites	14033-D	$0.00	14
		X	102	1	Rubber Edge Trim 1/16" Inside Width, 1/4" Inside Height, 10ft	Edge trim for lid, reduce risk of cuts	N/A	McMaster-Carr	8507K52	$8.88	2


6X ∅5/16 THRU ALL
1.26
∅1.00
2.18
∅6.00
.25
NOTES
UNLESS OTHERWIISE SPECIFIED:
1. ALL DIMS. IN INCHES
2. TOLERANCES:
X.XX = ±0.05
SOLIDWORKS Student Edition.
For Academic Use Only.
Section:03
Tolerance: ±.05
Title: Mold Lid
Drwn. By: Cory Wilson
ME 429 - Qtr Year
Dwg. #:12-101
Date: 3/3/2015
Scale: 1:3
Chkd. By: Don Wood

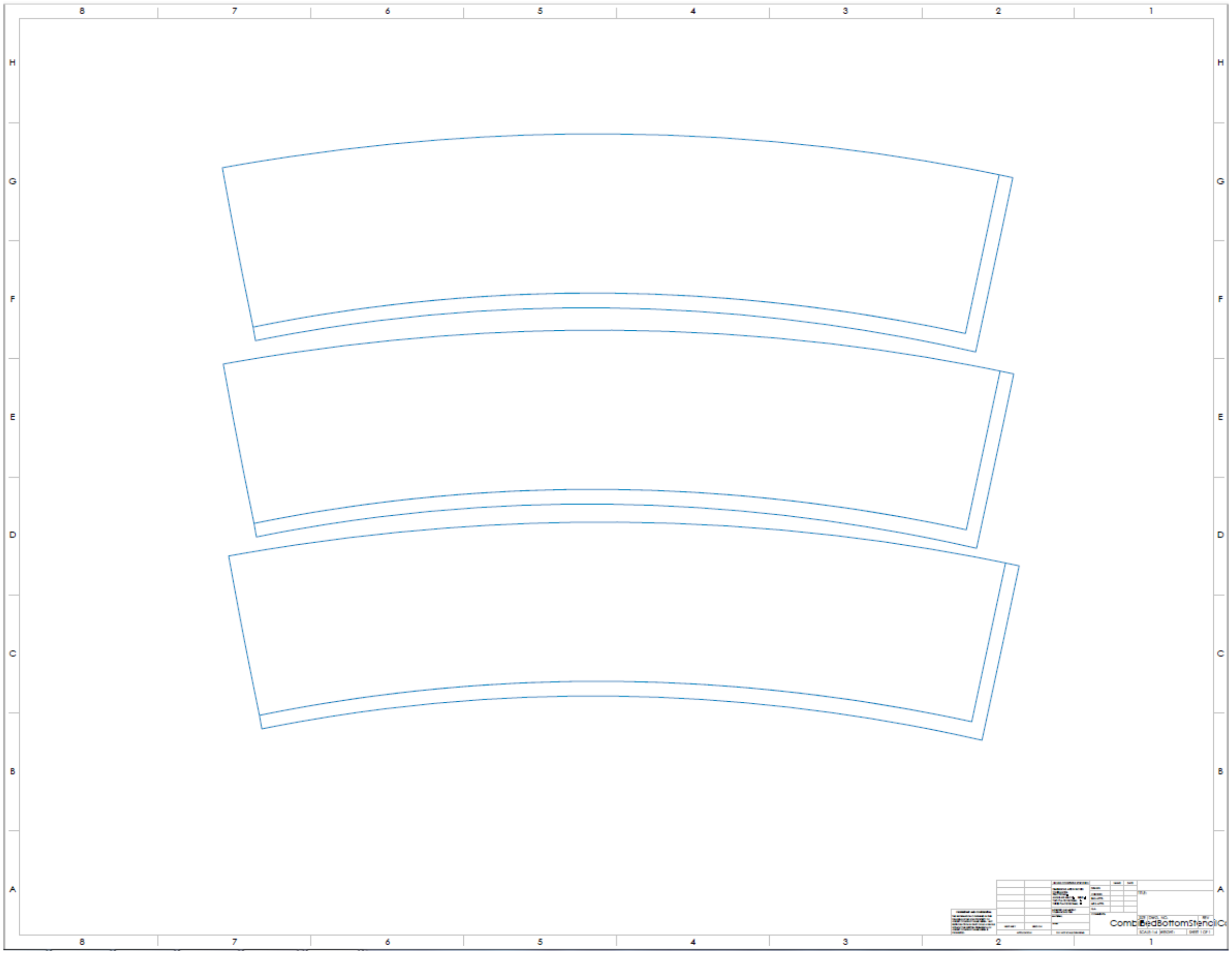

6X ∅.323
5/16" Clearance Hole
12X ∅.386
3/8" Clearance Hole
A
A
R2.520±.005
R5.750±.005
2X14.000
Scale 1:8
R.800
.030
5.384
5.497
∅9.000
SECTION A-A
SOLIDWORKS Student Edition.
For Academic Use Only.
Cal Poly Mechanical Engineering
ME 429 - Qtr Year
Lab Section:03
Dwg. #:0-12-1
Tolerance: ±.030
Title: Carbon Fiber Top Mold
Date: 2/16/2015
Scale: 1:4
Drwn. By: Eli Rogers
Chkd. By: Don Wood


12X ∅.386
A
A
5.750
Scale 1:8
2X14.000
∅9.000
6.652
5.500
R.800
SECTION A-A
SOLIDWORKS Student Edition.
For Academic Use Only.
Cal Poly Mechanical Engineering
ME 429 - Qtr Year
Lab Section:03
Dwg. #:0-12-2
Tolerance: ±.030
Title: Carbon Fiber Bottom Mold
Date: 2/16/2015
Scale: 1:4
Drwn. By: Eli Rogers
Chkd. By: Don Wood



SOLIDWORKS Student Edition.
For Academic Use Only.

Cal Poly Mechanical Engineering	Lab Section:03	Tolerance: ±.005	Title: Top Mold Insert		Drwn. By: Eli Rogers
ME 429 - Qtr Year	Dwg. #:0-11		Date: 2/16/2015	Scale: 1:2	Chkd. By: Don Wood



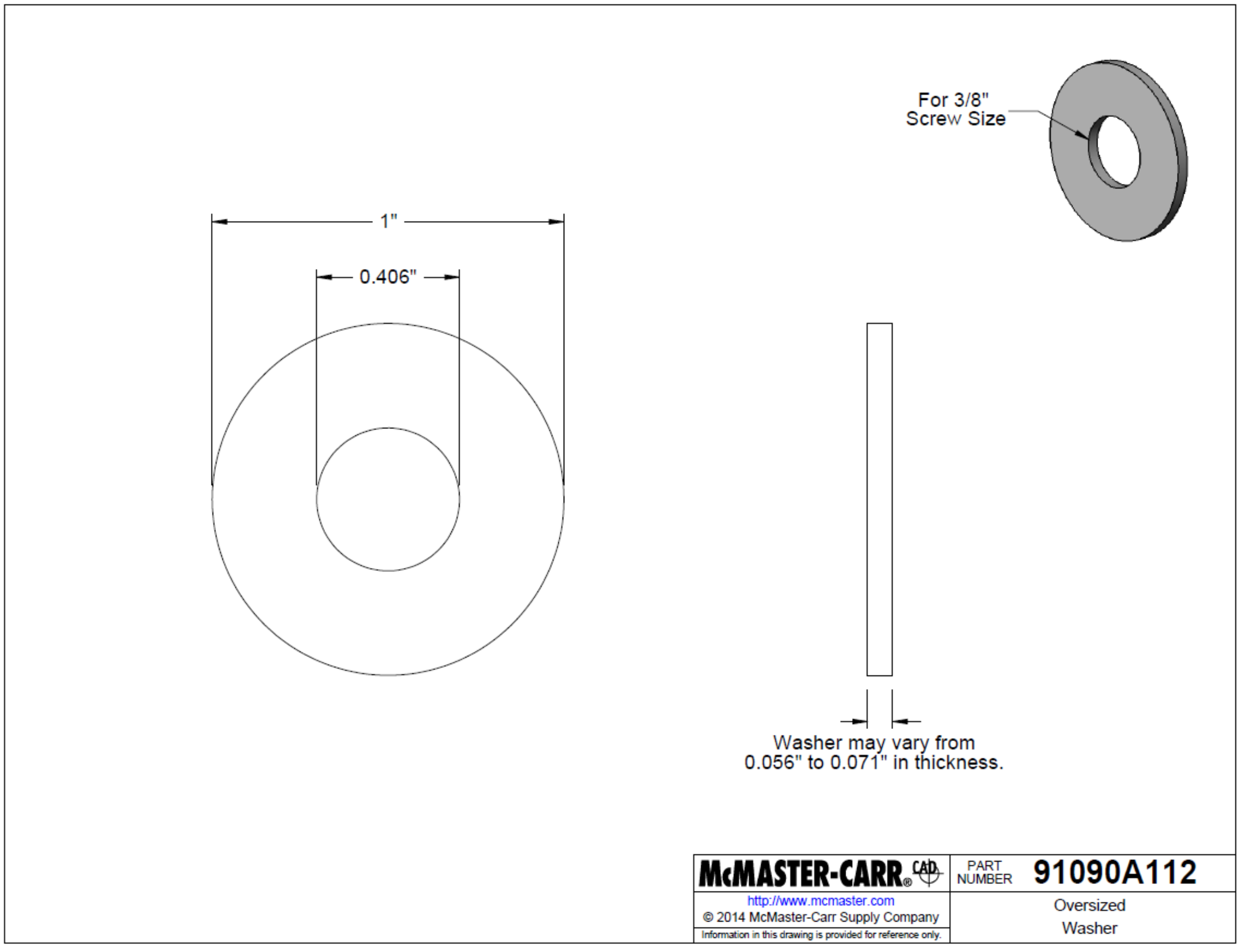
CombiBedBottomStencilC
DWG. NO.
REV
SCALE 1:4
WEIGHT:
SHEET 1 OF 1

APPENDIX C: PRICING INFORMATION

Table 10: List of suppliers and expenses.

Bear Minimum Expenditures			6/2/2016
Date	Supplier	Description	Cost
2/17/2016	ACP Composites Inc.	Carbon Fiber Pre-Preg	$688.29
2/13/2016	Amazon	Plaster of Paris	$43.16
3/6/2016	BuildYourCNC.com	Porter Cable Series 690 / 7500 Kit (Collet)	$139.64
2/13/2016	Fibre Glast	Breather and Bleeder, Polyester Peel Ply, Bagging Film, Yellow Sealant Tape	$93.47
2/13/2016	Grainger	Spring-Cam Latch	$166.54
2/15/2016	McMaster-Carr	Socket Head Cap Screws, Washers, Rivets	$64.08
2/23/2016	McMaster-Carr	Rubber Edge Trim	$15.13
3/3/2016	McMaster-Carr	Delrin	$37.62
2/18/2016	Online Metals	Aluminum Plate	$15.60
3/3/2016	Revchem Composites	Duratec Hi-Gloss Topcoat, Frekote NC-700	$271.69
2/23/2016	Smooth-On	EZ-Brush Silicone - 1 Gallon Unit	$202.09
2/2/2016	The Home Depot	Gorilla Wood Glue, MDF	$56.99
3/27/2016	The Home Depot	Plaster of Paris	$17.26
4/2/2016	The Home Depot	Glue Sticks	$5.37
4/4/2016	The Home Depot	Paint Brushes	$8.08
11/22/2015	Wild Ideas	Bearikade - Weekender Rental	$33.60

APPENDIX D: VENDOR SPECIFICATIONS AND DATA SHEETS



BATTALION

Spring-Cam Latch, Nonlocking, Slotted Head, Natural Finish, 2-5/16" Width

Price
$28.90 / each

Deliver one time only
Auto-Reorder Every 1 Month
1 Add to Cart
+ Add to List

Availability for Qty 1 Go
Shipping Pickup
Expected to arrive **Wed. Feb 17.**
Ship to: **93401** (Change)

How can we improve our **Product Images**?

Compare

Be the first to write a review | Ask & Answer

Item # 4RPY3 Mfr. Model # 4RPY3 UNSPSC # 31162407
Catalog Page # 2402 Shipping Weight 0.07 lbs.

Country of Origin **USA** | *Country of Origin is subject to change.*

Note: Product availability is real-time updated and adjusted continuously. The product will be reserved for you when you complete your order. More

Technical Specs

Item	**Spring-Cam Latch**	Width	**2-5/16"**
Locking Type	**Nonlocking**	Depth	**11/16"**
Latch Type	**Slotted Head**	Grip	**1/16" to 3/8"**
Material	**302/303 Stainless Steel**	Mounting Hole Dia.	**9/16"**
Finish	**Natural**	Hole Prep Center Lines	**1-15/16"**
Height	**11/16"**	Panel Through Hole/Screw Size	**9/64"**

Stretchlon 800 Bagging Film

Part # - 1688 & 1788

Available in 60" wide sheet, or 120" wide centerfolds.
Stretchlon 800 is a high temperature elastic film for any mold. This vacuum bagging film is rated for temperatures up to 400°F and can stretch to 450% of its original length. Stretchlon 800 film is compatible with our polyester, vinyl ester and epoxy resins.

Compared to Stretchlon 200, the 800 is a slightly thicker material and has slightly less elongation properties. One advantage is temperature. Stretchlon 800 is rated for temperatures up to 400°F, while the Stretchlon 200 is only rated for up to 250°F.

Stretchlon® is a registered trademark of Airtech International.

Product Properties		ASTM
Elongation at Break %	450	D882
Tensile Strength psi N/mm²	 10,000 69	D882
Max. recommended use temperature(1)	400° F 204° C	
Melt point by DSC	410° F 210° C	D3418
Chemical materials to avoid:	Strong Oxidizers / Phenol Compounds (2)	
Density g/cm³	1.11	D792
Yield in²/lb/mil m²/kg/25µm	 24,280 34.5	
Color	Orange	
Shelf Life	Indefinite	

NOTES:
(1) Maximum recommended use temperature is dependent upon the duration at maximum temperature and is process specific. Airtech recommends testing prior to use.
(2) Stretchlon 800 is recommended for epoxies and BMI resins. Stretchlon 800 is not recommended for phenolic resins.

Fibre Glast Developments Corporation
385 Carr Drive
Brookville, Ohio 45309
Phone – 800.214.8579
Fax – 937.833.6555
www.fibreglast.com

Yellow Sealant Tape

Part # - 580

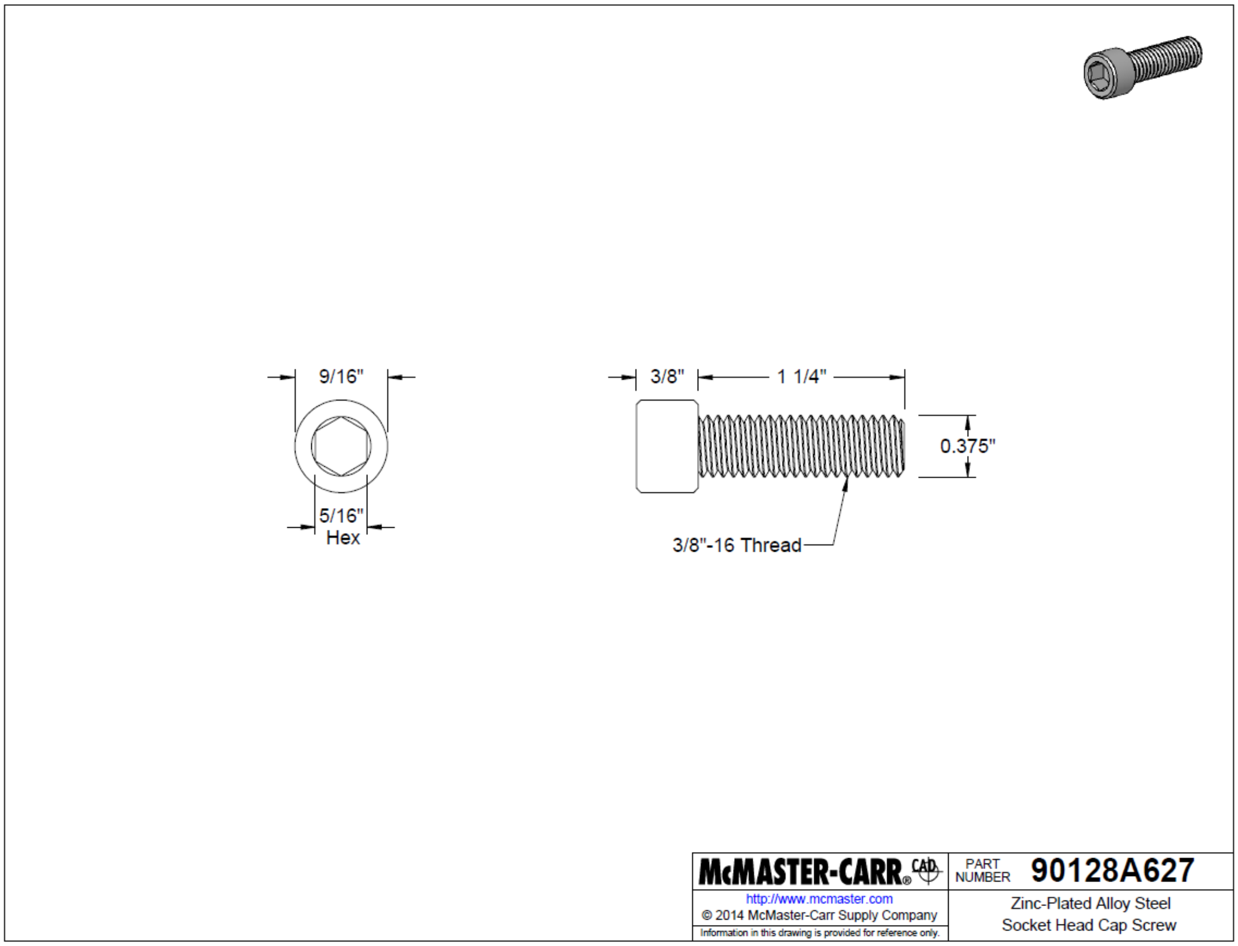
Leak Free and Extra Tacky
This tape will seal the bag to aluminum, steel, fiberglass, nickel, and graphite tool surfaces while supplying more aggressive tackiness than #581. Extra tackiness makes this tape less likely to shift or spring leaks under vacuum but it can be more difficult to reposition if initial placement is not precise. Maximum service temperature is 400 degrees F. 1/2" wide, 1/8" thick, and 25' per roll.

Description
Economical multi-purpose sealant tape with high tack and removes easily from metal or composite tools. 400°F. (204°C.)

Physical Properties	
Color	Yellow
Base material	Synthetic Rubber
Maximum Recommended Use Temperature (1)	400°F. (204°C.)

(1) Maximum recommended use temperature is dependent upon the duration at maximum temperature and is process specific.

Fibre Glast Developments Corporation
385 Carr Drive
Brookville, Ohio 45309
Phone – 800.214.8579
Fax – 937.833.6555
www.fibreglast.com

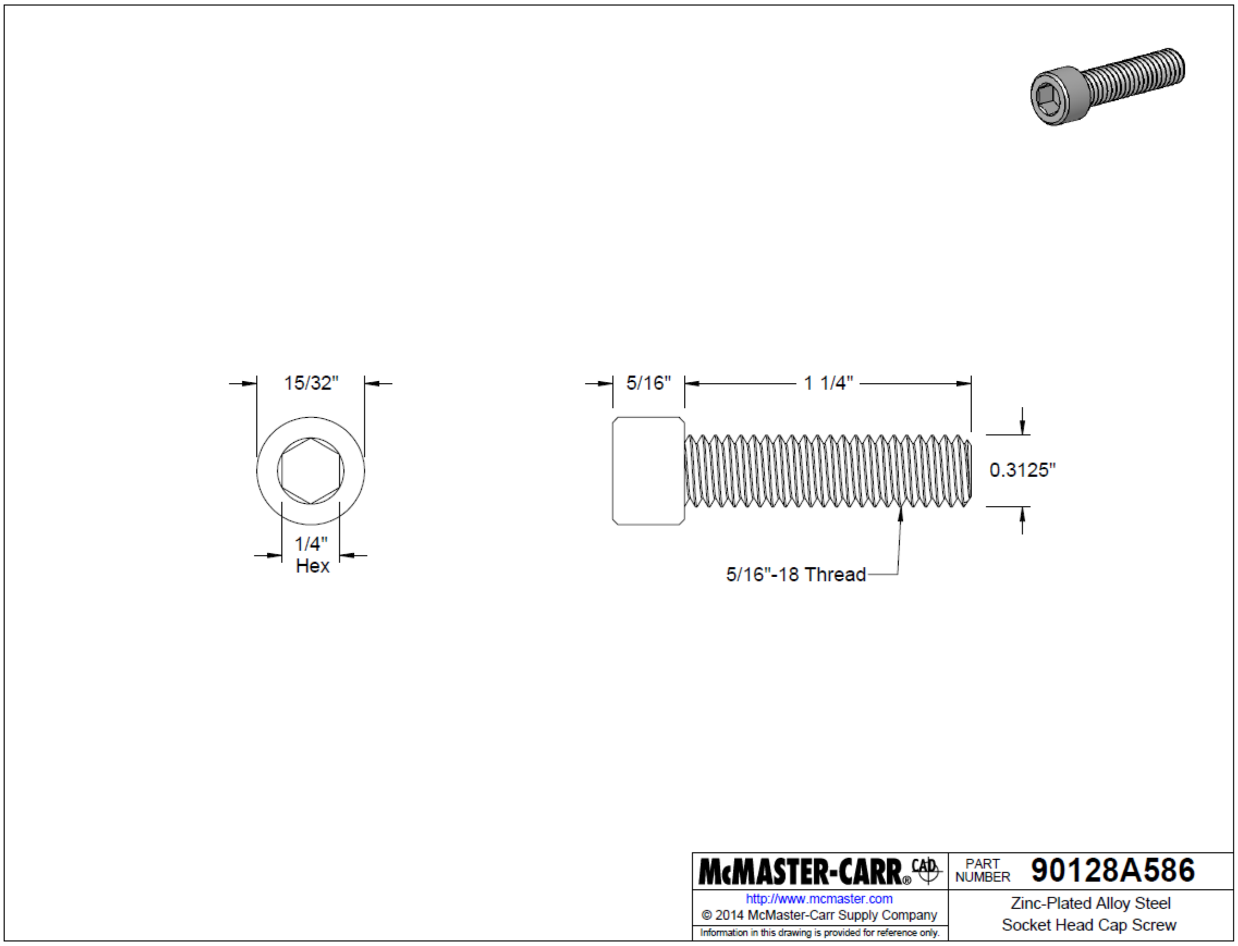

9/16"
5/16"
Hex
3/8"
1 1/4"
0.375"
3/8"-16 Thread
McMASTER-CARR CAD
PART NUMBER
90128A627
http://www.mcmaster.com
© 2014 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.
Zinc-Plated Alloy Steel
Socket Head Cap Screw

Vacuum Connector w/ Locking Ring

Airtech's Vac Valve 402A is a reusable, high temperature vacuum connector that allows a quick and reliable way to connect vacuum hoses to vacuum bags. The four piece design of this high temperature vacuum connector allows for a tighter connection with an increase in autoclave pressure. When assembled, controlled force is applied to the pressure plate and a solid and reliable air-tight seal is formed.

Physical Properties	
Construction	3 piece: base plate, pressure plate, locking ring
Material	Light weight Aluminium
Base Plate Diameter	2.5", round
Gasket Material	Silicone
Screw Thread	1/4" male NPT
Assembly Style	Threaded Locking Ring
Manufacturer	Airtech International
Manufacturer Part Number	Vac Valve 402A

Technical Properties	
Max Temperature	500°F


15/32"
1/4"
Hex
5/16"
1 1/4"
0.3125"
5/16"-18 Thread
McMASTER-CARR CAD
http://www.mcmaster.com
© 2014 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.
PART NUMBER
90128A586
Zinc-Plated Alloy Steel
Socket Head Cap Screw

EZ-Brush® Vac Bag Silicone

Brushable Platinum Silicone Rubber

SMOOTH-ON

www.smooth-on.com

PRODUCT OVERVIEW

EZ-Brush® Vac Bag Silicone is a brushable platinum cure silicone developed especially for making high performance, re-usable vacuum bags. **EZ-Brush® Vac Bag Silicone** is easy to mix and apply. Mix ratio is 1A:1B by volume and rubber can be applied with a brush or spatula to vertical surfaces without sagging.

Pot life is 30 minutes, recoat time is 1 hour. Rubber cures with negligible shrinkage to a soft, flexible rubber (Shore 20A) with very high elongation and tear strength. Newly made bags can be removed from the tool in 3.5 hours and used immediately in production with polyester or epoxy resin systems and will withstand temperatures up to 500° F /260° C.

Compared to conventional vacuum bagging systems, **EZ-Brush® Vac Bag Silicone is much faster** at delivering a production-ready silicone bag resulting in a tremendous time and labor savings. Since bags are re-usable, long term material costs are greatly reduced.

PROCESSING RECOMMENDATIONS

Safety - Use in a properly ventilated area. Wear safety glasses, long sleeves and rubber gloves to minimize contamination risk. Wear vinyl gloves only. Latex gloves will inhibit the cure of the rubber.

Preparation - Materials should be stored and used at room temperature (73° F / 23° C). Warm temperatures will reduce the working time of this material. This product has a limited shelf life and should be used as soon as possible. Work environment and tool surface should also be at room temperature. **Because no two applications are quite the same, a small test application to determine suitability for your project is recommended if performance is in question.**

TECHNICAL OVERVIEW

Mix Ratio: 1A : 1B by volume	
Mixed Viscosity, cps: 20,000	(ASTM D-2393)
Specific Gravity, g/cc: 1.08	(ASTM D-1475)
Specific Volume, cu. in. /lb.: 25.7	(ASTM D-1475)
Pot Life: 30 minutes (73° F / 23°C)	(ASTM D-2471)
Cure time: 3.5 hours (73° F / 23°C)	
Color: Translucent Green	
Shore A Hardness: 20	(ASTM D-2240)
Tensile Strength, psi: 550	(ASTM D-412)
100% Modulus, psi: 46	(ASTM D-412)
Elongation @ Break: 364%	(ASTM D-412)
Die B Tear Strength, pli: 120	(ASTM D-624)
Shrinkage, in./in: < .001	(ASTM D-2566)

All values measured after 7 days at 73°F / 23° C

Cure Inhibition - Platinum silicones are especially susceptible to cure inhibition by a variety of contaminants (such as sulfur and uncured epoxy resin) resulting in tackiness at the pattern interface or a total lack of cure. Latex, tin-cure silicone, sulfur clays, certain wood surfaces, newly cast polyester, epoxy or urethane rubber may cause inhibition. If compatibility between the rubber and the surface is a concern, a small-scale test is recommended. Apply a small amount of rubber onto a non-critical area of the pattern. Inhibition has occurred if the rubber is gummy or uncured after the recommended cure time has passed.

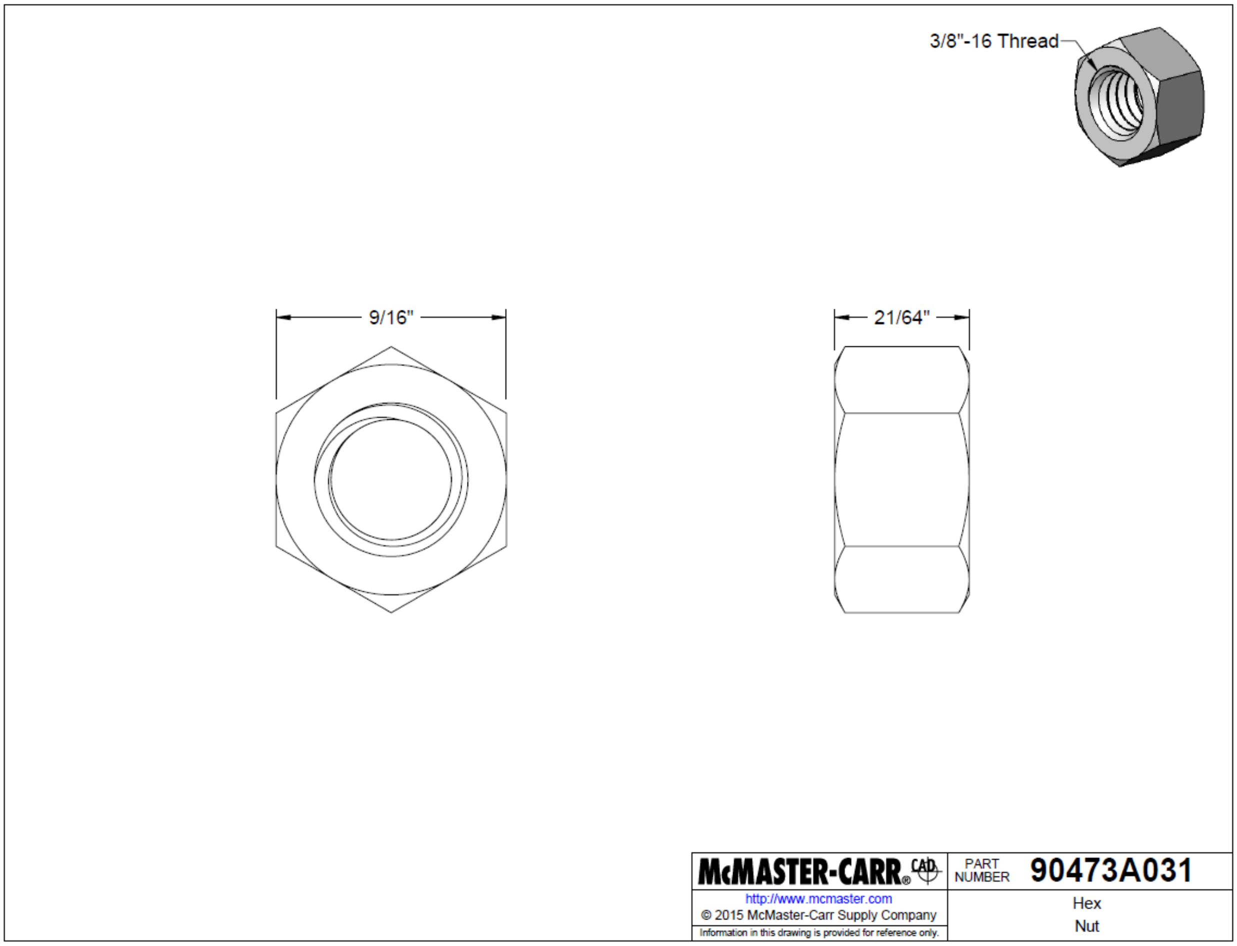
To prevent inhibition, a "barrier coat" of clear acrylic lacquer sprayed directly onto the pattern is usually effective. Allow to thoroughly dry.

Note: Even with a sealer, platinum silicones will not work with modeling clays containing heavy amounts of sulfur. Do a small scale test for compatibility before using on your project.

If there is any question about the effectiveness of a sealer/release agent combination, a small-scale test should be made on an identical surface for trial.

MEASURING & MIXING...

Before you begin, pre-mix Part B thoroughly. After dispensing required amounts of Parts A and B into mixing container (1A:1B by volume or weight), **mix thoroughly by hand or turbine mixer (available at your local Smooth-On distributor). Material should be mixed for 2-3 minutes making sure that you scrape the sides and bottom of the mixing container several times.** After mixing parts A and B, vacuum degassing is recommended to eliminate any entrapped air. Vacuum material for 2-3 minutes (29 inches of mercury), making sure that you leave enough room in container for product volume expansion.


3/8"-16 Thread
9/16"
21/64"
McMASTER-CARR® CAD
PART NUMBER 90473A031
http://www.mcmaster.com
© 2015 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.
Hex
Nut

LOCTITE

Technical Data Sheet

LOCTITE® FREKOTE 700-NC™

Known as 700-NC™
January 2015

PRODUCT DESCRIPTION

LOCTITE® FREKOTE 700-NC™ provides the following product characteristics:

Technology	Mold Release
Appearance	Clear, colorless[LMS]
Chemical Type	Solvent Based Polymer
Odor	Solvent
Cure	Room temperature cure
Cured Thermal Stability	≤400 °C
Application	Release Coatings
Application Temperature	13 to 135 °C
Specific Benefit	• No chlorinated solvents • High gloss finish • High slip • No contaminating transfer • No mold build-up

LOCTITE® FREKOTE 700-NC™ offers excellent release properties for the most demanding applications and is a great all-purpose release agent. LOCTITE® FREKOTE 700-NC™ releases epoxies, polyester resins, thermoplastics, rubber compounds and most other molded polymers.

TYPICAL PROPERTIES OF UNCURED MATERIAL

Specific Gravity @ 25 °C 0.755 to 0.764[LMS]

Flash Point - See SDS

GENERAL INFORMATION

This product is not recommended for use in pure oxygen and/or oxygen rich systems and should not be selected as a sealant for chlorine or other strong oxidizing materials.

For safe handling information on this product, consult the Safety Data Sheet (SDS).

Mold Preparation

Cleaning:

Mold surfaces must be thoroughly cleaned and dried. All traces of prior release must be removed. This may be accomplished by using Frekote® PMC or other suitable cleaner. Frekote® 915WB™ or light abrasives can be used for heavy build-up.

Sealing New/Repaired Molds:

Occasionally, green or freshly repaired molds are rushed into service prior to complete cure causing an increased amount of free styrene on the mold surface. Fresh or "production line" repairs, new fiberglass and epoxy molds should be cured per manufacturer's instructions, usually a minimum of 2 -3 weeks at 22°C before starting full-scale production. Fully cured previously unused molds should be sealed before use. This can be accomplished by applying one to two coats of an appropriate Frekote® mold sealer, following the directions for use instructions. Allow full cure of the appropriate Frekote® mold sealer before you apply the first coat of LOCTITE® FREKOTE 700-NC™ as outlined in the directions of use.

Directions for use:

1. LOCTITE® FREKOTE 700-NC™ can be applied to mold surfaces at room temperature up to 135°C by spraying, brushing or wiping with a clean lint-free, cloth. When spraying ensure a dry air source is used or use an airless spray system. Always use in a well ventilated area.
2. Wipe or spray on a smooth, thin, continuous, wet film. Avoid wiping or spraying over the same area that was just coated until the solvent has evaporated. If spraying, hold nozzle 20 to 30cm from mold surface. It is suggested that small areas be coated, working progressively from one side of the mold to the other.
3. Initially, apply 2 to 3 base coats allowing 5 to 10 minutes between coats for solvent evaporation .
4. Allow the final coat to cure for 15 to 20 minutes at 22°C.
5. Maximum releases will be obtained as the mold surface becomes conditioned to LOCTITE® FREKOTE 700-NC™ . Performance can be enhanced by re-coating once, after the first few initial pulls.
6. When any release difficulty is experienced, the area in question can be "touched-up" by re-coating the entire mold surface or just those areas where release difficulty is occurring.
7. **NOTE**: LOCTITE® FREKOTE 700-NC™ is moisture sensitive, keep container tightly closed when not in use. The product should always be used in a well ventilated area.
8. **Precaution:** Users of closed mold systems (rotomolding) must be certain that solvent evaporation is complete and that all solvent vapors have been ventilated from the mold cavity prior to closing the mold. An oil-free compressed air source can be used to assist in evaporation of solvents and ventilation of the mold cavity.

Henkel

Polyester Peel Ply

Part # - 583

Ideal for secondary bonding

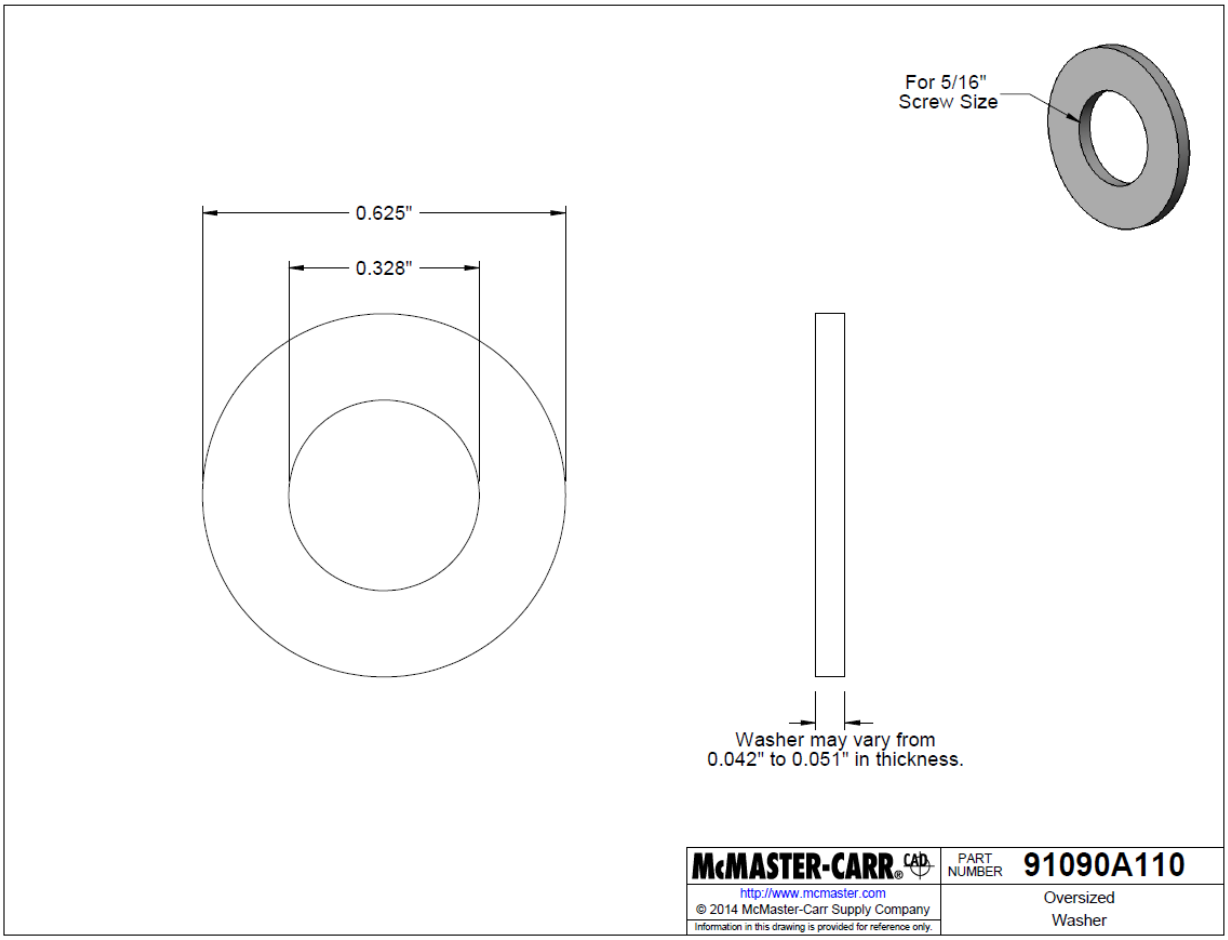
Our Polyester Peel Ply is scoured and heat set. It leaves a uniformly textured surface when removed from your laminate, ideal for secondary bonding operations. It is compatible with all composite manufacturing processes at temperatures up to 480 degrees F. Polyester Peel Ply works with all of Fibre Glast's composite materials and resins. This peel ply is also compatible with phenolic systems. Available in 60" wide rolls/packages.

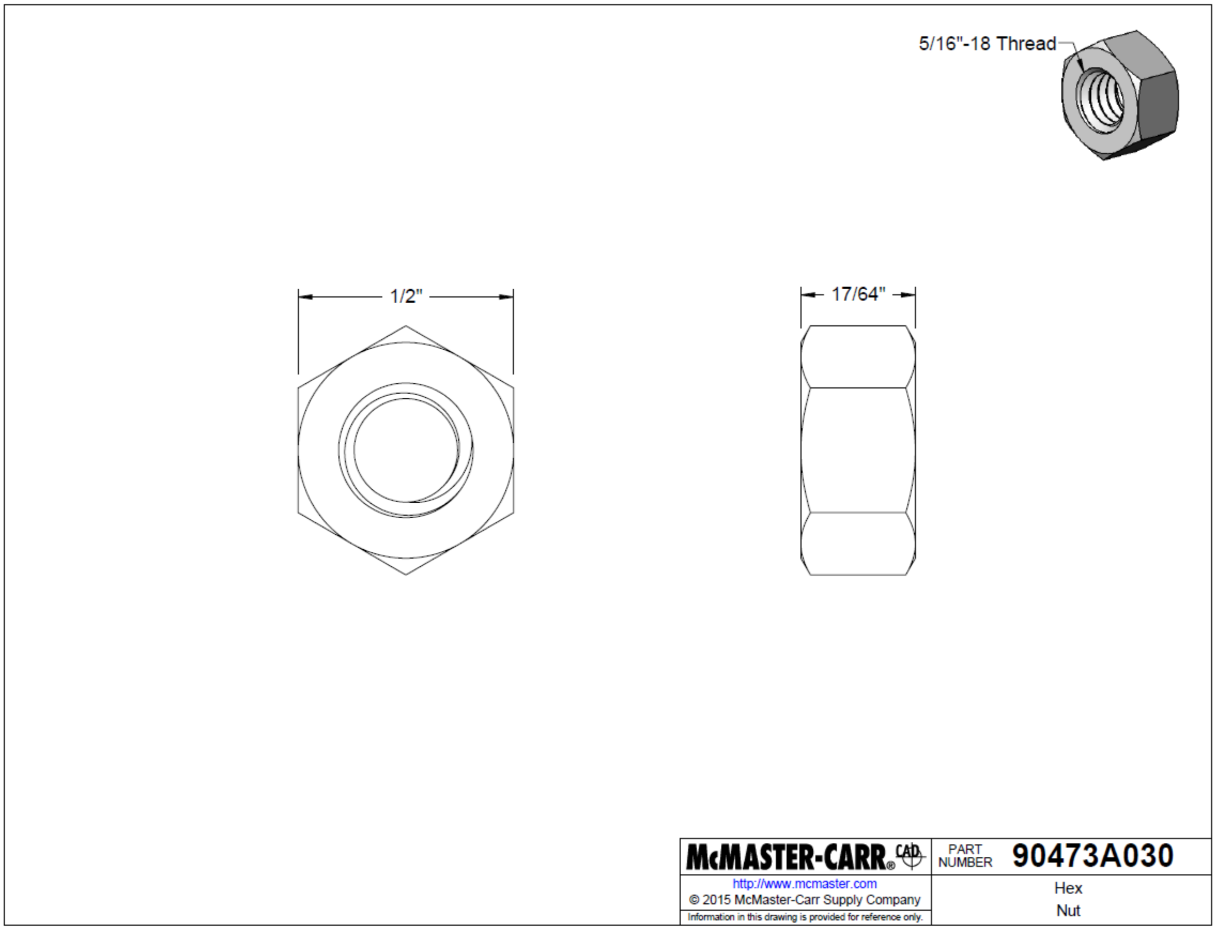
Application

#583 is designed for vacuum bag lay-up composites and metal-to-metal bonding structures. #583, 100% polyester fiber melts at approximately 480°F (249°C) and is resistant to phenolic resin system degradation. The fabric leaves a fine surface impression for priming and secondary bonding.

Physical Property	Value	Metric Equivalent	Test Method
Roll Width	60 in (min.)	157 cm	ASTM-D-3774
Weight	2.5 oz/yd^2 (min.)	87 g/m^2	ASTM-D-3776
Finished count Warp Fill	 120 end/in (min.) 60 picks/in (min.)	 47 ends/cm 24 picks/cm	ASTM-D-3775
Tensile Strength (Grab) Warp Fill	 130 lbs. (min.) 160 lbs. (min.)	 578 Newtons 712 Newtons	ASTM-D-5034-95
Thickness	0.005 in ± .005 in	0.127 mm	ASTM-D-1777
pH	4.5-7.0		FTM-2811
Extractable Materials (Petroleum Ether Method)	0.5% (max.)		ASTM-D-2257

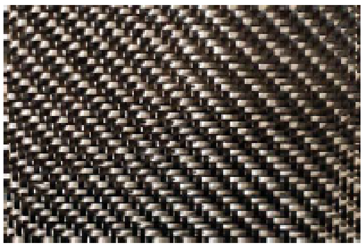
Fibre Glast Developments Corporation
385 Carr Drive
Brookville, Ohio 45309
Phone – 800.214.8579
Fax – 937.833.6555
www.fibreglast.com


For 5/16"
Screw Size
0.625"
0.328"
Washer may vary from
0.042" to 0.051" in thickness.
McMASTER-CARR CAD
PART NUMBER
91090A110
http://www.mcmaster.com
© 2014 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.
Oversized
Washer


5/16"-18 Thread
1/2"
17/64"
McMASTER-CARR CAD
PART NUMBER 90473A030
http://www.mcmaster.com
© 2015 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.
Hex
Nut

1-800-811-2009
www.acpsales.com

Carbon Fiber Room Temperature Storage Prepreg



Our Carbon Fiber Room Temperature Prepreg is a 5.9oz 2x2 twill weave fabric woven from 3K carbon fibers and impregnated with a thermosetting epoxy resin system. It is storable at room temperatures and does not require freezer storage. With the long out life of the resin matrix, the carbon fiber prepreg can be shipped and handled at room temperatures. It is ideal for use when a long shelf life is desired, high-temperature capabilities are not required and controlled resin content is wanted.

Physical Fabric Properties

Weight	5.9 oz/yd^2
Thickness	.012"
Construction (W x F)	13x13 2x2 Twill Weave
Fiber Type	3K Carbon Fiber Standard Modulus PAN, 33MSI
Resin Matrix	Thermosetting Epoxy
Resin Content	36%

Technical Resin Properties

Density	1.229 g/cc
Tg (fromG" DMA curve)	270°F
Tensile Strength	10.7 ksi
Tensile Modulus	440 ksi
Elongation @ Break	4.0%
Tg after 24hr Water Boil	169°F
Water Absorption	3.9%

Cure Cycles

There are three optional cure cycles. All three will produce similar properties.

1.
   - 5°F-per-minute ramp up to 310°F (154°C)
   - Hold for 1 hour
   - <5°F-per-minute ramp down to at least 150°F (66°C) before removing from oven

2.
   - 5°F-per-minute ramp up to 290°F (154°C)
   - Hold for 2 hours
   - <5°F-per-minute ramp down to at least 150°F (66°C) before removing from oven

3.
   - 5°F-per-minute ramp up to 270°F (154°C)
   - Hold for 4 hours
   - <5°F-per-minute ramp down to at least 150°F (66°C) before removing from oven

Shelf Life/Storage

The material should remain sealed when not is use and be stored indoors, out of the weather.

- The shelf life is 6 months from the date of manufacture when the maximum storage temperature shall not exceed 90°F (32°C).
- The shelf life is 12 months from the date of manufacture when the maximum storage temperature shall not exceed 75°F (24°C).
- The shelf life is 30 months from the date of manufacture when the maximum storage temperature shall not exceed 0°F (-18°C), with an additional 6 months at <75 °F (24°C).

78 Lindbergh Ave I Livermore, CA 94551
1-800-811-2009 I P. 925-443-5900 I F. 925-443-5901

Breather and Bleeder

Part # - 579 & 1779

Easy to Drape and Binder Free
This high fill non-woven polyester will easily drape and conform closely to the contours of your part. It does not contain any binders which could close off air flow within the mold, and it will readily soak up excess resin.

As a breather, these products are used in the vacuum bagging process to evacuate all of the air in the bag while applying vacuum. A breather allows for even pressure to be applied over the entire surface of the laminate. The breather also allows for any gases produced during the cure to be evacuated from the laminate to your vacuum source. Compared to #579 four ounce, the #1779 seven ounce breather can be used in higher pressure cure cycles and helps to provide a lower amount of surface porosity.

If used as a bleeder, these products absorb excess resin that was applied during the layup process. After the vacuum bagging process is complete, the breather bleeder is simply thrown away. Compared to #579, the #1779 seven ounce breather bleeder will absorb more resin from the laminate which can result in a dry part unless carefully controlled.

If you are working under 40 psi, the #579 is the most commonly selected breather bleeder. If working between 40psi and 85psi, the seven ounce breather is ideal. Both breather bleeders are 60" wide.

Physical Properties	579	1779
Color	White	White
Nominal Weight oz./yd.2 (g/m2)	4.0 (135)	7.0 (237)
Maximum Recommended Use Temperature (1) °F. (°C)	400 (204)	400 (205)
Fire Retardant	N/A	N/A

NOTES:
(1) Maximum recommended use temperature is dependent upon the duration at maximum temperature and is process specific.

Fibre Glast Developments Corporation
385 Carr Drive
Brookville, Ohio 45309
Phone – 800.214.8579
Fax – 937.833.6555
www.fibreglast.com

A Quality Product from Hawkeye Industries Inc.

Duratec® Vinyl Ester Hi-Gloss Topcoat

An easily applied topcoat for tooling and in-mold applications.

Usage
To topcoat patterns, plugs and molds and to topcoat post-painted parts.

Features
You'll get an easily applied, tough durable topcoat, with minimal porosity with Duratec Vinyl Ester Hi-GlossTopcoat.

Here's why you should choose Duratec Vinyl Ester Hi-Gloss Topcoat—

High HDT—heat distortion temperature of 300˚F, 150˚C.

Easy to apply—sprays quickly.

Resists fisheyes—unique additives reduce the risk of fisheyes and pinholes during the spray application.

Smooth finish—minimum orange peel.

Hard finish—you'll get a hard, chemical-resistant finish.

High gloss—sands easily and polishes to a non-wax, tack-free high gloss finish.

Duratec Vinyl Ester Hi-Gloss Topcoat

1904-045 Clear

1902-045 Black

(Link to MSDS)

Hawkeye Industries Inc.
P O Box 415 Bloomington, CA 92316
Tel 909-546-1160; Toll Free 800-977-0060; Fax: 909-546-1161
Email productinfo@duratec1.com Web www. duratec1.com

APPENDIX E: ANALYSIS DETAILS

The bolt calculations were an iterative process involving a selection of the type of bolt to be used by size. Once the size was selected, calculations were performed to select how many bolts would be needed for the given conditions. For example, regular hex head bolts were selected from McMaster Carr to test in the calculations. The bolt's threaded lengths as well as their nominal diameter were used to find the tensile stress area. This area was then used to find the bolt stiffness. Properties were gathered from the screw size table shown in Table 11. The following tables and equations can be found in Shigley's Mechanical Engineering Design 10th Edition.

Table 11: Diameters and Area of Unified Screw Threads. *Source: Mechanical Engineering Design, 10th Edition*

Size Designation	Nominal Major Diameter in	Coarse Series—UNC			Fine Series—UNF		
		Threads per Inch N	Tensile-Stress Area A_t in^2	Minor-Diameter Area A_r in^2	Threads per Inch N	Tensile-Stress Area A_t in^2	Minor-Diameter Area A_r in^2
0	0.0600				80	0.001 80	0.001 51
1	0.0730	64	0.002 63	0.002 18	72	0.002 78	0.002 37
2	0.0860	56	0.003 70	0.003 10	64	0.003 94	0.003 39
3	0.0990	48	0.004 87	0.004 06	56	0.005 23	0.004 51
4	0.1120	40	0.006 04	0.004 96	48	0.006 61	0.005 66
5	0.1250	40	0.007 96	0.006 72	44	0.008 80	0.007 16
6	0.1380	32	0.009 09	0.007 45	40	0.010 15	0.008 74
8	0.1640	32	0.014 0	0.011 96	36	0.014 74	0.012 85
10	0.1900	24	0.017 5	0.014 50	32	0.020 0	0.017 5
12	0.2160	24	0.024 2	0.020 6	28	0.025 8	0.022 6
$\frac{1}{4}$	0.2500	20	0.031 8	0.026 9	28	0.036 4	0.032 6
$\frac{5}{16}$	0.3125	18	0.052 4	0.045 4	24	0.058 0	0.052 4
$\frac{3}{8}$	0.3750	16	0.077 5	0.067 8	24	0.087 8	0.080 9
$\frac{7}{16}$	0.4375	14	0.106 3	0.093 3	20	0.118 7	0.109 0
$\frac{1}{2}$	0.5000	13	0.141 9	0.125 7	20	0.159 9	0.148 6
$\frac{9}{16}$	0.5625	12	0.182	0.162	18	0.203	0.189
$\frac{5}{8}$	0.6250	11	0.226	0.202	18	0.256	0.240
$\frac{3}{4}$	0.7500	10	0.334	0.302	16	0.373	0.351
$\frac{7}{8}$	0.8750	9	0.462	0.419	14	0.509	0.480

The following equation was used in order to find the bolt stiffness:

$$k_b = \frac{A_d A_t E}{A_d l_t + A_t l_d} \qquad (1)$$

where A_d is the nominal diameter area, A_t is the tensile stress area, E is the Modulus of Elasticity of Steel, l_t is the threaded length and l_d is the bolt length excluding the grip length. Once the bolt stiffness was found, an analysis was performed on the material stiffness. Shown below is the equation used to find the material stiffness of the bolted region between the two carbon fiber plates of the middle section:

$$k_m = \frac{0.5774\pi E d}{2\ln\left(5\frac{0.5774l+0.5d}{0.5774l+2.5d}\right)} \qquad (2)$$

Here, k_m is the material stiffness, E is the modulus of elasticity of carbon fiber, d is the nominal major diameter of the bolt, and l is the grip length. Also by using the previously calculated bolt stiffness and material stiffness we were able to find the stiffness constant C below using the stiffness constant equation:

$$C = \frac{k_b}{k_b + k_m} \qquad (3)$$

There were a few more steps in the calculation before using the final bolt equation to find the number of bolts needed. First, the preload needed to be calculated by using the equation:

$$F_i = 0.75 A_t S_p \qquad (4)$$

F_i is the preload on the bolt where A_t is the tensile strength area and S_p is the minimum proof strength. The minimum proof strength is dependent on the grade of the bolt to be used. The bolts we selected for the middle section from McMaster Carr are grade 8; therefore a minimum proof strength was selected from Table 12.

Table 12: ASTM specifications and properties for steel bolts

ASTM Desig-nation No.	Size Range, Inclusive, in	Minimum Proof Strength,* kpsi	Minimum Tensile Strength,* kpsi	Minimum Yield Strength,* kpsi	Material	Head Marking
A307	$\frac{1}{4}$–$1\frac{1}{2}$	33	60	36	Low carbon	
A325, type 1	$\frac{1}{2}$–1	85	120	92	Medium carbon, Q&T	
	$1\frac{1}{8}$–$1\frac{1}{2}$	74	105	81		
A325, type 2	$\frac{1}{2}$–1	85	120	92	Low-carbon, martensite, Q&T	
	$1\frac{1}{8}$–$1\frac{1}{2}$	74	105	81		
A325, type 3	$\frac{1}{2}$–1	85	120	92	Weathering steel, Q&T	
	$1\frac{1}{8}$–$1\frac{1}{2}$	74	105	81		
A354, grade BC	$\frac{1}{4}$–$2\frac{1}{2}$	105	125	109	Alloy steel, Q&T	
	$2\frac{3}{4}$–4	95	115	99		
A354, grade BD	$\frac{1}{4}$–4	120	150	130	Alloy steel, Q&T	

Finally using all the previously calculated values we can use Shigley's equation below to find the number of bolts needed for the given conditions:

$$N = \frac{C n_L P_{total}}{S_p A_t - F_i} \qquad (5)$$

N is the total number of bolts to be used for the given application where C is the stiffness constant, n_L is the factor of safety which in our case is 2, P_{total} is the total force exerted on the bolts, S_p is the minimum proof strength, A_t is the tensile stress area, and F_i is the proof-load on the bolt. Because these calculations are such an iterative and tedious process, an excel program was created in which various input could be changed and N, the number of bolts could be calculated. This greatly reduced the amount of time spent on calculations for the bolts in the middle section. Note that these bolt calculations were only for the middle section, the top section on the other hand has to be analyzed separately due to thermal stresses. These thermal stresses will be discussed later on.

The bolt calculations for the top section were done in a similar manner to those done in the middle section. An image of the top section can be seen in Figure 13. An aluminum plate will be bolted to the top of the carbon fiber mold. This is to accommodate the pressure given off by the vacuum bag inserted inside of the canister. The hole at the top of the aluminum plate is where the pressure hose will be inserted to pressurize the vacuum bag. As mentioned earlier, the calculations for the top section bolts followed the same procedure and used the same equations as the middle section from Shigley's Design book. The only difference between the middle section and the top section is that the top section's total force exerted value will incorporate thermal stresses. These thermal stresses will be discussed later on. Therefore, after performing the bolt iteration process outlined in the middle selection analysis, a selection of 6 bolts were to be used at a size of 5/16 inch.

Initially the top section was to have blind bolts. This was because after the aluminum plate is bolted to the top of the carbon fiber mold, it is not possible to fasten the other side of the bolt from inside the canister. Blind bolts would allow us to fasten the bolt from one end and still be able to fasten both the aluminum and carbon fiber materials together. When calculating the cost of the blind bolts, it was discovered that the cost of one of these bolts was $13.30. This was quite expensive especially when compared to the much cheaper cost of the regular middle section bolts. Therefore by using 6 of these bolts, the total comes to $79.80. After discussing the pricing of these bolts, the group decided to construct "homemade" blind bolts. This will be done by using regular bolts and slotting the ends of them with a table grinder. This will require more labor; however, the amount of time spent slotting 6 bolts is estimated to take 30 minutes at the most. This is well worth the time because we will be saving at least $70.

When analyzing the middle section involving the flange consisting of the two carbon fiber plates bolted together, we were able to neglect forces from thermal stresses and have them accounted for in the factor of safety of 2. This is due to the fact that the coefficient of thermal expansion for carbon fiber is very low, about 4×10^{-7} (per °F). Shown in Figure 61 is a bar graph of relevant coefficients of thermal expansion.

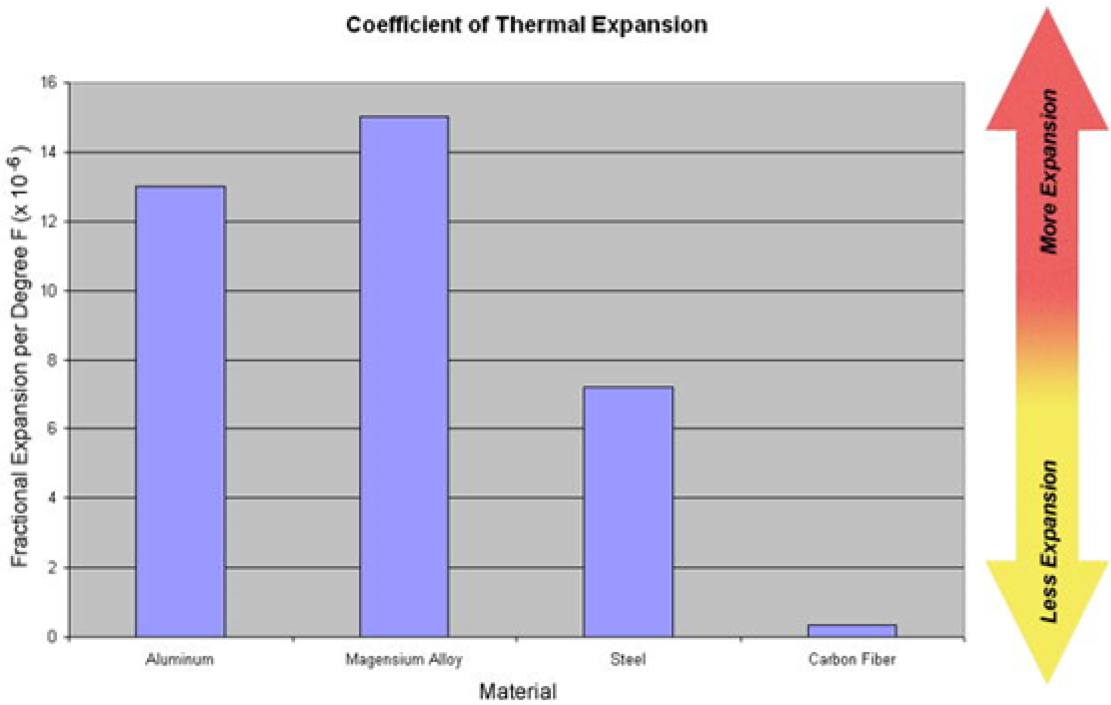


Figure 61: Graph showing the fractional coefficient of thermal expansion for various metals and carbon fiber.

As can be seen the coefficient of thermal expansion for aluminum is significantly higher than carbon-fiber. Because the top section contains an aluminum plate, thermal stresses and forces from thermal expansion must be taken into account when doing the bolt calculations.

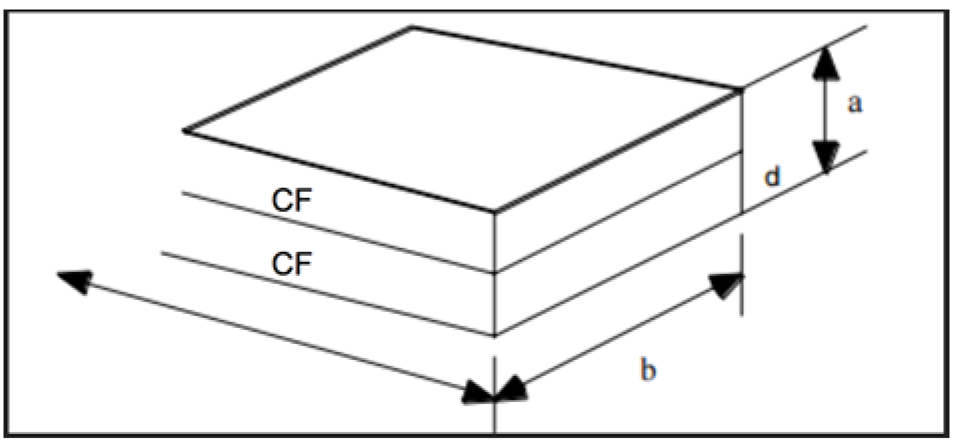


Figure 62: Schematic of Carbon-Fiber Molds Bolted Together

Figure 62 shows the middle sections model schematic. The two carbon-fiber plates will not expand greatly due to the low coefficient of thermal expansion when placed in the oven. This is why we were able to neglect thermal stresses and forces from thermal expansion on the bolts. For reassurance, minimal forces were assumed to be taken into account from the factor of safety of 2. It should also be noted that the mold was originally designed for a pressure of 100 psi. After further research on the accurate pressure to be use, we found that we only needed a pressure of 50 psi. Therefore, essentially the factor of safety is now at 4 rather than 2. In Figure 63 is a model schematic of the top section consisting of the aluminum and carbon-fiber material bolted together.

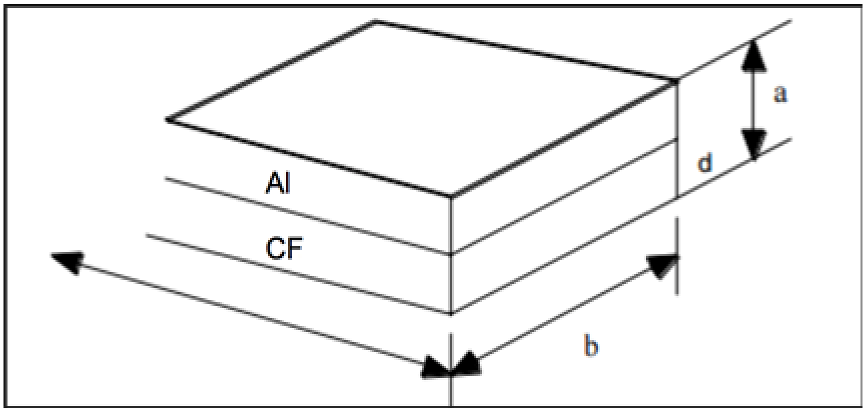


Figure 63: Schematic of Aluminum and Carbon-Fiber Materials Bolted Together

When aluminum is heated to high temperatures it contracts. Therefore, according to the coefficient of thermal expansion for aluminum, it will contract more than the carbon-fiber. This difference in expansion and contraction causes bending stresses and shear forces at the plates. These bending stresses and shear forces have to be accounted for in the bolt calculations for the top section. Although the additional thermal forces did not yield a particularly high value, it did require an additional bolt to be used had there not been an analysis for thermal stresses. This model is shown below in the Figure 61.

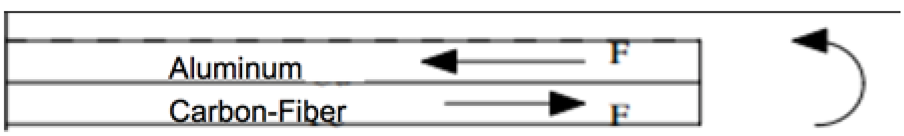


Figure 64: Bending Stresses and Shear Forces in the Top Mold.

<u>Abaqus Model</u>

To create the Abaqus model, the main canister housing was imported into Abaqus from the pre-existing Solidworks model using a .sat file Within Abaqus, the canister was set up as a 3-D deformable shell part. To reduce the run-time, the can was simplified by creating a vertical partition down the center and eliminating one half of the container. Due to the symmetry of the model and applied loading, this is a beneficial operation that will greatly increase the efficiency of running the program. In order to apply differing composite layups to specific sections of the canister, the part was partitioned even further. These partitions segmented the middle and top sections from the rest of the canister so that the additional layers could be implemented at those sections.

Appropriate material properties were created to represent the carbon fiber fabric that would be used on the the actual product. See Table 13 for a summary of the corresponding material properties that were input into Abaqus. The next step in setting up the model was to create and apply the carbon fiber layup schedule. All sections were set up so that the fiber orientation was with reference to the layup orientation. The thickness of each layer was set to 0.012" and the previously created carbon fiber material was assigned to each section. The default value of three was used for the number of integration points. For the general areas of the canister, four individual layers were created with these properties. For the middle and top sections, an additional layer with the same properties was added on to represent the added unidirectional carbon fiber added to reduce stress.

Table 13: List of the property materials input into the carbon composite dialogue box.

E_1 [MSI]	E_2 [MSI]	E_3 [MSI]
10.15	10.15	0.10
G_{12} [ksi]	G_{13} [ksi]	G_{23} [ksi]
725	725	725

In addition to the canister, two surfaces were created which would represent the ground and impactor surfaces. Both of these surfaces were created as 3D analytical rigid parts. Since these surfaces are not really of interest, it was deemed appropriate to use such a part as it does not require for these surfaces to be meshed. This will pay off in reduced run-times.

These three parts were instated in an assembly and oriented in the position as shown in Figure, with the impactor surface acting of the side face of the container and each surface in contact with the canister. Appropriate interactions were applied such as defining contact between all surfaces with the interaction properties set as hard contact along the normal direction and rough contact along the tangential direction. Rigid body constraints were added to the impactor and ground surfaces. Boundary conditions were then added. These included fixing the ground surface in place with an encastre condition as well as restricting the rotation degrees of freedom for the impactor plate. A symmetrical boundary condition about the x axis on the canister edges were it was split to account for the missing half of the container. An initial condition of V3 equal to -96.26 was added to simulate the impact of 100 pounds dropped from a one foot distance.

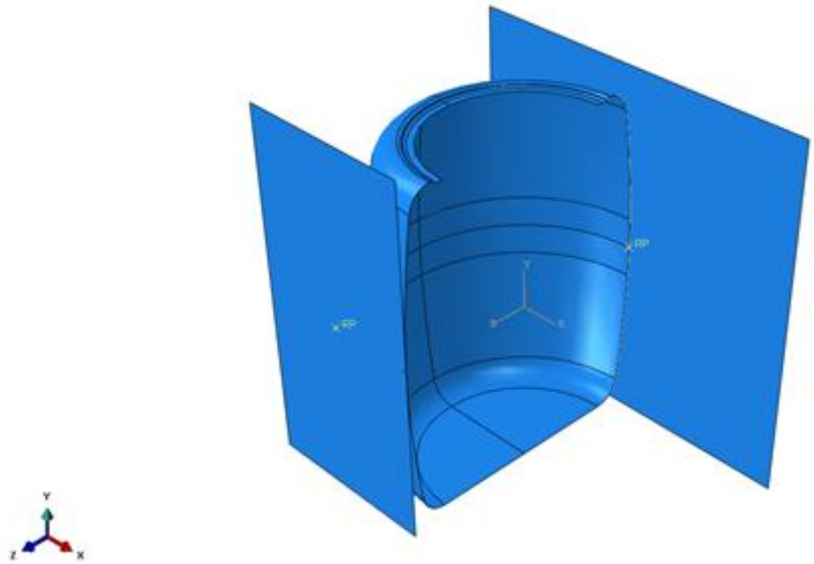


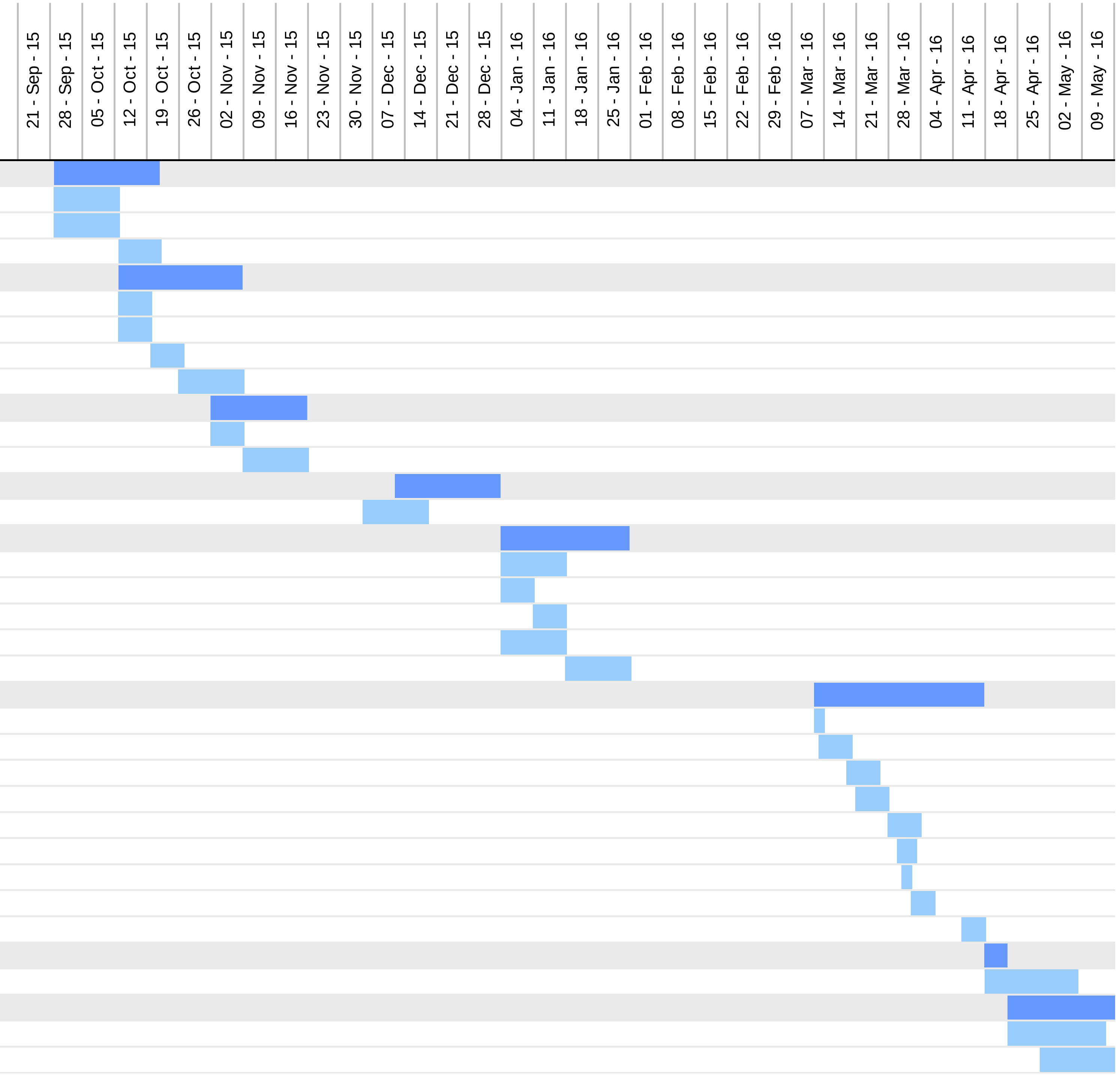
Figure 65: Abaqus model of the split canister as well as analytical rigid surfaces which serve as the ground and impactor surfaces.

The next step in the process was to mesh the canister. A convergence study was conducted and an appropriate seed size of 0.25” with a corresponding 32340 degrees of freedom. The can was meshed using standard shell elements. Afterwards, a new explicit dynamic step was created using a 0.025 second time increment. A corresponding job was created and then run to complete the process.

For the layup schedules involving extra material at the middle and top sections, appropriate partitions were created so that they could be assigned a composite layup in Abaqus separate from the rest of the canister.

APPENDIX F: GANTT CHART

WBS	Tasks	Task Lead	Start	End	Duration (Days)	% Complete	Working Days	Days Complete	Days Remaining
1	**Task Definition**		9/29/15	10/21/15	23	100%	17	23	0
1.1	Background Research		9/29/15	10/12/15	14	100%	10	14	0
1.2	Requirements List		9/29/15	10/12/15	14	100%	10	14	0
1.3	Project Proposal		10/13/15	10/21/15	9	100%	7	9	0
2	**Conceptual Design**		10/13/15	11/8/15	27	100%	19	27	0
2.1	Abstraction		10/13/15	10/19/15	7	100%	5	7	0
2.2	Definition of Function and Subfunctions		10/13/15	10/19/15	7	100%	5	7	0
2.3	Morphological Matrix		10/20/15	10/26/15	7	100%	5	7	0
2.4	Evaluation of Concepts		10/26/15	11/8/15	14	100%	10	14	0
3	**Preliminary Design Review**		11/2/15	11/22/15	21	100%	15	21	0
3.1	Concept Evaluation		11/2/15	11/8/15	7	100%	5	7	0
3.2	Design Development		11/9/15	11/22/15	14	100%	10	14	0
4	**Winter Break**		12/12/15	1/3/16	23	100%	15	23	0
4.1	Prototypes	Eli	12/5/15	12/18/15	14	100%	10	14	0
5	**Detailed Design**		1/4/16	1/31/16	28	100%	20	28	0
5.1	Modeling		1/4/16	1/17/16	14	100%	10	14	0
5.1.1	Can Modeling		1/4/16	1/10/16	7	100%	5	7	0
5.1.1.1	Can Mold Design		1/11/16	1/17/16	7	100%	5	7	0
5.1.2	Lid Modeling		1/4/16	1/17/16	14	100%	10	14	0
5.2	Analysis		1/18/16	1/31/16	14	100%	10	14	0
6	**First Article Manufacturing**		3/12/16	4/17/16	37	100%	25	37	0
6.1	Molds Machining		3/12/16	3/13/16	2	100%	0	2	0
6.1.1	Mold Post Processing		3/13/16	3/20/16	7	100%	5	7	0
6.2	Plaster Molds		3/19/16	3/21/16	7	100%	1	7	0
6.2.1	Plaster Molds Post Processing		3/21/16	3/27/16	7	100%	5	7	0
6.3	Carbon Fiber Mold Layup and Cure		3/28/16	4/3/16	7	100%	5	7	0
6.5	Top Plate		3/30/16	4/2/16	4	100%	3	4	0
6.6	MDF Jig		3/31/16	4/1/16	2	100%	2	2	0
6.5	Manufacutre Bladder		4/2/16	4/6/16	5	100%	3	5	0
6.6	First Test Article		4/13/16	4/17/16	5	100%	5	5	0
7	**Testing**		4/18/16	4/22/16	5	100%	5	5	0
7.1	Impact Testing		4/18/16	5/7/16	20	100%	15	20	0
8	**Production**		4/23/16	5/20/16	28	100%	20	28	0
8.1	Cure 5 Bear Cans		4/23/16	5/13/16	21	100%	15	21	0
8.1.1	Post-Process Cans		4/30/16	5/20/16	21	100%	15	21	0



APPENDIX G: TESTING RESULTS

Table 14: List of test deflection results.

Test #	Height of Can	Diameter of Can	Top Deflection	Side Deflection
1	11.002”	8.5”	0.5”	2.25”
2	10.5”	9”	0.2”	0.75”
3	11”	8”	<0.1”	1.25”-1.5”
4	11”	8”	<0.1”	4-5”

APPENDIX H: Matlab CLT Code

```
%
%CLT
%

clear all
close all

%set up a diary file
diary CLTng.dat

%units are US customary (lb, in, E in psi)

%% Dimensions of bear can

Dia = 10; %10 inch diameter
Length = 10; %10 inch length

% total laminate definition in matrix below
% [ply angles, thicknesses, matl. #]

%Set up for two materials

% Data in there now is
%1-carbon
%2-Eglass

% Laminate is defined in this matrix little "L" or l (sorry it looks like a
one)
% [ angle  thick  matl #]
l=[   0      1*.0065   1;
      0      1*.030    5;
      0      1*.012   2];



% this is the total laminate
% cut, paste, edit above to study your laminate of choice

% size command to get number of plies
n = size(l,1) ;

%      Lamina Properties
%      matrix for engineering constants
      %E1     E2    v12  G12   a11     a22
 E = [36.8e6 .9e6  .30  .45e6   -.5e-6  15e-6; %M46J
      9.88e6 9.88e6  .05  .7e6    0.0e-6  0.0e-6; %Hybrid
      11.6e6 11.6e6 .05  .7e6   0       0 ; %cloth MTM49
      0.001   0.001   0.001     0.001     0       0 %empty space
      200e3 200e3 .3   145.2e3 0        0; %syncore properties
      4e5   4e5    .3   3e4     0       0];  %balsa
 % a's are CTE's not used yet!
```

```
%intiialize the ply distance and ABD matrices

h = zeros(n+1,1);
A = zeros(3);
B = zeros(3);
D = zeros(3);
% Form R matrix which relates engineering to tensor strain
R = [1  0  0;
     0  1  0;
     0  0  2];

% find the total thickness
total = sum(l,1);
thick = total(1,2);



% locate the bottom of the first ply
h(1) = -thick/2.;
imax = n + 1;
%loop for rest of the ply distances from midsurf
for i = 2 : imax
   h(i) = h(i-1) + l(i-1,2);
end

%loop over each ply to integrate the ABD matrices
for i = 1:n

   %ply material ID
   mi=l(i,3);
   v21 = E(mi,2)*E(mi,3)/E(mi,1);
   d = 1 - E(mi,3)*v21;

   %Q12 matrix
   Q = [E(mi,1)/d          v21*E(mi,1)/d      0;
        E(mi,3)*E(mi,2)/d   E(mi,2)/d          0;
        0                  0                E(mi,4)];


   %ply angle in radians
   a1=l(i,1)*pi/180;

    %Form transformation matrices T1 for ply
    T1 = [(cos(a1))^2        (sin(a1))^2              2*sin(a1)*cos(a1);
         (sin(a1))^2        (cos(a1))^2             -2*sin(a1)*cos(a1);
         -sin(a1)*cos(a1)    sin(a1)*cos(a1)   (cos(a1))^2-(sin(a1))^2 ];


   %Form Qxy
   Qxy = inv(T1)*Q*R*T1*inv(R);

    % build up the laminate stiffness matrices
   A = A + Qxy*(h(i+1)-h(i));
```

```
   B = B + Qxy*(h(i+1)^2 - h(i)^2);
   D = D + Qxy*(h(i+1)^3 - h(i)^3);

   %load alphs into and array
   a=[E(mi,5); E(mi,6); 0.0];



%end of stiffness loop
end

%change the display format for compliance matrix
format short e

A = 1.0*A;
B = .5*B;
D = (1/3)*D;

%
%
%
K = [A, B;
     B, D];

%put in mechanical loads here
%mech loads
  Nx=0;
  Ny=100;
  Ns=0;
  Mx=0;
  My=0.0;
  Ms=0.0;
%
% builds array of loads
load = [  Nx;
          Ny;
          Ns;
          Mx;
          My;
          Ms];



% Plate compliance
%
C = [inv(K)];
%
%solve for strains and curvatures
e = C*load;
%

%
% reduction factor for ultimate (pseudo A-basis use .80)
RF=.80;
%
%
```

```
% allowable strains reduced to account for ultimate strength after impact
% row1 is carbon
% row2 is E-glass
% transverse prperties assumed same
% load allowable strains into array
%     ELU         ELUP        ETU       ETUP      ELTU
ea = [RF*.014   RF*.012   RF*.007   RF*.031  RF*.0296; %must edit this
variable <----- for aditional types of fiber
      RF*.02    RF*.018   RF*.0067  RF*.031  RF*.0296;
      RF*.014   RF*.012   RF*.007   RF*.031  RF*.0296;
      RF*.014   RF*.012   RF*.007   RF*.031  RF*.0296;
      RF*.0135   RF*.0135   RF*.007   RF*.031  RF*.0296;
      RF*.0135   RF*.0135   RF*.007   RF*.031  RF*.0296];
%
%
%zero out results array
ERES = zeros(2*n,6); %strain results
SRES = zeros(2*n,6); %stress results

stressxy = zeros(2*n,4);
strainxy = zeros(2*n,4);
% loop over each ply and calculate strain
for i=1 : n;
   %loop over top and bottom of each ply
   %starting at the top of ply
   for j=1 : 2;
   %
   ply = i;
   loc = j;

   z = h(i-1+j);
   %   need angles and transform back to principal directions
   el= [ e(1)+z*e(4);  e(2)+z*e(5);  e(3)+z*e(6)];

   %ply material ID
   mi=l(i,3);
   v21 = E(mi,2)*E(mi,3)/E(mi,1);
   d = 1 - E(mi,3)*v21;

   %Q12 matrix
   Q = [E(mi,1)/d          v21*E(mi,1)/d      0;
        E(mi,3)*E(mi,2)/d   E(mi,2)/d          0;
        0                  0              E(mi,4)];

   %
   %ply angle in radians
   a1=l(i,1)*pi/180;

    %Form transformation matrices T1 for ply
    T1 = [(cos(a1))^2       (sin(a1))^2               2*sin(a1)*cos(a1);
        (sin(a1))^2        (cos(a1))^2              -2*sin(a1)*cos(a1);
        -sin(a1)*cos(a1)    sin(a1)*cos(a1)   (cos(a1))^2-(sin(a1))^2 ];

    %Form Qxy
   Qxy = inv(T1)*Q*R*T1*inv(R);
```

```
    stxy = Qxy*el;

    % ply srain in principal coords
    ep = R*T1*inv(R)*el;

    % ply stress in principal material coords
    sp = Q*ep;

% uses MAX Strain criteria
%failure index now looks at two different materials

% check fiber direction
   if ep(1) > 0.0;
      FI = ep(1)/ea(mi,1);
      FIF=FI;
     elseif ep(1) <= 0.0;
        FI = abs( ep(1) )/ea(mi,2);
        FIF=FI;
   end

   %chck transverse direction
   if ep(2) > 0.0;
     F1 = ep(2)/ea(mi,3);
   elseif ep(2) <= 0.0;
     F1 = abs( ep(2) )/ea(mi,4);
   end
%

  if F1 > FI;
   FI = F1;
  end
%
%
% check shear
   F1 = abs( ep(3) )/ea(mi,5);
  if F1 > FI ;
   FIe = F1;
  elseif F1 <= FI;
   FIe = FI;
  end

  % FIF is failure index on fiber failure
  % FIe is the highest failure index which could be fiber, transverse or
  % shear


  %load the results array principal material directions

    % strain
    ERES(2*i+j-2,1)=l(i);  %ply angle
    ERES(2*i+j-2,2)=ep(1); % strain in ply 1 direction
    ERES(2*i+j-2,3)=ep(2); % strain in ply 2 direction
    ERES(2*i+j-2,4)=ep(3); % strain in ply 12 or shear strain
    ERES(2*i+j-2,5)=FIe;   % highest failure index
```

```
    ERES(2*i+j-2,6)=FIF;   % failure indice on fiber

    %stress  now, note failure index is based on max strain and just repeated
    %here now with the stresses
    SRES(2*i+j-2,1)=l(i);  %ply angle
    SRES(2*i+j-2,2)=sp(1); % stress in 1 direction
    SRES(2*i+j-2,3)=sp(2); % stress in 2 direction
    SRES(2*i+j-2,4)=sp(3); % Shear stress in 12
    SRES(2*i+j-2,5)=FIe;   % highest failure index
    SRES(2*i+j-2,6)=FIF;   % failure indice for fiber or 1 direction

    % XY here now with the stresses
    stressxy(2*i+j-2,1)=l(i); %ply angle
    stressxy(2*i+j-2,2)=stxy(1); % stress in 1 direction
    stressxy(2*i+j-2,3)=stxy(2); % stress in 2 direction
    stressxy(2*i+j-2,4)=stxy(3); % Shear stress in 12

    strainxy(2*i+j-2,1)=l(i);  %ply angle
    strainxy(2*i+j-2,2)=el(1); % stress in 1 direction
    strainxy(2*i+j-2,3)=el(2); % stress in 2 direction
    strainxy(2*i+j-2,4)=el(3); % Shear stress in 12


end
%
end
ERES=ERES*1;
SRES=SRES*1;
stressxy=stressxy*1;
strainxy=strainxy*1;


Index = [SRES(:,1),SRES(:,6)]
MaxI = max(SRES(:,6))
A
B
D

diary off

%% Impact Analysis

%% Top/Bottom Impact

U = 100; %lb-ft
S = pi*(Dia/2)^2-pi*(Dia-thick)^2/4;
k = A(2,2)*S/Length;

Dist = sqrt(2*U/k)

Strain = Dist/Length

SF = .01/Strain;
```