Bear Minimum: Ultralight Composite Bear Canister

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List of Nomenclature

FEA - Finite Element Analysis

SIBBG - Sierra Interagency Grizzly Bear Association

Layup - Carbon Fiber being placed onto mold surface for curing

CAD - Computer Aided Design

1 Introduction & Abstract

The goal of this report is to review the final detailed design for the Bear Minimum Senior Project. The report will provide the background information and the objectives required to complete the designs, a discussion about the methods taken to select the final designs with initial FEA and prototyping, and the detailed design including all necessary geometry, material, manufacturing, cost and safety information. In addition, Section 5 includes the formal documentation describing the procedures and results of manufacturing the canister body, which was already designed by last year's senior project team. The target audience for this project is the ultralight backpacking community. Ultralight backpacking is a niche category of backpacking camping. Ultralight backpackers are willing to pay more money for lighter products, even if the item only saves them a few ounces. They are the stakeholders for this project, along with the project sponsor, Nick Hellewell.

The ultralight backpacking community needs a strong, easy to use, safe bear canister that is lighter than current market products for trekking in the backcountry. A full design of the lid for the bear canister is to be completed. This includes the locking mechanism to ensure it is bear proof, the interface between the lid and the canister, and the structure of the lid so it passes the strength and weight specifications. The lid, along with the already designed canister body, is to be manufactured with formal documentation. The lid will initially be tested separately and then with the canister body as an assembly. All tests will be to either verify or reject one or more of the design specifications listed later in this document. The overarching goal of the project is to find a balance of two project requirements: making a rigid lid that is, when combined with the canister body, less than 1.3 lb_f and still meeting the Interagency Grizzly Bear Committee (IGBC) certification strength requirements. A complete list of the project goals is in the objectives section including two reach goals.

2 Background

2.1 Rules, Regulations & Codes

2.1.1 Rules

Bear canisters provide a safety barrier between a backpacker's food and wild bears. A certified canister not only provides ease of mind, but is more likely to keep the user and food safe. Testing is needed to ensure that bear canisters are market ready and outdoor ready. The governing agency for bear canister testing is the Interagency Grizzly Bear Committee (IGBC) which runs the testing and certification. The Sierra Interagency Black Bear Group (SIBBG) used to perform testing so older bear canisters may still have the SIBBG certification.

Not all tested canisters are certified in all National Parks. Individual parks such as Yosemite, Sequoia, and Inyo National Parks have their own list of certified canisters. [1].

Approved testing by the IGBC currently must take place in the West Yellowstone facility between the dates of April 1st to October 31st for live bear testing. As of October 2016, live bear canister testing costs $400 and an additional $75 for video footage. [2] The canister assembly must pass both the visual inspection and live bear inspection which are defined as follows:

Visual Inspection:

> "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." [3]

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 1⁄4'' or less to be considered 'passed.'" [4]

For the Sierra Interagency Black Bear Group the testing happens in three distinct phases. Although the SIBBG group is not currently in operation, their testing procedures provide a good baseline certification. Older existing products still retain the SIBBG certification, so it is beneficial for testing the strength characteristics of a canister. A bear canister needs to pass all three phases of the SIBBG testing in order to receive certification. These phases are listed as follows [5]:

1. A 100 lb_f weight will be dropped from 1 foot high. No failures in the materials or assembly shall result. Elastic deflections must be less than 0.25 inch.
2. No failures shall result while in constant contact with bears.
3. Upon meeting the first two conditions, the canister receives "conditional approval" and begins 3 months of field testing. If the canister fails just once during field testing, it will lose conditional certification

2.2 Existing Solutions for Similar Problems

Most existing bear canisters resemble a cylindrical or side-curved cylindrical pressure vessel. This allows the canisters to be longitudinally strong, store food easier, reduce stress concentrations at corners, and fit inside a pack well. Some vessels use their shape to have multiple purposes either as a stool or lids that function as cooking pans.

Other forms of food storage for bear protection are also available. A outdoor guide to food handling storage from Recreational Equipment Incorporated (REI) highlights some of the less common types of food storage methods. [6]

- **Bear wire:** Cable strung between trees which you can hang food bags from. Replaces the need for natural tree branches.
- **Bear poles:** Tall, metal, stationary, man-made poles which resemble artificial trees. The provide metal limbs and hooks for campers and backpackers to hang items from.
- **Bear hangs:** There are two types of bear hangs. The first is counterbalancing which is to use a mass similar to your food mass to hoist your food up a tree with a rope. Alternatively, bear-bagging is throwing a small mass over a branch to get a rope up to hoist food.

- **Bear boxes:** Man made and stationary bear resistant containers often found in popular campsites. They are very large and rectangular in shape. They provide quick and easy access to food when mobility is not needed.
- **Bear bags:** Small sacks of durable material which vary in volume. They allow bears to grab the bag but not puncture it or the contents.

Although the cylindrical canister shape is popular, other solutions to dealing with hungry bears is using items such as bear sacks or bear boxes. Bear sacks follow the traditional method of storing food in a bag and hoisting it over a tree limb to keep it off the forest floor. These sacks are made of kevlar or other tough material, but they lack the storage space and bears have been known to go onto tree limbs to tear through supporting ropes. Bear boxes on the other hand are stationary, heavy duty, and expensive and are only provided at a small number of campsites. For the avid ultralight backpacker neither of these two solutions may work in areas dense with bears.

2.3 Existing Products & Benchmarking

For the basic backpacker, owning a canister may seem like an arduous task as the canisters can weigh 2-3 lb_f and are bulky in size and geometry. Despite these drawbacks, canisters are necessary to avoid conflicts with bears and are legally required in certain backpacking areas. Wildlife biologist Kate McCurdy noted that bears are intelligent animals and will slowly recognize the look and feel of bear canisters over time and recall they are not worth the effort to break into. There have been instances of bears in the New York Adirondack mountains learning how to open bear canisters such as the BearVault 500. One particular bear had learned how to push in a tab with her teeth that allowed the canister lid to be screwed off. [7].

The current market for bear canisters is full of a variety of options ranging from canisters holding a few days of food storage (300 cubic inches) to a week's worth of food storage (650 cubic inches) which is the target size for the Bear Minimum canister. In order to better gauge the competitiveness and innovative solutions currently available, Table 1 below highlights key attributes in competitive market products. Although there are quite a few models of bear canisters, most canisters are basic in design and geometry. A 2010 study found that although canisters were similar, 69% of backpackers surveyed using canisters used the Garcia Backpacker's Cache canister. Additionally only a small percentage of canisters (11%) were rented, and 9% complained that they needed more volume [8]. Our research yielded ten of the most popular bear canisters on the market. Our findings are highlighted in Table 1 below.

Table 1. Current product benchmarking research was conducted to compare specifications of products in the bear canister market.

Product Name	Materials Used	Volume	Size LxD	Weight	Price	Weight to Volume Ratio	Price to Volume Ratio	Latching Mechanism	Certified
		[in³]	[in x in]	[oz]	[$]	[oz/in³]	[USD/in³]	--	(IGBC /SIBBG)
Bearikade Weekender	Carbon Fiber and Aluminum	650	10.5 x 9	31	$288	0.05	0.44	O-Ring Seal with 3 Quarter Turn Metal Fasteners	Tested, but not certified
Bearikade Expedition		900	14.5 x 9	36	$349	0.04	0.39		
Hunny Canister	Ultem © resin, ceramic alloy	710	12 x 9	25	$39	0.04	0.05	2 lids, 3 screw side door	Not Tested
BearVault BV500	Poly-carbonate	700	12.7 x 8.7	41	$80	0.06	0.11	Screwtop with single ratchet lock	IGBC & SIBBG
BearVault BV450		449	8.7 x 8.3	33	$67	0.07	0.15		
Counter Assault	Polymer Blend	716	14 x 9	58	$70	0.08	0.1	3 Stainless Steel Turn Locks	IGBC & SIBBG
UDAP No-Fed-Bear	Polymer	455	10 x 8	39	$60	0.09	0.13	2 Stainless Steel Turn Locks	IGBC
Backpackers Cache Garcia	ABS polymer	615	12 x 8.8	43	$75	0.07	0.12	Screwtop	IGBC
Lighter1 Big Daddy	Poly-carbonate	650	13 x 8.7	36	$100	0.06	0.15	Twist and Lock Lid	IGBC
Bear Minimum	**Carbon Composite**	**650**	**11 x 9**	**20.8**	**$500**	**0.03**	**0.83**	**Not Determined**	**Not Tested**

IGBC = Interagency Grizzly Bear Committee
SIBBG = Sierra Interagency Black Bear Group

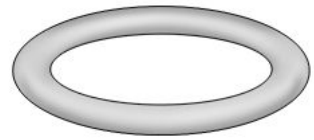
Ultralight backpackers need a solution which is just as strong as the existing solutions, contains the same volume, but ultimately is much lighter. The ultralight backpacking market is a niche market, but with product scarcity, it can be rationalized to use more expensive materials for a lighter canister. Weight, more than cost, is of utmost importance for ultralight backpackers. Aside from basic parameters such as volume, size, and weight, other benchmarking attributes of interest are the weight to volume ratio and price to volume ratio.

The weight to volume ratio indicates how effectively the material is used in the product. It is optimal for a canister to be both light and have a large capacity. Bear Minimum excels in this category as it uses light composites while maintaining a large volume.

The second attribute of interest is the price to volume ratio. This indicates and normalizes how expensive the product is for how much space you get inside. Customers ideally want a high weight to volume ratio and low price to volume ratio. The cell shading in Table 1 indicates how well each of the canisters performed in these key categories with green being the best performing.

A critical part of the lid design is developing a compatible latching mechanism with the existing canister body, as the latching mechanism is within the scope of the Bear Minimum project. The second to last column in Table 1 briefly states the latching mechanism used on other canisters. One common type is the button quarter turn metal fastener. These are small button sized twist locks that have a swinging lock to unlatch the lid. These button quarter turn fasteners require a coin or other slim object to turn them successfully. This ideally prevents a bear from using a claw to open the canister. Table 2 below highlights common latching mechanisms used for canisters, packages, bags, or food storage devices. Some of these latching mechanisms could be incorporated into a bear canister.

Table 2. Benchmarking was performed on various lid latching mechanisms.

Latch Type	Product	Description	Image
O-ring with clamp	Common water bottle	Rubber ring which acts as an interface between edges. Used for sealing rather than latching.	
Notched Slider latch	Common hinge latch	Slide to the side and then in the perpendicular direction. Spring loaded prevents accidental opening.	
Tabbed Latches	Tupperware or windows	Pushing and pulling to engage or disengage latch. Requires two pieces to move independently.	
Buckle	Backpack Strap buckle	Common pack buckle allows for quick clipping of strap segments.	
Springloaded	Car seat slider	Spring loaded interface between sections. Spring acts like safety, but by default is open.	
Screw	Bottle threaded	Threaded bolt or threaded lid allows for tight joining of assembly parts.	
Ratcheting	Ratcheting Mechanism or strap ratchet	Ratcheting method allows for tightening in one direction. Mechanism will not release accidently. High stress on individual teeth.	
Band with latch	Metal pipe tie band	Metal pipe or band ties allow for radial clamping and tightening using a screw.	
Images from McMaster-Carr Catalog [9]			

The final column in Table 2 is if the product has passed the Interagency Grizzly Bear Committee (IGBC) testing for the canister. This testing must be passed in order for the product to be used in some areas. Almost all the current market canisters have passed one form of testing aside from the Bearikade, Hunny Cannister, and Bear Minimum. The bearikade has been tested and proved with wild bears but is not formally certified. The Hunny Canister is still in the development and funding phase, but could pose a formidable market opponent to the Bear Minimum canister if it is certified.

Prototype canisters from 2015's senior project failed to pass the deflection test requirement of less than 0.25 inches of deflection under a specified static load. Structural stiffening material will need to be used for the canister lid, and possibly canister body. One of the most common types of structural stiffening is using a sandwich core, as seen in Figure 1 below.

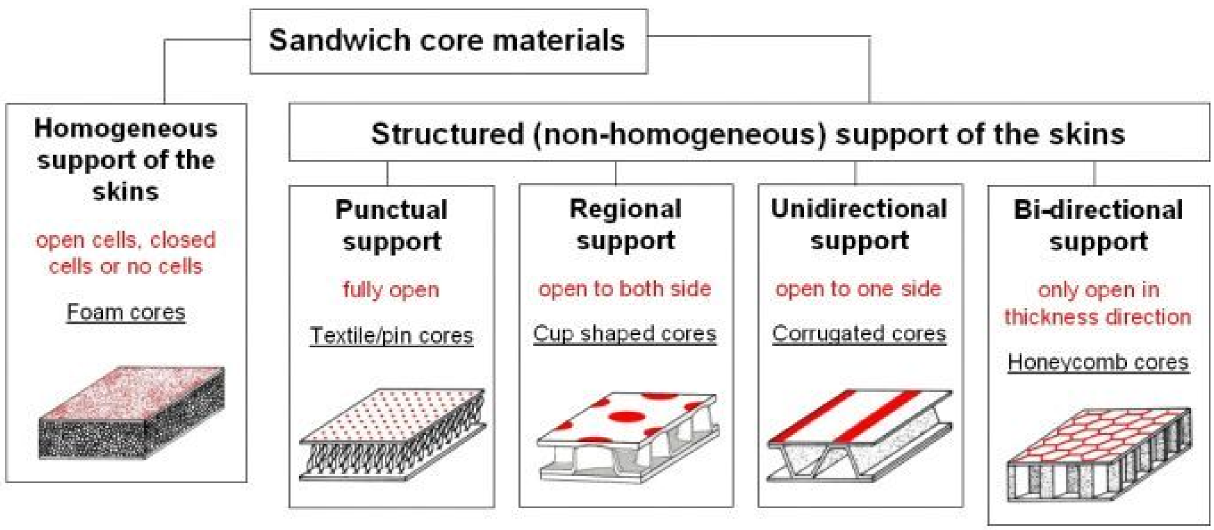


Figure 1. A flow chart categorizing common sandwich core materials and geometries is shown. [10]

Sandwich core geometry is crucial as it allows thin and light core material with geometric advantages such as a beam or honeycomb pattern to achieve higher strengths. Sandwich core materials can vary from metal all the way to foam and is further expanded on in Table 3 below.

Table 3. Mechanical characteristics of composite sandwich core types are shown.

Type	Subtype	Density [lbm/ft^3]	Compressive Strength [psi]	Shear Strength [psi]	Core Features
Honeycomb	Nomex	3	72 -290	50-145	Common, light, good rigidity
	Aluminum	4.5	440	75	Denser, but stronger than nomex. Corrosion and heat resistance
Vinyl Sheet Foam	Divinycell	3-4	87	81	Good under impact and loading cycles,thermoplastic, low water absorption, compatible with resin systems, good with most layup processes.
	Divinymat	3.8	87	81	Conforms easily to curved shapes (160°F max)
End Grain	Balsa Wood	9.7	2	435	Easily layup with processes, suitable for elevated temperature cure prepreg. Good fatigue properties
Polyurethane	Sheet Foam	2-10	20-27	16-22	Does not crack swell, or split under water exposure. High strength to weight. Same properties as mix and pour foam 300°F max. Degrades with long term sunlight. 1.3% water absorption
	Mix and Pour	3-4	87	81	
	Honeycomb and filled in cells	5-13	72-290	81	Same properties as honeycomb and sheet foam. Foam provides shear resistance for honeycomb

2.4 Patents

Extensive research was conducted on current patents to make sure the final Bear Minimum canister parts or functions do not infringe on existing ideas associated with a US patent. The two most relevant patents are further discussed below.

Relevant Patent #1:

The patent that holds the most relevance for this project is a patent claimed by our competitor, Wild Ideas, LLC, regarding the Bearikade series of bear canisters.

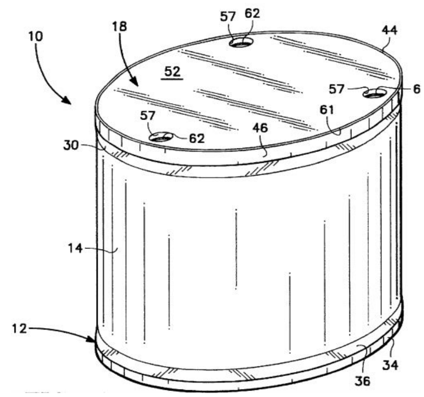


Figure 2. US Patent 6,343,749 B1 shows the Bearikade bear canister assembly from a top isometric view [11].

The patent eliminates the possibility of very specific inward facing collar orientation with channels for the locking mechanism. If possible attributes of the Bear Minimum canister, after ideation and prototyping, lead to a design similar to the one stated in this patent, the patent will be revisited and further analyzed.

Relevant Patent #2:

Another relevant patent is assigned to Netra Plastics. They claim a canister with recesses on the inner surface of the canister body with corresponding fingers sticking down from the lid. The canister assembly is shown in Figure 3.

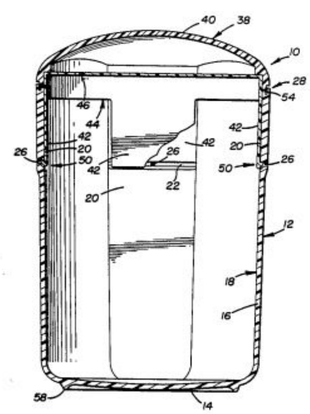


Figure 3. Image attached to patent number 4,801,03. Netra Plastic's claimed canister in side section partially cutaway view. Numbers 50 and 26 are

pointing to the male outward finger curvature and female recesses, respectively [12].

Similarly, if explored ideas for the Bear Minimum canister assembly are relevant to Netra Plastic's claimed canister, the patent will be revisited and further analyzed.

2.5 Past Technical Problems

The Bear Minimum project is a continuation of the *Ultra-Light Bear Canister* senior project from 2015. The senior project report from the 2015 year is available through the Cal Poly Digital Commons under mechanical engineering [18]. Section 5.3 of the report highlights manufacturing issues and recommendations. Some of these failures are common composite manufacturing issues, while some are project specific due to the unique geometry, bladder molding, and custom two-piece bladder tooling.

The 2015 year team created the canister body, but they did not create a canister lid to complete the assembly. This resulted in both fiber failure and excessive horizontal deflection when the assembly was subject to the drop test. This may be attributed to either little technical knowledge, inaccurate stress assumptions, stress concentrations, poor propagation along load paths, or incorrect boundary conditions.

Team dynamics of last year's project also posed a technical roadblock as many of the team members were not familiar with either lightweight backpacking products or basic composite manufacturing processes. Although the Bear Minimum team is comprised of only two individuals the members have knowledge that spans both areas.

Some manufacturing problems that arose were from the molds and machines used to create the molds and bladder. The shopbot used to machine out the foam mold cavity had errors in depth and cutting feed rate resulting in a two week delay. A foam core was also made to create a silicone bladder for the internal geometry of the canister. The silicon bladder had many wrinkles in it and prevented future layups from having a good surface finish and layer laminate. The autoclave used to cure the molds did not allow moisture to release well causing condensation. Additionally the molds did not release well causing them to need to be removed by destructive means.

The mold pattern used also posed significant issues as the two piece mold caused a flange in the composite to form during manufacturing. This flange needed to be reinforced and cut off after the post-bond was complete. This also provided significant alignment issues as the flanges needed to be aligned properly with a bolt pattern.

2.6 Common Testing & Validation Procedures

2.6.1 Destructive Testing

Destructive testing is common method of testing material properties but results in broken samples that must be thrown away. Composite samples often yield at stresses much lower than data tables suggest. This can be due to a variety of factors such as porosity, poor layer bonding, foreign material, excess resin or fiber, or user error. The most common is porosity, which is caused by "incorrect, or non-optimal, cure parameters such as duration, temperature, pressure, or vacuum bleeding of resin." It is possible for composite samples to have tensile strengths closer to half of the commonly accepted values

There are two main destructive tests which can utilized: tensile testing and acid digestion testing. Tensile testing is quite common and lets us either evaluate the canister properties, the corrugate properties, or our carbon laminate properties. All three would provide valuable data and allow for better understanding the material properties. Acid digestion is simple method of finding the fiber volume of the sample. It eats away at the epoxy to reveal just the fibers. It helps determine the void percentage. In other words it helps calculates the amount of resin content in the sample for analysis by using the difference in weights.

2.6.2 Non Destructive Testing

Nondestructive testing (NDT), unlike destructive testing, does not ruin the part and does not require a tensile sample. NDT is widely used on parts that are already made into the final product and geometry.

NDT defers from destructive testing in that it locates the source problematic areas, it does not require a sample, it's more easily repeatable, and keeps the part intact. NDI can vary from inexpensive such as tap testing, to expensive methods such as shearography for critical parts. Often NDT will be utilized on consumer ready parts ready for use, an extreme example of this would be a Boeing 787 fuselage.

The most common non-destructive testing methods and a brief description are highlighted below:

- Visual Inspection
    - NDT using no equipment. Surface checks for abrasions, cuts, dents, bubbles, layer delamination, and general contamination. A simple first line of investigation.

- Tap Testing
    - Secondary testing following the visual testing which using a pulse input, or tap and listens to the sound. The sound is effective at showing areas of delamination and porosity when the sound changes. The tap test is widely used, cost effective, and computer software compatible.

- Ultrasonic
    - Similar to the tap test, ultrasonic testing listens to the echo of a pulse or the wave that is transmitted through the sample. Ultrasonic is much more accurate than the tap test and can detect delamination, porosity, and matrix damage.

- X-Ray Inspection
    - Inspection with X rays is a proven technique that can penetrate thick laminates and non-planar geometry. It is used to detect density changes in the sample allowing it to detect more flaws such as moisture in the sample as well as the general porosity and delamination.

- Heat Flux Thermography
    - Using infrared cameras to monitor the sample, heat is transferred across the sample. Thermography measures the effects from thermal changes and locates delaminations and contamination such as moisture and solvents.

- Electrical
    - Flaws in a composite sample change the electrical resistivity of the sample. Aligning positive and negative leads on both sides of the sample allows an electrical field to be generated. Resistivity changes in the sample can be detected by mapping the field.

- Shearography
    - Shearography measures the deformation of a sample when under a loaded condition. Any deformations will clearly show up on the in plane and out of plane deflection profiles as distinct changes in slope. The deflection change indicates a delamination, crack, or crushed core. Various means of loading can be used in shearography such as heat excitement, vacuum pulling, and vibrations.

The bear minimum team hopes to perform NDT on our final canisters if ample resources are available. Cal Poly currently does not have many resources for NDT, so testing needs to be outsourced or simple in nature.

3 Objectives

3.1 Project Goals

3.1.1 Project Goals for Current Scope

The project goals were created along with the customer requirements of the project. Similar to developing the customer requirements, a broad knowledge of the current bear canister market was necessary to develop the project goals. Proposed goals by Nick Hellewell are also included in the project goals which are listed below.

1. A successful manufacturing job of the canister body (designed last year) will be completed and documented. *
2. A lid that is a structural element of the canister assembly will be designed, built, and tested.*
3. The canister assembly will be tested by two drop tests. A 100 lb_f weight will be dropped from 1 ft high once on the side of the canister assembly and once on the top of the assembly.*
4. The canister will have an inside volume of at least 650 in^3.
5. The canister will have a maximum mass of 1.3 lb_f.
6. The total cost of the project expenditures will not exceed $2000.
7. The lid & canister body interface will have a locking mechanism.
8. Lid removal will not take longer than 30 s.
9. Lid removal will not require any external tools.
10. The canister assembly will not puncture through thin fabrics such as a backpack or tent therefore sharp edges will be avoided.

* These goals define the scope of the Bear Minimum Project

3.1.2 Project Reach Goals

The reach goals do not fall under the current scope of the project, and will only be addressed if time permits. Two reach goals are listed below.

1. The manufacturing process will be improved until it is repeatable and reliable.
2. The mechanical design of the canister body will be revisited and improved. This reach goal will only be necessary if the canister assembly fails the strength tests.

3.1.3 Project Scope and Boundary Sketch

The current scope of the Bear Minimum project was agreed upon by Nick Hellewell (Bear Minimum Project Sponsor), Dr. Peter Schuster (Senior Project Coordinator), and Adam Eisenbarth and Rama Adajian (Bear Minimum Team Members).The scope of the project is also represented in the boundary sketch, Figure 4.

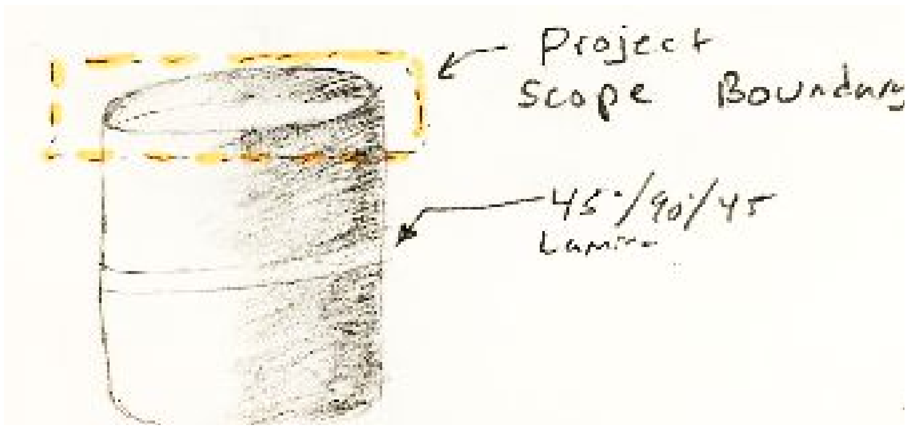


Figure 5. The boundary sketch is a visual representation of the scope of the project. The only part that will be within the project scope through the complete design process is the canister lid.

3.2 Quality Function Deployment (QFD) Process

3.2.1 Overview

The Quality Function Deployment (QFD) process was utilized once the project goals and customer requirements were established. The customer requirements are a list of guidelines which meet the needs of the ultralight backpacking community; therefore, some statements contain some subjectivity and vagueness. The QFD process creates operational definitions of these statements turning qualitative information into quantitative criterium. The House of Quality, which is attached in Appendix A, was the technique used during the QFD process resulting in the development of the design specifications as seen in Table 5. Furthermore, an explanation of how the QFD process was enacted for the Bear Minimum Project is in sections 3.2.3.1, 3.2.3.2, and 3.2.4.

3.2.2 Customer Requirements

The customer requirements for this project were developed by analyzing the current market for bear canisters. This was done by posting forum discussions on Reddit [18] and

TrailGroove [19] in order to reach out to the ultralight backpacking community. Personal friends and family, who participate in ultralight or regular backpacking, were also consulted for further information and preferences on possible bear canister features and price range expectations. An extensive review on competitor's products was also conducted to become more knowledgeable about this market. The list is based on the current market along with requirements proposed by the project sponsor Nick Hellewell. The list of the customer requirements is shown in Table 4.

Table 4. Customer Requirements were developed from last year's project description and talking with the project stakeholders.

Requirement Category	Description
Part Geometry and Characteristics	Canister must be lightweight Canister may not have any large openings or gaps Canister must be big enough to fit enough food for a three night backpacking trip for two people
Operation	Canister does not need extra tools to open compartment besides items commonly brought while backpacking Canister must accommodate a wide variety of hand shapes and sizes
Forces and Torques	Canister must be tested against the once administered SIBBG strength standards
Materials	All materials used for the canister must be EHS (Environmental Health and Safety) certified
Safety	Canister may not have any sharp or protruding edges Canister parts cannot classify as choking hazards
Motion	Canister must have a latching mechanism so bear cannot open canister lid
Production	Molds must be easily created in-house Manufacturing must be possible using equipment at Cal Poly Canister parts and assembly must be tested
Quality Control	Canister has minimal visible weave distortion on exterior Canister has minimal void fraction
Assembly	Canister lid is easy to put on and take off Canister lid must sit flush with top surface
Cost	Total cost for the canister cannot exceed $2,000. This includes costs required for any stage in the design process.

3.2.3 Design Specifications

The design specifications of the Bear minimum project are listed in Table 5 below and developed with the QFD process.

Table 5. Project Design Specifications

Category	#	Specification	Target	Tolerance	Risk	Verification	Derivation Method
Part Geometry	1	Internal Volume	650 in^3	Min	L	I	P
	2	Size (Length x Diameter)	11" x 9"	+/- 0.25"	L	I	P
	3	Total Weight	1.3 lb_f	Max	M	A,I	P
	4	Lid Weight	0.2 lb_f	Max	M	A,I	P
	5	Largest gap diameter	0.25"	Max	M	[A,T]	BTC
Quality Control	6	Diameter of the opening in canister body	6.5"	+/- 0.25"	L	I	P
	7	Void volume fraction	5%	Max	M	[T,I]	CS
Operation	8	Torque necessary to open canister	5.1 ft-lb_f*	Max	L	T	RS
Forces and Torques	9	Weight dropped during the drop test from 1 ft high	100 lb_f	Min	H	A,T	BTC
Safety	10	Filleted edge radius	0.125"	Min	M	I	P
	11	Removable parts sizes (choking hazard)	1.75" x 1"	Min	L	I	RS
Motion	12	Time to remove latched lid	30 sec	Max	L	T	RS
Production and Quality	13	Amount of weave distortion on exterior (normalized by surface area)	15%	Max	H	I,T	CS
	14	Time in live contact with bear (according to SIBBG Certification)	60 min	Min	H	T	BTC
Cost	15	Total cost	$2,000	Max	M	A	P

Table 5 (continued). A key for the last two columns is provided.

Risk of not meeting goal:	Verification:	Derivation Method:
H = High M = Medium L = Low * = Raw data NASA [18]	A = Analysis T = Testing I = Inspection S = Similarity [ ] = Subject to change	RS = Research & Statistics CS = Composite Standards BTC = Bear Testing Certification Standards P = Predetermined

3.2.3.1 Compliance Discussion

Four methods to determine specification compliance and verification will be administered: analysis, testing, inspection, and similarity. Software programs including but not limited to SolidWorks, EES, Matlab, and Abaqus will be used for the analysis compliance. Testing will include formal tests where specific parameters will be defined and tested. Inspection includes simple measurements including but not limited to distance, mass, force, and torque measurements. Specifications which comply with similarity include comparing a certain specification to a similar part or function. For this project, because the Bear Minimum canister will be an innovative product in a small niche market, no similarity compliances will exist.

3.2.3.2 Risk Discussion

Risks are rated a low, medium, or high rating. This is representative of the likelihood a canister characteristic will comply to the respective specification. The reason a high rating was assigned to the 100 lb_f drop test specification is the result of failure encountered during the drop test for testing 2015's Bear Minimum canister. The same canister body design will be manufactured and tested. The only difference is the addition of the lid which will act as a structural member in the canister assembly. A high risk was assigned to the timed live bear testing specification for similar reasons to the drop test specification. This test has never been administered for a fully composite bear canister, therefore there is a possibility of not complying. A high risk was assigned to the amount of weave distortion due to the difficulties with composites manufacturing. Research on composites manufacturing, along with information from last years senior project, shows the manufacturing for shapes such as a cylindrical composite part to pose challenges relating to the weave distortion of the composite fibers.

3.2.4 QFD Discussion

The methods for deriving the design specifications, in Table 5, from the customer requirements can generally be categorized into four areas. Each specification will be further explained within the category it falls into.

1. Research and Statistics (RS). This category relates to items where a statistic or other research based information were used to derive a specification from a customer requirement.

    a. Customer requirement: Canister lid is easy to put on and take off
    Specification: The maximum torque necessary to open the canister lid is 5.1 ft-lb_f.
    Method & Explanation: Statistical research was conducted to determine the average one handed maximum torque supination for a female. Two standard deviations, to accommodate 99% of the sample size, were subtracted from this number to get a final value of 5.1 ft-lb_f [21].

    b. Customer requirement: Canister parts cannot classify as choking hazards
    Specification: Minimum size for removable parts is 1.75"x1"
    Method & Explanation: Research was conducted to check the legal code for the size of a choking hazard. The minimum size for a part to be considered a choking hazard is 1.75"x1" inches.

    c. Customer requirement: Canister lid is easy to put on and take off
    Specification: Maximum time to remove latched lid is 30 s.
    Method & Explanation: This specification was derived by a trial with a very large factor of safety introduced. Trials to time the operation of opening the Bear Vault canister were conducted. The time span ranged from 6 seconds to 10 seconds for people who had knowledge of how the latching mechanism works on the Bear Vault. A design factor of safety ranging of 3 to 5, respectively was applied to calculate the maximum opening time of 30 s. The reason a large factor of safety was included is due to the relative lack of importance for the amount of time to open a bear canister. Obviously, a customer would not want to spend an hour opening the canister; however, spending 30 s three to five times a day is not a negligible factor with regards to the demand of the product.

2. Predetermined (P). The specifications in this category were either given to us by Nick Hellewell or were already determined by the Bear Minimum team last year. Because the canister body design was completed last year along with molds used to manufacture the body, some specifications for the canister are already set and predetermined.

    a. Customer Requirement: Canister must be big enough to fit enough food for a three night backpacking trip for two people
    Specification: Minimum internal volume of 650 in^3

Method & Explanation: The molds from last year's senior project team will be used to manufacture this project's canister body which is the determining factor of the internal volume. The addition of the lid might add some internal volume, but the volume cannot decrease.

b. Customer Requirement: Canister must be big enough to fit enough food for a three night backpacking trip for two people
Specification: Canister size (Length x Diameter) of: 11" x 9" +/- 0.25"
Method & Explanation: The molds from last year's senior project team will be used to manufacture this project's canister body which is the determining factor of the canister's length and diameter. The addition of a lid could potentially add length to the canister; however, a tolerance of +/- .25" will account for all selected possible lid designs and manufacturing anomalies. If a lid adds more than .25" of length to the canister, the design would be too bulky and most likely too heavy.

c. Customer Requirement: Canister must be lightweight
Specification: Maximum total weight of 1.3 lb_f
Method & Explanation: The weight of the canister assembly was set by Nick Hellewell based on his idea for an ultralight bear canister. For this canister to appeal to the ultralight backpacking market, there has to be a maximum allowable weight constraint, and this was where that line was drawn. This then sets the total weight of the canister assembly to 1.3 lb_f because of the already predetermined weight of the canister body of 1.1 lb_f.

d. Customer Requirement: Canister must be lightweight
Specification: Maximum lid weight of .2 lb_f
Method & Explanation: The weight of the canister assembly was set by Nick Hellewell based on his idea for an ultralight bear canister. This then sets the lid weight to .2 lb_f because the already designed and manufactured canister body weighs 1.1 lb_f. This data is available from last years senior project's Final Design Report. [22]

e. Customer Requirement: Canister must accommodate a wide variety of hand shapes and sizes
Specification: Diameter of the opening in the canister body will be 6.5" +/- 0.25"
Method & Explanation: The molds from last year's senior project team will be used to manufacture this project's canister body which is the determining factor of the canister's opening diameter. Research last year went into figuring out a

sufficient opening diameter to accommodate all hand sizes. A tolerance of +/- 0.25" will account for all manufacturing anomalies.

f. Customer Requirement: Canister may not have any sharp or protruding edges
Specification: Minimum filleted edge radii of 0.125"
Method & Explanation: The molds from last year's senior project team will be used to manufacture this project's canister body which is the determining factor of the canister's filleted edge radii.

g. Customer Requirement: Total cost for the canister cannot exceed $2,000. This includes costs required for any stage in the design process.
Specification: Maximum total cost of $2,000
Method & Explanation: This cost projection was imposed by Nick Hellewell.

3. Composite Standards (CS). The composite industry defines a successful manufactured composite layup as having: (1) A maximum void volume fraction of 5% [19] for defining a successful composite part and (2) The amount of weave distortion to not exceed 15% of total surface area. These are two specifications derived from the customer requirements of having a canister that has minimal void fraction and a canister that has minimal visible weave distortion on exterior, respectively

4. Bear Testing Certification Standards (BTC). Because the canister assembly will be applying for certifications from the IGBC, and the SIBBG test still reveals relevant load cases to a bear interaction, specifications were derived according to the requirements imposed to pass the certification process. The criterium directly transfer to our specifications table. They are listed below.

    a. Customer Requirement (proposed by Nick Hellewell): Canister must be tested against the once administered SIBBG strength standards.
    b. Specifications:
        i. A minimum weight of 100 lb_f must be dropped during the drop test from 1 ft high. This mean the canister body cannot experience any structural failure of parts or deflections over 0.25 in (meeting the test criteria). Our specification states that this is the minimum weight the canister must withstand.
        ii. The canister must spend a minimum of 60 minutes in live contact with a bear
        iii. The maximum gap diameter for a bear canister is .2 inches
        iv. The minimum weight during the drop test from 1 ft high is 100 lbf

4 Management Plan

4.1 Milestones

A key attribute to a highly successful project is the ability to quickly establish a base timeline. One common method of creating an organizational timeline is creating a Gantt chart. A Gantt chart identifies key milestones and the estimated time to completion. Each of these milestones can be linked to other milestones or sub-milestones to create an overall outline of the project. The basic project framework, as established by the senior project curriculum, is the primary proposal, preliminary design proposal, critical design proposal, and the final project report. These important dates are from the senior project syllabus or determined by the team and are as follows:

- **October 25, 2016:** Project Proposal Due (Course Goal)
- **November 5, 2016:** Manufacture canister body from 2015 senior project (Team Goal)
- **November 17, 2016:** Preliminary Design Report Due (Course Goal)
- **February 7, 2017:** Critical Design Report Due (Course Goal)
- **March 16, 2017**: Project Update (Course Goal)
- **May 2, 2017:** Hardware and Safety Demo (Course Goal)
- **June 2, 2017:** Project Expo and Final Report Due (Course Goal)

Our team organization is simple due to a small team size of two people. The responsibilities established in our team project highlight these areas.

4.2 Gantt Chart

A useful method of organization is a Gantt chart. A Gantt chart provides a visual timeline of the project to see how project tasks and events are sequenced. The Bear Minimum project follows the basic outline highlighted in the senior project syllabus.

It is year long project contains four base milestone: the project proposal (PP), preliminary design report (PDR), critical design report (CDR), and the final project expo (FDR). The project proposal and two design reports document the conceptualization, design process, prototyping, and building of the canister. A complete Gantt chart can be seen in Appendix F with task descriptions and completion percentages.

4.2.1 Outstanding Tasks

The Gantt chart discussed above describes the basic outline for the project. Outstanding tasks that were included in the Gantt chart have been tentatively scheduled. The Bear Minimum team has reduced the potential design options into two categories. One involves a top opening canister (including lid and latching mechanism) and the second category involves a middle opening canister where the "clamshell" like design would allow the canister to open in the center without a lid. An analysis to determine which style of canister will be selected can be seen in Section 6. Meetings with our project sponsor and obtaining general community opinion from online forums was also taken into consideration.

Additionally the opportunity of having a custom bladder created from a 3rd party vendor is being investigated. If the custom bladder is worth the additional cost for the increased part quality and ease of manufacturing it will be added to the manufacturing process. The custom bladder will have a lead time and also need very specific CAD files such that a simple male mold can be used for the bladder manufacturing. In return, it is anticipated that a custom bladder will increase part quality by allowing higher pressures (up to 100 psi_g) and repeatable part quality.

Lastly, basic proof of concept prototyping has been included within the PDR. More extensive prototyping in the future will be included in later reports. These remaining prototypes may be made from rapid prototyping or using "wet" carbon instead.

4.3 Team Member Roles

Responsibilities for Adam Eisenbarth:

a. Communications Lead
- Be main point of communication with sponsor and other campus experts
- Facilitate meetings with sponsor and project coordinator

b. Team Treasurer
- Maintain team's travel budget and logistics
- Maintain team's material budget and expense sheet

c. CAD lead
- Creates and ensures that CAD drawings are completed
- Collects CAD drawings for external and stock parts used

Adam will function as the main point of contact for this project as our communications officer and and treasurer. He will be the primary email coordinator between our sponsor and our

project team and facilitate meetings. It is important he maintains proper contact and records expenses when purchasing materials and receiving reimbursements.

Adam's final role is to be the coordinator of the CAD drawings. He will be creating the detailed drawings and ensure that any parts used in the assembly are documented well for reports and team reference.

Responsibilities for Rama Adajian:

a. Information Management & Chief Editor
   - Store information for team Google Drive
   - Record manufacturing processes used
   - Edit official documents and reports

b. Scheduling Coordinator
   - Maintain a Gantt chart and update on a regular basis
   - Log hours of meetings and workdays

c. Manufacturing Lead
   - Responsible for leading manufacturing efforts and overseeing work safety
   - Work with shop techs or professors to schedule shop or lab time as needed

Rama will function as the information manager as well as the testing and manufacturing lead. He will ensure that technical reports are up to date and managed properly through information management applications such as Google Drive, Gantt charts, and Google Calendar.

On the technical side, Rama will be responsible for managing the testing and manufacturing efforts for the team. This may include gathering materials, scheduling shop times, and coordinating with professors to gain insight on manufacturing processes, testing procedures, or testing fixtures and jigs.

4.4 Safety Hazard Identification Checklist

The safety hazard identification checklist provides a list of hazards regarding aspects of the project which have been identified to ensure they are addressed in the final design and manufacturing. The design hazard checklist can be seen in Appendix F at the end of this report. A total of six hazards were identified and potential corrective actions were brainstormed for this project. A quick description of each hazard and mitigation plans are as follows:

- Sharp edges or features on part
    - All composite layups have sharp edges where fibers inadvertently stick out, delamination occurs, or between seaming locations. These edges are sharp in nature and are easily mitigated by proper design or (1) sanding the edges with fine grit sandpaper and (2) use of rubber or soft materials to cover up exposed edges.

- Design requires user to exert abnormal effort or physical posture during usage
    - The latching mechanism may require the user to grip the canister base firmly while one or two hands are needed to open any releases. These releases can be made such that they are (1) light in force needed to open and (2) ergonomically placed for hands.

- Materials known to be hazardous to humans involved in the design or manufacturing
    - The current release agent used to remove the canister from the mold after curing is Frekote ®. Frekote is extremely toxic, causes skin irritation, and ingestion is harmful to the central nervous system or fatal under prolonged exposure. According to the National Fire Protection Association (NFPA) it has a flammability class of 3 indicating it is flammable at temperatures of 73 to 100°F. This can be corrected by (1) using respirators and latex gloves when handling and applying release agents and (2) using a wax based release such as Partall Paste® or water based release such as FibRelease® to remove the canister from the mold.

- System exposed to environmental conditions such as humidity, cold & hot temperatures.
    - The canister is intended for use in the outdoors. This implies it will be exposed to rough environmental conditions for long durations of time. Composite materials are particularly susceptible to hot temperatures, pressure, and moisture. Many epoxies are thermoplastics and will become fluid under high temperatures. Moisture in the air will affect the canister as carbon will retain 1-2% moisture by weight and wood based composites will start to deteriorate. Additionally, heating up of the canister may cause the internal air of the canister to heat up, expand , and increase in pressure. These three environmental issues can be addressed by (1) using epoxies that are solid at 120°F, (2) avoid exposure of wood or bamboo core material to the environment, and finally (3) ensure the composite can handle an internal pressure of 17.8 psia under heated conditions. The "dry" transition temperature of our prepreg epoxy is 185°F allowing hot air to escape after this threshold. See appendix B for hand calculations.

- System used in unsafe manner.
    - With the barrel shaped design it is possible that a small child or user may accidentally place the canister on his or her head. The canister could also accidently be sat on without the lid attached causing it to fall in. Backpackers should (1) keep out of reach

of children by providing a warning label for the user, and (2) not use the canister as a stool unless canister is secured completely.

- Other potential hazards.
  - Carbon dust can provide significant hazards in both manufacturing and use. Normal wear and tear on the canister will cause it to slowly degrade and dust may be spread around. The proximity to the user's food provides a slight concern as carbon dust may get in contact with the food. The effect of ingesting carbon dust is not known; however, it can cause skin and eye irritation to exposed areas. This can be improved by (1) adding a thin layer of sealant material to the inside of the canister to catch dust.

5 Manufacturing the Previous Canister Body

5.1 Overview

The Bear Minimum project is a continuation of the 2015-2016 senior project. To better understand the project, experience technical challenges, and improvements to make, it was determined it would be beneficial to manufacture the canister per design and manufacturing methods determined in 2015. Using previous equipment and tooling a canister was successfully created the test canister body. In accordance to our project scope the manufacturing process has been clearly documented below.

5.2 Molds

Figure 6. The bottom (front) and top (back) molds are shown. The bottom mold has the prepreg pressed into it ready for curing.

Reusing the previous molds from the last year was the most economical method of recreating the canister body. To make the molds, last year's project team machined medium density fiberboard (MDF) negative molds Cal Poly Aerospace Hangar ShopBot. Plaster was poured into the MDF mold creating a positive mold. These plaster molds were finally joined together and 9 layers of carbon fiber tooling prepreg fabric were laid-up over the plaster to create the final negative carbon mold shown in Figure 6. Finally, surface roughness and finish was improved by using Bondo auto filler and sandpaper.

5.3 Pre-Layup Procedure

Before the layup can begin, the equipment and materials must be obtained and processed. The silicon bladder used to form the inner surface of the canister is susceptible to wear and tear from handling and oven pressurization. A leak test was performed using water as the fluid of choice and careful observation of water droplets. One small leak was discovered and patched using two part 1:1 mix ratio EZ-brush silicon and letting set overnight at room temperature.

Secondly, both the bladder and mold surfaces must be cleaned, sanded if needed, and a release agent applied to the surfaces. A release agent ensures the composite part can easily be separated from the mold and bladder surfaces after it is done curing. The mold surfaces and bladder were coated with 5 layers of the release agent Frekote ® . Failure to apply a release agent or film means the part or mold must be removed by destructive methods.

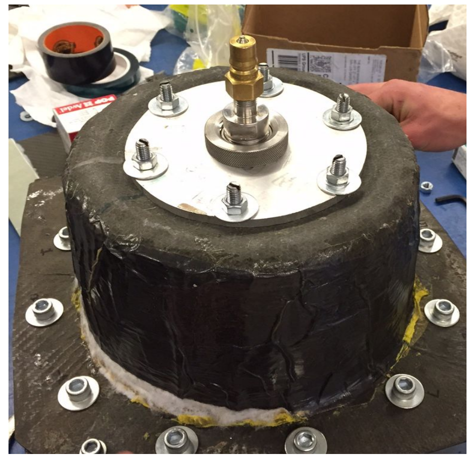
Minimal processing equipment was needed for the canister manufacturing. A small vacuum assisted in compressing the bladder to the insert through the top of the canister, then the pressure port was inserted and all seals were double checked.

5.4 Layup Procedure

The laminate plies are prepared by removing a section of the prepreg carbon fiber roll and laying it flat on a clean surface. Templates prepared from the 2015 Bear Minimum Project team act as cutting guidelines for the carbon sheets. Each template is taped to the plastic wrap on the prepreg and the shapes are cut out using an exacto knife.

The plies are carefully pressed into the canister top and bottom mold halves by hand and adjusted as needed. This technique can be seen in Figures 7 and 8 where carbon is being pressed. The top half of the canister needs four layers wrapped around the diameter. Each layer's seam needs to be rotated 90° from the previous layer's seam. This ensures that stress concentrations at the seams do not multiply in one area. These seam are also reinforced by overlapping the edge

layers by ¼” for strengthening. To ensure proper laminate bonding and minimal void content, care must be taken to ensure the layers are properly pressed against the mold and previous layers. This is done carefully by hand and then final pressing is done using a soft polymer squeegee. For difficult to access or stiffer areas a heat gun set on low at 225°F can be used to temporarily soften the prepreg so plies can then be fully pressed into the mold.



Figures 7 & 8. Left: Composite layers are pressed in by hand into the mold. Right: Alignment bolts holding mold assembly together with pressure port and plate at top.

The canister assembly consists of the bottom and top halves of the mold. The top mold half is carefully aligned and set down onto the bottom mold with a vertical 1” overlap seam. The two halves are easily aligned with four corner alignment bolts. Once aligned the two halves can be bolted together with the remaining 10 thicker bolts as seen on the right in Figure 8. The bladder can then be attached to the metal support plate, inserted into the cavity, and inflated.

5.5 Curing and Post Processing

The prepreg carbon fiber is manufactured as an epoxy-carbon matrix. The epoxy is a thermoplastic and must be heated to allow for changes in geometry. Heating of the prepreg carbon fiber is achieved with the help of a large oven and the Honeywell HC 900 controller. The curing process is specific to the epoxy and documentation needs to be obtained to verify the cure cycle. The composite canister is sealed up and placed into the oven for curing and the curing process is as follows:

- Load cure recipe into computer and remote load to Honeywell HC 900 oven.
- Place canister into oven away from walls. Elevate the canister with cylinder blocks to allow airflow under base and more even heat distribution.

- Pressurize canister bladder by attaching canister nipple to internal oven pressure line. Open pressure line and pressurize to 30 psi_g by adjusting pressure regulator.
- Start cure cycle: Monitor process and cure progress using integrated thermocouples. Cure canister using epoxy manufacturer's recommended cure cycle below:
  - **Ramp up** oven to 250° F at a rate of 4°F per minute.
  - **Hold** temperature at 250°F for 180 minutes (3 hours).
  - **Ramp down** temperature at rate of 4°F per minute until 130°F.
- Open oven doors to assist with cooling. Cool until 110°F.
- Shut off air pressure line, blowers, and oven power. Release bladder pressure with nipple before opening canister.

5.6 Results and Discussion

5.6.1 Overview

The prototype canister based on 2015's design specifications came out with a great surface finish. The extra time used to press in the fabrics to get a nice outside layer was quite evident in the final product. The team was happy with the results, but unfortunately there were difficulties removing the bottom half of the mold from the canister. Since the canister was not manufactured with the lid seam it provided new difficulties in removing the base mold.

5.6.2 Suggestions for Improvement

The manufacturing process provided valuable knowledge for working with prepreg carbon fiber. Improvements that can increase the efficiency and part quality are identified below:

1. Increase bladder pressure:

   A better part and surface finish would be achieved if the bladder pushes the prepreg carbon up against the mold walls with a larger force. We used a pressure of 25 psi_g when curing the canister which allowed for a good surface finish and ply lamination. A higher pressure would help achieve an even better lamination, even carbon distribution, and a superior surface finish.

2. Purchase a custom bladder:

   In order to increase the bladder pressure, it is recommended to purchase a custom bladder. This bladder would provide three main benefits. First, the bladder would have smooth surfaces. This would remove the seams and inconsistencies in the current silicon

bladder which diminish the quality of the surface finish of the part. Secondly, a higher pressure could be achieved due to the integrated pressure port into the bladder. Higher pressure would make the canister body more robust. Lastly, a more repeatable process could be achieved as multiple bladders in the future could be used knowing that they are identical.

3. Pleat composites as needed:

    As with many composite processes, successfully laying up a 2D ply onto a curved 3D surface poses issues. Small pleats in non-critical areas of the plies may help the composite better sit inside the mold. This would help the laminate better sit and adhere to the mold surface and previous layers.

4. Remachine top metal alignment ring:

    The metal alignment ring used at the top of the canister to align the pressure port was not made very precisely. A better machined alignment ring would prevent air from escaping, align the bolts better, and form a better seal on the vacuum line. A groove could also be cut for vacuum tape to be easily placed into. The tape helps form an airtight backup seal in case the pressure port has leaks.

5. Make better cutting templates:

    The templates used to cut the carbon sheets were SolidWorks drawings that were printed on a plotter. The templates were taped down to the prepreg sheets for cutting. By using plexiglass or acrylic templates, the manufacturer could cut more precise plies. An acrylic stencil would also be transparent which would help with alignment.

6. Improve method of releasing mold:

    The mold release agent used successfully worked on the top half of the canister, but the bottom half proved very difficult to remove without a lip to grab onto with our prototype canister. An improved mold release method could be achieved with better draft angle, mold geometry, or release agent.

6 Design Development

6.1 Overview

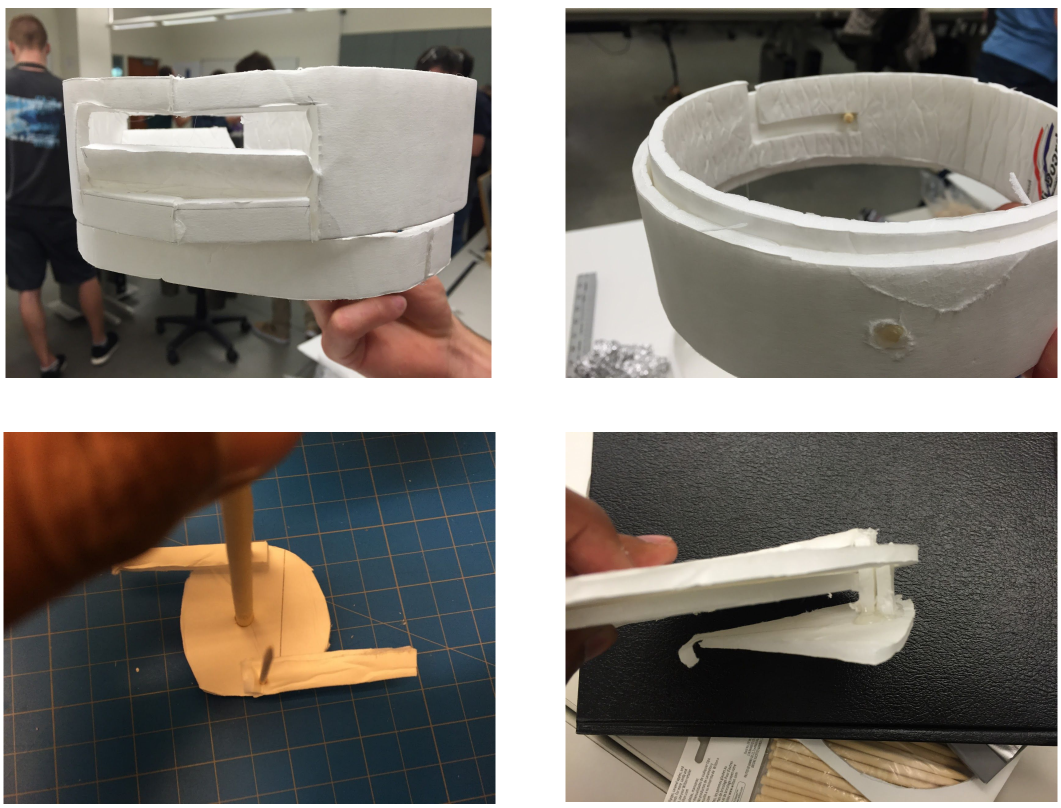
This section will discuss the methods deployed during the process of selecting the final design of the Bear Minimum project. The process started with the ideation phase where any possible solutions were conceived. Concept models were then completed to see physically how certain functions would work. The models were also constructed to do some simple prototyping of possible designs. To narrow down the number of possible designs, a Go/No-Go assessment paired with the Pugh matrix process was completed resulting in a narrowed down list of which ideas could be successful or what ideas to eliminate before further evaluation. For ideas that passed the Go/No-Go assessment of the Pugh matrices, sketches were created and are in Appendix D. Reference the sketches when the functions of the possible designs are unclear. A decision matrix process was then conducted to narrow down the possible ideas to one design for a middle opening canister, and one design for a top opening canister. Each selected design showed potential to provide an adequate solution to the problem. CAD models were constructed for these two designs and then were prototyped with wood, metal, and rapid prototyping methods. Hand calculations analyzing the two designs under load cases representative of the drop tests were completed to verify the strength characteristics of the possible designs. The strength analysis paired with the prototyping allowed for a mostly comprehensive evaluation to select a final design.

6.2 Ideation Process

The ideation process was launched using different techniques and strategies to think of creative solutions. Each strategy was geared towards generating ideas for a single function of the bear canister. Three functions were defined for the Bear Minimum canister lid: propagating loads, attaching to the canister body, and locking into the canister body. Three brainstorming session were held to generate as many ideas for each function as possible. Within the propagating loads function, ideas fell under two main categories: core materials and corrugation geometry. Over twenty ideas were generated for each function. The ideation process did not have any limitations, therefore ideas as unrealistic as a magnetic lid, or inception corrugation: corrugation within corrugation arose, still leaving a multitude of good ideas. After the ideation process, a simple Go/No-Go process, based on intuition, and Pugh matrix scores, was conducted to filter out the unrealistic ideas. However, aspects of these unrealistic ideas led to some improvements on other possible designs which were then evaluated further.

6.3 Concept Modeling

Selected ideas pertaining to a certain function of the bear canister were modeled with foam board and other craft supplies. Often, a new idea consists of a general plan of what it will look like and how it will behave. However, until it is modeled with materials or a CAD program, a mental void exists between the big idea and the details. The purpose of the concept modeling exercise was to physically show how certain ideas will function - a proof of the concept. Out of the three functions defined during the ideation process, only the attaching to the canister body and locking into the canister body functions were modeled. The propagating loads function was not modeled during this exercise because the only ideas generated for this function pertained to either (1) a core material which would be ordered from a third party manufacturer, or (2) a corrugated geometry, or pattern, which can be sketched very easily (e.g. a square corrugation pattern, or a trapezoidal corrugation pattern). Pictures were taken during the exercise and are shown in Figures 9-12.



Figures 9-12. Concept modeling prototypes are shown for (from upper left, going clockwise) a buckle crown, peg and channel, sliding spring loaded leaflets, and rotating spring loaded fingers attachment-locking mechanisms.

6.3.1 Overview

The purpose of the Pugh matrix process was to provide a preliminary evaluation of all possible designs which were generated from the ideation process and/or the concept modeling stage. Weighting of each criterion is not considered; therefore, the approach only reveals rough results. Four different Pugh matrices were evaluated during this process. They were adapted from the categories observed during the ideation process: core materials, corrugation geometry, opening location, attachment mechanism, and locking mechanism. The criteria by which each design was evaluated, was developed from the customer requirements and the design specifications. Depending on the Pugh matrix, only some of these criteria were relevant.

Once the matrices were outlined, each team member evaluated all possible designs within each Pugh matrix. The evaluation was a crude approach assigning a (+), (-), or (0) to each criterion compared to the baseline design for each alternative design. The baseline design was assigned zeros in each criterion. Evaluations for each team member were compared to create final Pugh matrices. Each design consideration was then evaluated using the Go/No-Go approach, and by comparing the sums of each design. The results, along with each Pugh matrix, are shown in the corresponding sections below. The Pugh matrices also allowed more idea generation for new designs. For example, poor scoring designs that scored well in a certain design criterion were observed, and in some cases, included in a well scoring design with a poor score in that same design criterion. A reevaluation of design criteria for poor scoring designs also took place to generate new ideas. Advantageous characteristics of one design were combined with advantageous characteristics of another to make a new design. All of these were strategies to execute an effective evaluation process.

6.3.2 Core Materials

The scope of the bear minimum project requires the lid to be a structural element. Plies of carbon fiber alone will provide strength in the principal 2D plane, but no structural strength in the normal “out-of-plane” direction. It may necessary to include a core material to be sandwiched in with the carbon fiber plies. Table 6 below highlights potential materials for the canister lid which were investigated. They include materials such as honeycomb, foam, wood, and other fibers.

From the composite cores, it was clear that the foam cores fared well because they are cheap, easily shapeable, and provide equal strength and stiffness in all directions (anisotropicity). Carbon short fibers performed better than honeycomb due to its superior bonding strength to carbon and its ease of implementation. Lastly, Syncore, an incredibly thin core material, preformed the best due to its lightweight and easy "peel and stick" implementation.

6.3.3 Corrugate Geometry

The core material added to the lid part needs to maximize "out of plane" strength and stiffness while maintaining the lowest weight possible. Simple repeating corrugate geometry is a simple way of increasing the moment of inertia of the composite sandwich. Various corrugate styles are listed in Table 7 with the traditional honeycomb (hexagonal) pattern being the clear winner. Trapezoidal cross sections also scored highly because trapezoids have a large base area to propagate the load and Divinycell foam can even be purchased in this geometry.

Table 7. The Pugh matrix evaluating corrugate geometry for lid composite sandwiches is shown. A Go/No-Go evaluation was then completed.

Criteria	Baseline	Alternatives					
	Square	Square Checkerboard	Trapazoid	Hexagonal (Honeycomb)	Triangle	Circular (Uniweave)	Linear (flat walls)
Strength	0	+	+	+	-	0	0
Ease of Implementation	0	-	0	+	0	0	-
Availability	0	-	0	+	0	+	0
Ease of Manufacturing	0	-	+	+	-	-	+
Sum of Positives	0	1	2	4	0	1	1
Sum of Negatives	0	3	0	0	2	1	1
Total	**0**	**-2**	**2**	**4**	**-2**	**0**	**0**
GO/NO-GO	GO	GO	GO	GO	NO-GO	GO	NO-GO

The square checkerboard is an alternative square pattern that would be woven in two directions forming a checkerboard of peaks and valleys. The checkerboard, while performing low, may be potentially the strongest option if feasible. The checkerboard, along with four other corrugate patterns will be investigated later for strength, weight and viability.

6.3.4 Opening Location

A standard lid-opening (top) canister and a canister splitting in the middle to open were evaluated in the Pugh matrix in Table 8.

Table 8. The two possible opening locations, top and middle, were evaluated against relevant design criteria using the Pugh matrix process. The Go/No-Go evaluation is shown below.

Criteria	Baseline	Alternatives
	Top	Middle
Strength	0	+
Manufacturing Fesability	0	-
Weight	0	0
Ease of Use	0	0
Aesthetics	0	+
Cost	0	+
Sum of Positives	0	3
Sum of Negatives	0	1
Total	**0**	**2**

GO/NO-GO	GO	GO

Due to the rough number estimates of the Pugh matrix, both ideas were assigned a "GO". Both opening locations were further evaluated in a more comprehensive decision matrix.

6.3.5 Attachment-Locking Mechanism

The attachment mechanism and locking mechanism categories were combined to form one Pugh matrix due to the dependent relationship between the two. For example, a threaded attachment mechanism cannot be paired with rotating, spring-loaded leaflets. This is because the leaflets would not have a lip to engage with (see attachment D for sketches of each attachment and locking mechanism). In the Table 9 Pugh matrix below three attachment mechanisms were considered: flush, threaded, and buckle crown. Within these attachment mechanisms, various locking mechanisms were considered - all generated during the ideation phase.

The cutoff score for this Pugh matrix was -1. This left us with six possible attachment-locking mechanisms to be evaluated in a decision matrix.

6.4 Weighted Decision Matrix Process

6.4.1 Overview

Generating weighted decision matrices is the second round of “controlled convergence” of our potential ideas. The concepts which received a “GO” status from the pugh matrices were used in the decision matrices. The weighted decision matrices help us to refine the potential solutions by increasing the depth and criteria used to evaluate the concepts.

Similar to the Pugh matrices, the format of decision matrices is the same. Each concept is given a score for each criteria. However, each criteria was assigned a weight factor that the team deemed appropriate for the criteria. For example, having a high strength was weighted much higher than availability of the material. Each concept graded was given a score for each criteria. This criteria score was then multiplied by the criteria weight factor to get a total weighted score. The sum of the weighted criteria scores gave was the final score for the concept. This final score, although having no units or apparent scale, shows how concepts fare relative to each other.

6.4.2 Core Materials

Using the concepts that passed the pugh matrices Go/No-Go rating the core materials were analyzed more in depth. The areas of weight and strength were weighted to be the most important categories. The results below in Table 10 show that similar to the pugh matrices the carbon short fiber, and Divinycell foam core performed well, while syncore performed the best with score of 56, respectively. Syncore was the clear winner due to its small size and weight, ease of implementation and highly available, however it should be mentioned that based on application or geometry other materials should still be considered for areas under high shear or normal stress. For example, honeycomb is excellent in normal stress whereas kevlar is excellent in shear. The lid will generally be more in normal stress, while the middle seam might be more in shear stress.

6.4.3 Corrugate Geometry

Core materials provide baseline material strength, but corrugate geometry will provide thickness, increase moment of inertia, and reduce weight by taking out unused core material. The most common corrugate types were analyzed based on their basic cross section shape such as a square, circle, triangle, trapezoid, and hexagon. The winning shape, a hexagonal pattern, is common in honeycomb paneling. A repeating trapezoidal pattern also scored highly as it has a large base to propagate the load to the bottom supporting material. The square corrugate material scored the lowest due to its complex manufacturing and unavailability. The score breakdowns can be seen in Table 11 below.

Table 11. A final decision matrix was completed for the corrugated geometry.

Criteria	Weight	Corrugate Material									
		Square		Square Checkerboard		Trapazoid		Hexagonal (Honeycomb)		Circular (Uniweave)	
		Score	Wgt. Score	Score	Wgt. Score	Score	Wgt. Score	Score	Wgt. Score	Score	Wgt. Score
Strength	4	2	8	3	12	3	12	3	12	2	8
Ease of Implementation	3	2	6	1	3	2	6	3	9	2	6
Availability	1	2	2	1	1	2	2	3	3	3	3
Ease of Manufcaturing	3	2	6	1	3	3	9	3	9	1	3
Weight	5	2	10	1	5	2	10	2	10	3	15
Repairability	2	2	4	1	2	2	4	1	2	3	6
Total Score		**36**		**26**		**43**		**45**		**41**	

6.4.4 Opening Location

The only two opening locations considered were a top opening and a middle opening. For the middle opening canister, the entire canister body would split in the middle, therefore exposing the inside of the canister. It is important to note that not all top opening canisters or middle opening canisters will exhibit the same characteristics with respect to the criteria in the decision matrix seen in Table 12. However, this gives a general comparison between the two.

Table 12. Ideas for the opening location are evaluated using a decision matrix. The strength, manufacturing feasibility, and weight were the most important criteria for the opening location.

Criteria	Weight	Opening Location			
		Top		Middle	
		Score	Wgt. Score	Score	Wgt. Score
Strength	5	2	10	2.5	12.5
Manufacturing Fesability	5	2	10	2	10
Weight	5	2	10	2	10
Ease of Use	3	2	10	1	5
Aesthetics	1	2	10	3	15
Cost	3	2	10	2.5	12.5
Total Score		**60**		**65**	

The middle opening canister scored better than the top opening canister. The main reason was due to the strength evaluation. The middle opening canister was assumed to exhibit a stronger response to the loads the canister will experience in the drop tests due to the lack of a stress concentration area near the lid opening. This stress concentration area was the reason why last year's senior project canister failed. Because there is more subjectivity in this decision matrix than the others that were evaluated, a conclusion based on the score alone could not be made. It should be noted that the final evaluation will not completely eliminate a design based on the opening location.

6.4.5 Attachment-Locking Mechanism

The attachment-locking mechanisms were split up into two groups: mechanisms that would work with a top opening canister, and mechanisms that would work with a middle opening canister. Note that some attachment-locking mechanisms could fall under both groups. All but one of the evaluated ideas were ideas generated from the ideation phase. The Flush Fit, Internal Ring Pressure Tabs with Channels for a middle opening canister was thought of after the Pugh matrix process by combining advantageous characteristics from two other ideas. This idea utilizes the ring pressure tabs along with a female channel system. The decision matrix is seen in Table 13 has conditional formatting applied to the total weighted scores for a color representation of the scoring with green being the highest scoring. Sketches of each design were created for clarity of how the design works and are shown in Appendix C.

Coincidentally, the overall highest scoring attachment-locking mechanism was the idea generated after the Pugh matrix process. From the decision matrix results, the Flush Fit, Internal Ring Pressure Tabs with Channels for a middle opening canister scored the best in the middle opening group. The Flush Fit, Quarter-Turn Button (e.g. Garcia Model) for a top opening canister scored the best in the top opening canister group. After discussion about the evaluation process up to this point, these ideas were decided to be the two final attachment-locking mechanism designs which then went through an engineering assessment process.

6.5 Final Selected Designs

6.5.1 Overview

A final selected design was chosen for the two opening locations considered (top and middle of the canister body). Because having the opening location in the middle is a deviation from the design of typical bear canisters, comparing middle opening designs directly to top opening designs was not desirable to pick one final design. To arrive at the two final selected designs, the decision matrix results were observed and discussed. The highest scores for each opening location were taken for the final selected designs. This did not necessarily have to be the criteria as intuition played a factor when selecting the designs as well. Because both team members also agreed that the two winning designs made sense intuitively, the designs were confirmed. The final two designs were assessed according to a variety of engineering criteria. Sections 6.5.2 and 6.5.3 discuss this process in detail for each final design.

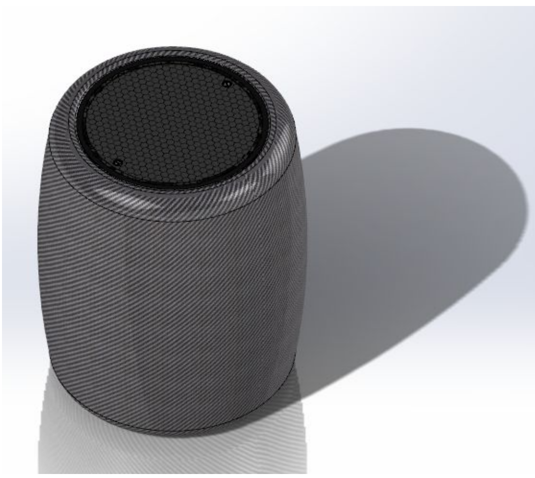
6.5.2 Engineering Assessment: Top Opening Design

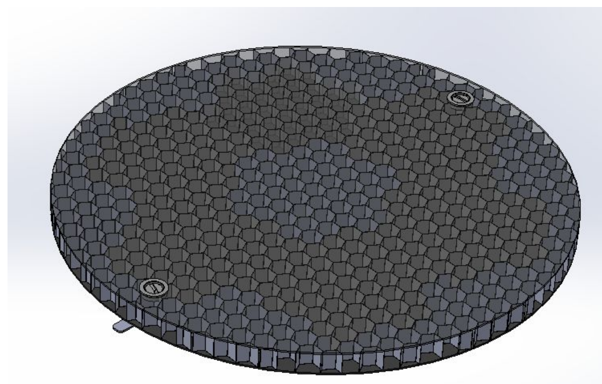
6.5.2.1 Overview

The selected design for the top opening canister is the simplistic quarter turn button latching mechanism similar to the Garcia canister. The quarter turn scored the highest on our decision matrix with a score of 52, four points higher than the second place design at 48. The canister design excelled due to its simplistic design, ease of manufacturing, low cost, and flush top made with a stiffening core material. The canister lacked in areas such as ease of opening due to the button needing a tool to open it. The canister design also scored just average in strength and bear resistance due the the high reliance on the two quarter turn button tabs. The other concern is that the strengthened lid may not structurally help the side loading case deflection which was the primary failure of the 2015 canister design.

6.5.2.2 Geometry & CAD Modeling

The geometry of the canister lid is quite simple and involves a few layers of carbon fiber with a honeycomb core. This composite sandwich provides good normal strength due to the honeycomb core and the carbon sheets provide shear strength. The lid is held in place with two metal quarter turn button pins which sit flush on the surface of the composite so that a bear cannot grab onto them. The quarter turn buttons have a small latch tab on the bottom that prevents the lid from falling or being pulled out. The lid and overall assembly renderings can be seen in Figures 13 and 14 below.





Figures 13 & 14. (Left) The canister assembly with the lid installed and locked was rendered. (Right) The canister lid rendering shows the honeycomb core and latching tabs.

6.5.2.3 Prototyping

The bear minimum team created a prototype of the quarter turn button lid using a composite sandwich, two pins, and two spring clips. The composite sandwich is thicker than desired but shows the honeycomb core well. After a composite plate was cured, a 6” diameter circle was cut out using a vertical bandsaw. Two holes were drilled in ¾” from the edge using a ½” drill bit for the pins. The top and bottom of the lid seen are seen in Figures 15 and 16. with the pins and spring latch tabs pushed into place. The spring latch tabs were cheaper and faster than manufacturing a solid metal tab for the latch and used just to show the tab concept and functionality.


Figures 15 & 16. (Left) A trimetric view of the lid prototype shows the preliminary button placements and protrusions. (Right) The bottom view of lid prototype shows the latching tabs.

6.5.2.4 Load Case Analysis

The main loading cases for our bear canister are the 100 lb_f weight dropped from 1 foot on the top of the canister and also the side of the canister. Simple hand calculations shown in Appendix C approximate the uniform pressure exerted on the canister lid as 226 psi. The model was created in solidworks and loaded into Abaqus for FEA analysis. The part was modeled using the following input settings and assumptions in Table 14.

Table 14. A lot of generalizing assumptions were made during for the preliminary FEA completed. This decreases the accuracy of the results.

Input Settings	Assumptions Made
● Material: Aluminum T6061 ○ Modulus of Elasticity (E) = 10E6 psi ○ Poisson's Ratio (v) = 0.33 ● Element type: Quadratic Tetrahedral elements with 75% Nodal Averaging ○ Element size = 0.20 inch ● Load: Uniform Vertical Pressure 226psi ● Boundary Condition: Pinned edges all around. (U1 = U2 = U3 = 0)	● Fixed statically all around, no rollers ● Conservation of energy on weight drop ● Isotropic material in elastic region ● Elastic modulus is equal to universally accepted value. ● Uniform pressure: weight contacts all of lid at same time ● No buckling of core material. ● Stress concentrations ignored where unrefined mesh cause divergence

Due to the long list of assumptions, our preliminary FEA results are of rough order of magnitude. The numbers may be significantly off from actual deflections, but by using the same

conditions and materials for each model, the relative differences between the two were observed. It should be of note that some high stresses were observed where stress concentrations occur and diverge infinitely. These concentrations did not include fillets for these models, and thus were not included in as the maximum stresses when calculating the factor of safety. The Von Mises stress visualization in Figure 17 shows that stress is highest at the edges and center of the lid.

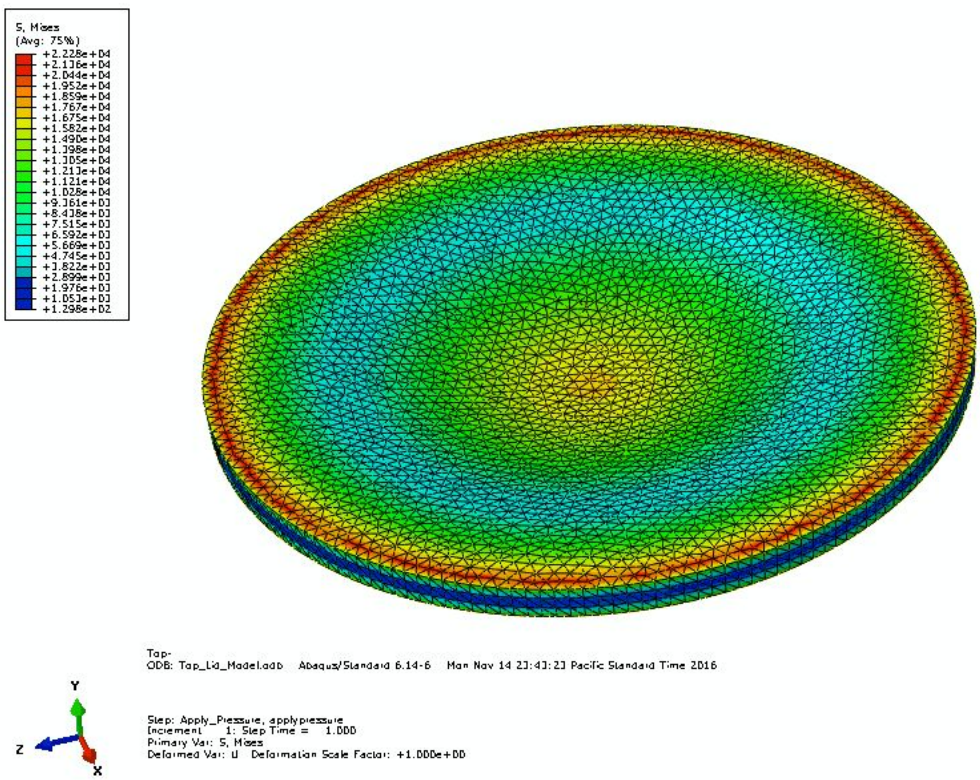


Figure 17. The Von Mises stress visualization for the lid of the top opening design shows maximum stresses around the top outer diameter.

In addition to the Von Mises stress, deflection of the lid is also of concern. The lid cannot deflect past the 0.25 inch deflection requirement. The material used for the FEA analysis is aluminum which has a very high elastic modulus. This means are deflection values are not valid for the final lid and are merely for comparison and identifying areas of high deflection. The lid is similar to a simply supported beam and was modeled as disk that was pinned all around the edge. The analysis determined the material would deflect around 0.05 inch, as seen in Figure 18, and had a safety factor or 1.89 meaning the aluminum would not fail.

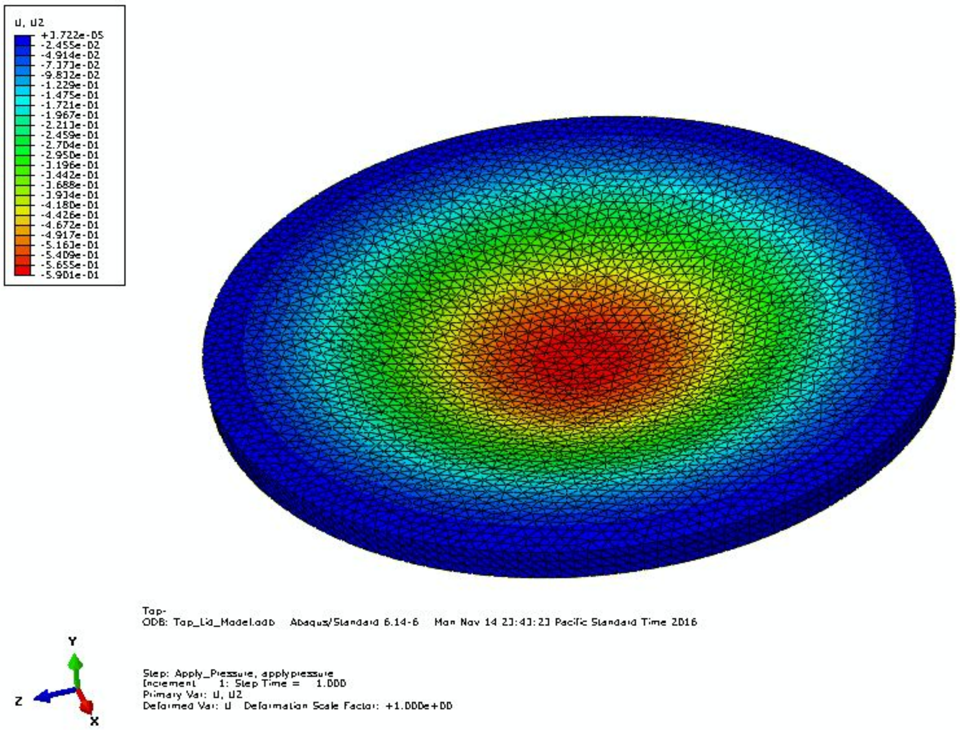


Figure 18. A deflection visualization for the lid of the top opening design shows maximum deflections at the center of the lid.

6.5.2.5 Material Selection

The materials of choice for the composite lid are carbon fiber and a lightweight core material. The first round will be made out of twill weave carbon fiber with a nomex honeycomb core. The honeycomb provides vertical stiffness and the carbon provides resistance to shearing and holds the core material in place. Lighter core materials and different geometrical patterns will be experimented with to improve the lid, such as a trapezoid shape Divinycell or square corrugate. The quarter turn button design will remain relatively constant with a metal pin, however, the rotated tab material can be changed.

6.5.2.6 Manufacturing Process

A case study was performed to research and evaluate three different manufacturing processes for the design of the finalized middle opening attachment-opening mechanism. All manufacturing research and challenges for the middle opening design is consistent for the top opening design. This case study is included in Appendix G.

The manufacturing process for the lid is quite simple involving only one layup needed. The individual components will need to be prepared as necessary:

1. Carbon plies and core material:

   The twill weave prepreg carbon and core material will be one layup with the core material being cut and sized accordingly. The core will be cut to approximate size and geometry and inserted into the sandwich. The materials need to be high temperature safe for when the part is cured. After curing, a dremel will be used to remove excess carbon.
2. Metal quarter turn pins and tab:

   The metal quarter turn pins will be purchased because they are inexpensive and widely available. If the diameter is not within tolerance they can be turned on a lathe to a specified diameter. The rotating tab which is the latch for closing the canister lid is packaged with purchase of the pins.

6.5.2.7 Testing

The lid will be tested in accordance to our project requirement which specifies a 100 lb_f weight be dropped from 1 foot onto the top of the canister and side of the canister. The deflection shall not exceed 0.25" to pass the test. Other tests of interest are the composite buckling test and tolerance gap test on the outer diameter of the lid. A buckling test would tell us how much pressure normal to the surface would cause the core material to crush or buckle. The results can be used to modify the core material or thickness. The side tolerance gap test would involve applying a varied load to the outer edge using an instron or other compression machine. The deflection would then be monitored until the sample reaches its yield strength and is outside of the elastic regime. The point of maximum elastic deformation governs the manufacturing tolerance needed on the outer radius of the composite lid.

6.5.2.8 Cost Estimate

A preliminary cost estimate for this design was conducted to compare it to the cost for the middle opening design. The part costs are shown in Table 15.

Table 15. A rough cost estimate is shown for each part of the selected top opening design.

Part	Quantity	Estimated Cost
Top half of canister body	1	$0.00
Bottom half of canister body	1	$0.00
Quarter turns	2 (subject to change)	$0.00
Lid (excluding core)	1	$0.00
Core	1	$20.84
Total		**$20.84**

The cost for each part will depend on a variety of things including the manufacturing process, the materials, and the molds (if necessary). If any of these change the next time the parts are manufactured, the cost could increase or decrease. With the current intended manufacturing process and materials list, the only costs lie in the core. High temperature Nomex honeycomb foam board was used for the initial cost analysis ($20.84 for a 625 mm x 625 mm x 5 mm board) [19]. Quarter turns were left over from last year's project which were unused. For the preliminary cost analysis, these stock parts were selected; therefore, the cost was zero. Excess prepreg carbon fiber was leftover from last year's project as well meaning the lid (excluding the core), and both halves of the canister body was projected at $0.00.

6.5.2.9 Incomplete Concept Considerations

If the top opening design is selected, many iterations will take place to better meet customer needs and/or specifications. Currently, the design only gives a rough idea of how it will function, and much more attention needs to be focused on details. A list of modifications to the current design and incomplete considerations is listed below:

1. The interface between the lid and canister body will be further analyzed. Currently, the interface is a flush fit with the current rolled edge design of the canister body. This will achieve the functions of attaching and locking to the canister; however, it might not achieve the propagating loads function. Options for this interface include, but are not limited to, an insert on the inside of the canister body which interfaces with the lid, or giving the canister body thickness with the use of a core material. The thickness of the body would allow the load to be transferred over a larger area. This affects the user convenience, strength and stiffness properties, and the weight of the canister.

2. The size, shape, number, and location of the quarter turns will be investigated. Stock quarter turns will also be selected to decrease cost. This affects the convenience for the user, the weight, manufacturability, and the strength and stiffness characteristics.

3. If a core is selected, the type, material, size, and shape will be looked into. Two types of cores were observed during the design development phase: standard cores, and a corrugated core. These will be further analyzed and tested to see which one is the lightest core which still provides adequate strength and stiffness properties. This affects the weight, manufacturability, strength and stiffness properties, and the canister volume.

4. The tolerances for all of the mating between parts will be further analyzed. This affects the manufacturability of each part, the aesthetics, the strength and stiffness characteristics, and the convenience for the user.

5. The dimensions of the diameter and thickness of the lid will be also investigated. The diameter has roughly been defined by the templates from last year which only allows for a certain size lid to fit onto the top half of the canister body. However, these templates could be modified to accommodate for different diameters. This affects the weight, and strength and stiffness characteristics, and interior volume.

If this is the selected design moving forward, all of these considerations will be discussed and finalized in the Critical Design Report.

6.5.3 Engineering Assessment: Middle Opening Design

6.5.3.1 Overview

From the decision matrix, the final selected design for the middle opening canister was the flush fit, internal ring pressure tabs with channels. It features a spring loaded locking mechanism where the hoop of the top half of the canister is compressed due to the interference of the pressure tabs and the canister body. The top half of the canister then locks into place when the pressure tabs extend into a cavity. This motion is restricted by a channel system which makes the design more bear proof. The concept is in its preliminary stages, so many features, dimensions, and geometries can, and most likely will, be revisited.

6.5.3.2 Geometry & CAD Modeling

The middle opening design was modeled in SolidWorks to gain a good visual representation of the functions and characteristics of how the canister will operate. The layout drawing, showing an exploded view of the components of the canister assembly, can be seen in Appendix K. The canister assembly consists of five parts: the two halves of the carbon fiber canister body, the male and female parts of the internal attachment ring, and the retaining plate. The two halves of the canister body use the design of the bottom half from last year's senior project, twice. The design for this year's project is in the internal attachment ring. A SolidWorks rendering showing the male and female parts of the internal attachment ring are shown in Figure 19.

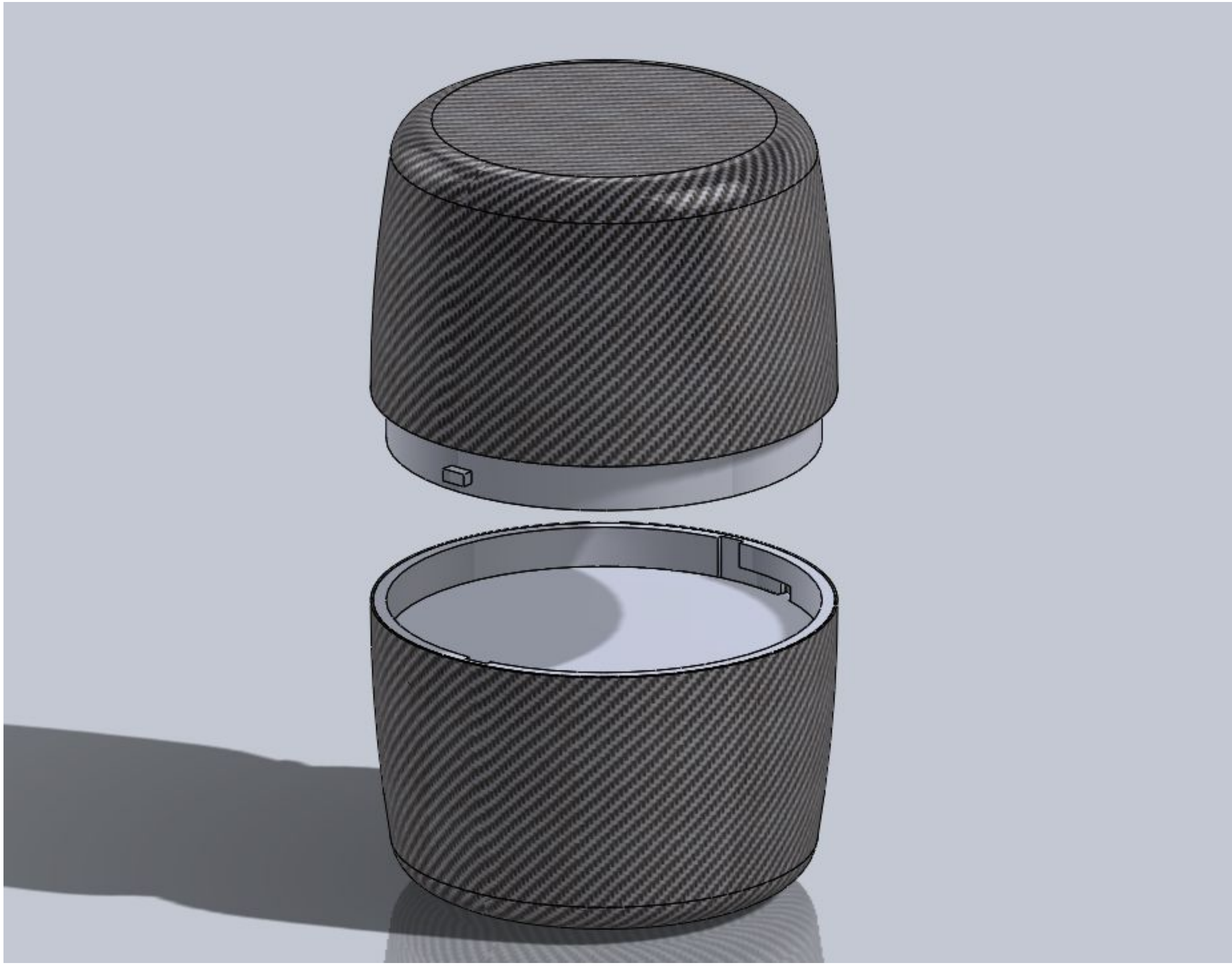
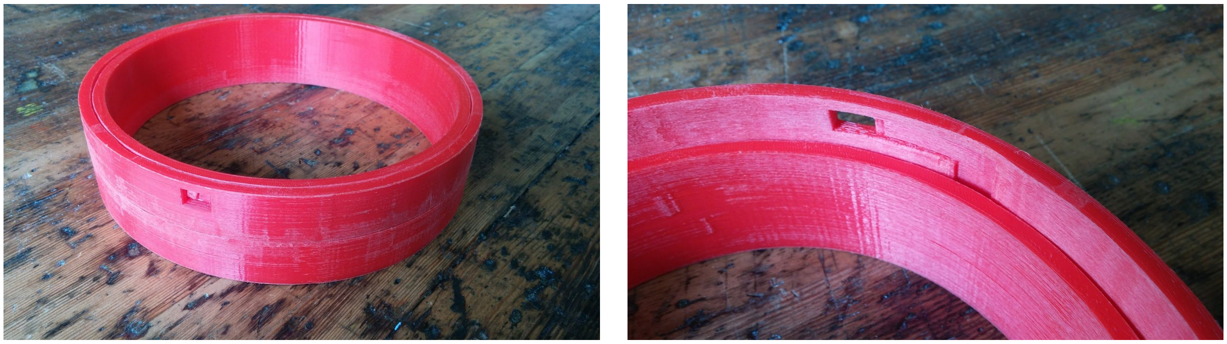


Figure 19. A rendering of the middle opening selected design is shown. Note that the retaining plate is the bottom in this view to see the interface. When closing the canister, the configuration will be flipped.

The male part of the internal attachment ring will be on the inside of the bottom half of the canister body. It will be attached so that the top surface of the larger diameter section will be flush with the top surface of the bottom half of the canister body, leaving the smaller diameter section with the pressure tabs protruding up above the canister body.

6.5.3.3 Prototyping

Rapid prototyping was completed for the two internal rings. The 3D printed parts were post processed to achieve clearance between the male and female rings. They are shown in Figures 20 and 21. The notches were over sanded to where no interference between the channel and the notch existed. For the notches to snap into the cavities, interference has to exist between the notches and cavities. This will be featured in future prototypes. The proof of concept for the attachment and locking mechanism was achieved, which was the main goal for the prototypes.



Figures 20 & 21. (Left) Sections of 3D printed prototype attached and locked. (Right) Close up view of the slot latching mechanism.

6.5.3.4 Load Case Analysis

Similar to the top opening canister design, the middle opening canister ring was analyzed in Abaqus. The boundary conditions, loads, program settings, and material were all held constant. This allows the two designs to be relatively compared for strength and deflection. The deflection visualization in Figure 22 for the 100 lb_f load case shows the middle opening design having relatively even stress distribution in the ring with the exception of a stress concentration at the 90° lip. This lip has infinite stress because there is no fillet in the corner. The more even stress distribution may prove advantageous because composite fibers won't need to be aligned in the loaded direction, thus allowing the same material to be used throughout the entire part.

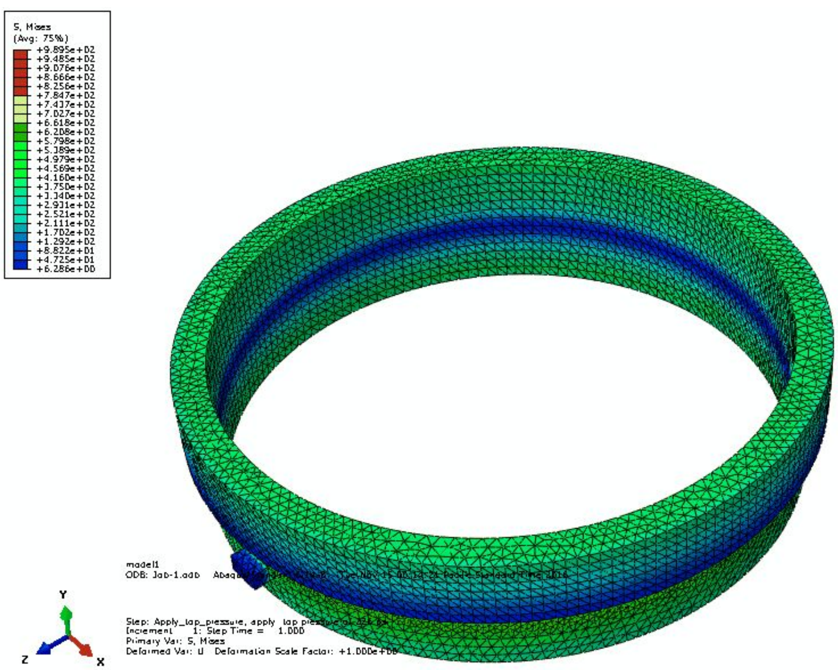


Figure 22. Von Mises stress visualization is shown for an analogous middle aluminum ring.

The middle opening design also showed a similar magnitude of deflection at around 0.05 inches. Figure 23 shows the deflection being the lowest at the fixed base and increasing as you move further up the ring.

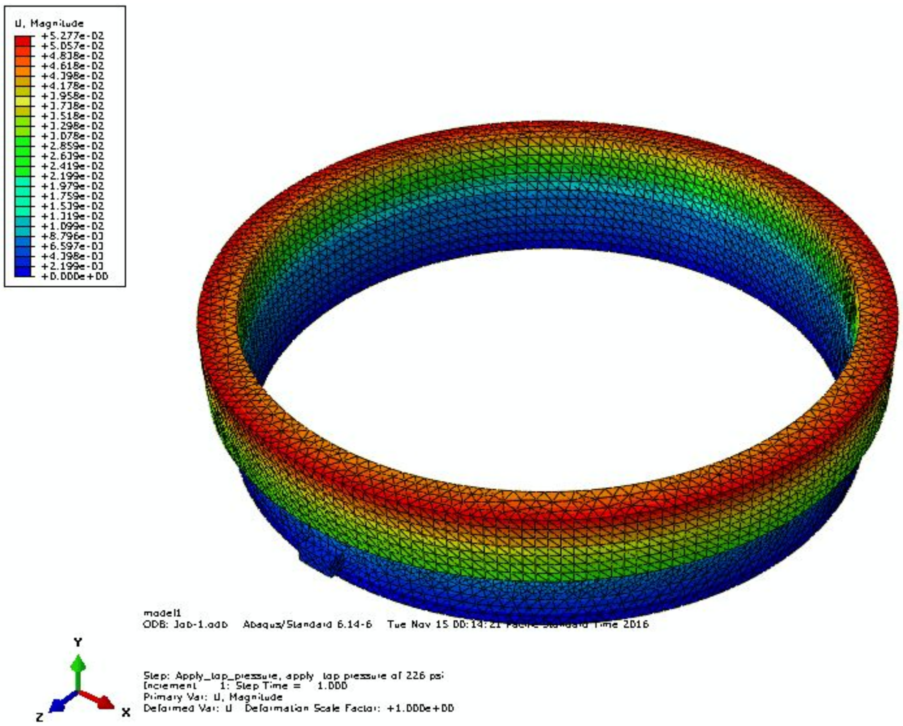


Figure 23. Deflection visualization for an analogous middle aluminum ring shows the largest deflections along the upper edge of the ring for a load in the critical direction.

A summary of the results for both FEA models can be seen in Table 16 which compares the normalized deflection, stress, and factor of safety for each model.

Table 16. Summary of FEA Results for the middle and top opening designs.

Criteria	Top Opening	Middle Opening
Normalized Maximum Deflection in Critical Direction [in]	1.12	1.00
Max von Mises Stress [psi]	16,911	9,889
Factor of Safety [-]	1.89	3.23
Model Degrees of Freedom [-]	273,012	237,963

The deflection of both models was comparable, with the side opening deflecting 12% less. The side opening also boasted a lower maximum stress and a corresponding higher factor of safety. Both models were analyzed using a similar number of degrees of freedom ensuring that one result was not significantly more accurate in computation.

6.5.3.5 Material Selection

Twill weave carbon fiber prepreg will be used for the first round makes of all parts. This is because the material is left over from last years project. The prepreg carbon fiber was determined to be an adequate solution to meet the strength and weight specifications during last years project. Some parts for this design might have too sharp of contours to capture with the prepreg carbon fiber. If this is the case, alternative materials such as Ultem resin, short fiber composites, or plastic materials may be considered.

6.5.3.6 Manufacturing Process

A case study was performed to research and evaluate three different manufacturing processes for the design of the finalized middle opening attachment-opening mechanism. The above section summarizes the case study. This case study is included in Appendix G.

The initial manufacturing process for each part of the middle opening design is listed below. As of right now, all materials will be carbon fiber prepreg. Achieving a well manufactured part with carbon fiber typically takes many trials. This is because a lot things can go wrong during this process. This plan sets out an initial manufacturing process. Depending on how the process goes, changes will most likely occur to ensure a more effective, reliable, and repeatable process.

1. Canister body:

   One of the required canister body halves has already been made (described in Section 5). The other half of the canister body would need to be made; however, the process is already known.

2. Retaining plate:

   The retaining plate will be a two ply layup of the prepreg carbon fiber. Two plies will allow for a lightweight part that will still be rigid when food is on it. The retaining plate will be manufactured with a vacuum bag lay up process.

3. Male internal attachment ring:

   A negative foam mold of the part without the pressure tabs will be created using the ShopBot. A positive plaster mold will then be made from the foam molds. The final negative carbon fiber molds will be made by laying up prepreg carbon fiber around the

plaster mold. The part will then be laid up in the carbon fiber mold using a bladder molding manufacturing process. The pressure tabs will be simultaneously laid up using a vacuum bag manufacturing process. After curing, the two pressure tabs will be post bonded to the male internal attachment ring. The amount of plies is unknown at this point. This will determine the thickness and weight of the part.

4. Female internal attachment ring:

   The same mold used for the male internal attachment ring will be used. The smaller diameter section will be filled in with either a metal or carbon fiber filler part exposing just the larger diameter section. The part will be laid up in this filled-in mold using a bladder mold manufacturing process. After curing, the channel and cavity will be cut out of the carbon fiber. The amount of plies is unknown at this point. This will determine the thickness and weight of the part.

6.5.3.7 Testing

Because there is no lid in this design, separate lid testing does not need to take place. Non-destructive testing and acid digestion testing are tentatively planned to be conducted to determine the void fractions and weave distortions in each part. The main stage of the testing phase will be the drop tests the SIBBG used to administer. A 100 lbf weight will be dropped on the side of the canister and on the top of the canister. If the canister does not deflect over 0.25 in and does not fail at any section, the canister passes. The last phase of the testing process is live bear testing. If the canister does not fail within one hour of contact with the bear, the canister passes and gets the certification.

6.5.3.8 Cost Estimate

A preliminary cost estimate for this design was conducted to compare it to the cost for the top opening design. The part cost breakdown is shown in Table 17.

Table 17. A rough cost estimate is shown for each part of the selected middle opening design.

Part	Quantity	Estimated cost
Half of canister body	2	$0.00
Restraining plate	1	$0.00
Male interior attachment ring	1	$144.52
Female interior attachment ring	1	*included in male interior attachment ring cost
Total		**$144.52**

The cost for each part will depend on a variety of things including the manufacturing process, the materials, and the molds (if necessary). If any of these change the next time the parts are manufactured, the cost could increase or decrease. With the current intended manufacturing process and materials list, the only costs lie in the internal attachment rings, specifically the cost to make the mold. High density foam board will be necessary for the foam molds ($98.95 for a 4" x 24" x 82" board) [23], and plaster ($45.57 for a pint) [24] will be necessary for the plaster molds. Because the female internal attachment ring will utilize the same mold, this cost is included in these material costs. Excess foam and plaster might be left over from last year making the total cost zero. All materials used will be prepreg carbon fiber left over from last year's senior project. This is why the material cost for the attachment rings and the total cost for the canister body and the retaining plate will be zero.

6.5.3.9 Incomplete Concept Considerations

If this design is selected, many iterations of the design will take place to better meet customer needs and/or specifications. The current design does not take into consideration a lot of important design features. A list of modifications to the current design and incomplete considerations is listed below:

1. The orientation of the male and female internal attachment ring parts will be looked into. This means, what are the benefits and drawbacks of having the female part attached to the lower half and the male part attached to the upper half of the canister body and vice versa. This affects the interface with the retaining plate, and the convenience for the user.

2. The size and shape of the pressure tabs will be looked into. A possible shape might be comparable to the pressure tabs on the BearVault canister: a sawtooth shape. This affects the convenience for the user, the weight, and the strength and stiffness characteristics.

3. The size and shape of the channel will be looked into. This affects the convenience for the user, and possibly the strength and stiffness characteristics, and the weight.

4. The tolerances for all of the mating between parts will be looked into. This affects the manufacturability of each part, the aesthetics, the strength and stiffness characteristics, and the convenience for the user.

5. The dimensions of the male and female internal attachment ring parts, and the retaining plate part will be looked into. This affects the weight, and strength and stiffness characteristics, and internal volume.

6. The interface of the retaining plate with the male or female internal attachment ring part will be looked into. This affects the weight, user convenience, and possibly the strength and stiffness characteristics.

7. The shape of the male and female internal attachment ring parts will be looked into. The parts have to be circular from the top view in order to fit into the canister body. One such possibility is to section the internal rings are where the channels and pressure tabs will be.

If this is the selected design moving forward, all of these considerations will be discussed and finalized in the Critical Design Report.

6.5.4 Conclusion

After the engineering assessment, the middle opening design is preferred by both team members. Both designs passed the proof of concept for two of the three functions defined in the ideation phase: attaching and locking to the canister body. These functions were verified after the prototypes were constructed. Preliminary FEA was completed to verify the third function of propagating loads. With the FEA, the middle opening design compared to the top opening design showed a factor of safety of approximately 1.8 times greater. The middle opening design also showed deflections in the critical direction of approximately 1.1 times less than the top opening design. As this was discussed before, it is important to restate that the assumptions and input settings for the FEA were not fully inclusive with respect to the canister's material properties, geometries, and loading cases. The results from the FEA represent a crude representation of the canister's response.

Along with the verifying and comparing the three functions for both designs, qualitative factors of the designs were also taken into consideration. One such factor was user convenience. Early concerns for the middle opening canister suggested the opening and closing of the canister would be an issue for the user. With the addition of the retaining plate, the design became more convenient for the user. Also, a valid argument was brought up stating the middle design would be more convenient than the top opening design. If small food items fall through the canister to the bottom of the canister when hiking, the entire canister has to be emptied to reach them. For the middle opening design, the two halfs are compartmentalized meaning that only half the canister would have to be emptied to reach the food item. Also, having a compartmentalized canister gives the user the option for a more strategic method of packing food items.

With everything being considered, Nick Hellewell and the team members for this year's Bear Minimum project have selected the final design for the attachment and locking mechanism to be the middle opening, flush fit, channeled, internal ring pressure tab system.

7 Final Design Details

7.1 Introduction

Once the middle opening, flush fit, channeled, internal ring pressure tab system was selected, a more focused and detailed process was conducted to determine the specifics of the design. This included, but was not limited to, things such as the size and shape of part features, tolerances between fittings, manufacturing processes, material selections, cost analysis, and safety considerations.

During the course of writing this report, a test was carried out to investigate the deflection and the ultimate compressive strength for the half canister body. After analyzing the test results, a large change was made to the design. The half canister body failed at 439 lbs while being deflected by 1.71 in. Figure 24 shows the resulting deflection from the load near failure.

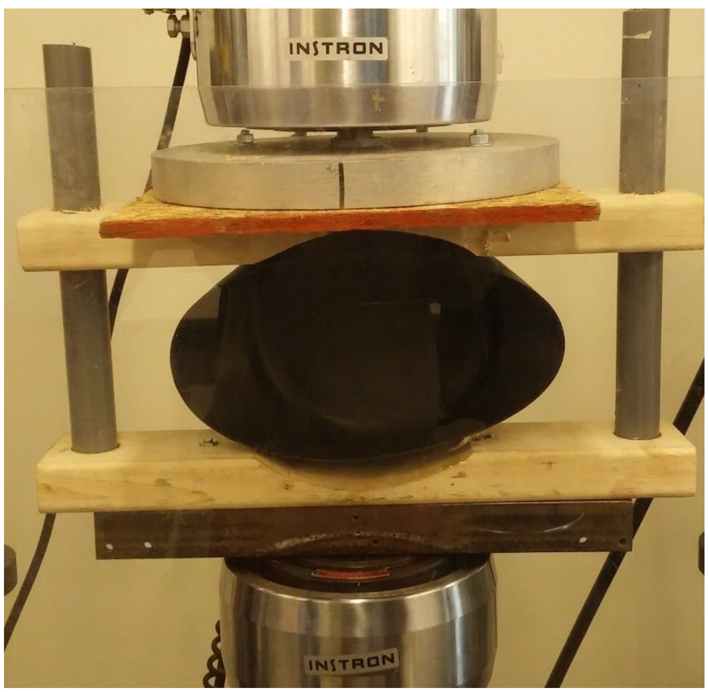


Figure 24. The canister half is shown near ultimate compressive loading. The deflection at failure was 1.71 in.

The compressive strength from the test was more than sufficient to pass the drop test. However, the large deflection observed would eventually lead to an entirely new design of the ring(s). The previous design was reliant of the canister halves to maintain the load while the

rings were merely for alignment. From the instron testing it was determined that the middle ring must be able to stiffen the canister and take a portion of the canister in order to meet our force and deflection requirements. Section 7.2 will describe the new design in detail.

7.2 Design Description

7.2.1 Physical Features

7.2.1.1 Canister Body

The canister body will be have the same geometry as the canister body that last year's team designed. Similarly to the other middle opening designs the canister body will consist of two canister bottoms. Therefore, the mold for the bottom half of the canister will be the only necessary mold for manufacturing the two halves. One canister half will then get three ⅛" inch holes drilled through the rim spaced 120° from one another and ¼" down from the canister edge. The drilled holes are for the locking mechanism.

7.2.1.2 Stiffening Ring Assembly

As discussed in the introduction, a major design change was made to the interior rings. The previous idea of having two rings internal to the canister was rethought and developed into a new idea: having one ring which provides more stiffness to both canister halves at the exposed edges. This part will now be referred to as the stiffening ring for the remainder of the report. The stiffening ring is a single ring which joins the two canister halves together with two tongue and groove interfaces spanning the entire rim of the canister. The edges of the two half canister bodies will act as the tongues, and the stiffening ring will consist of the two grooves opposing one another. Figure 25 shows a dimetric section view of the double groove interface featured on the stiffening ring.

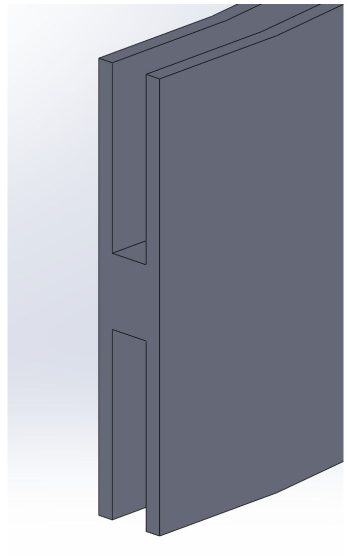


Figure 25. A dimetric view of the cross section reveals the double groove featured on the stiffening ring.

The stiffening ring will have a total of three holes drilled into it post cure. They will be ⅛" through holes evenly spaced 120°. These three holes line up with the three holes drilled into one of the canister halves mentioned above. Three 18-8 stainless steel knurled head thumb bolts will go through the drilled holes and will fasten to three low profile steel square nuts bonded to the inside of the stiffening ring. The bolt heads will be able to twist off by hand. In total, the bolts will fasten the two walls of the groove and the edge of the half canister body in between the walls. The stiffening ring will be permanently post bonded to the half canister without the drilled holes.

Another important feature is the elastic net. To deal with the problem of food spilling when closing the canister after packing it, an elastic net will be attached with six velcro strips near. The net will catch the food items not allowing them to spill out. Because the velcro strips are attached to the inner surface of the stiffening ring, the half canister with the stiffening ring bonded to it will be the half that the user flips upside down when attaching and locking the assembly. An exploded isometric model of the stiffening ring assembly along with the edges of the canister rims is shown in Figure 26.

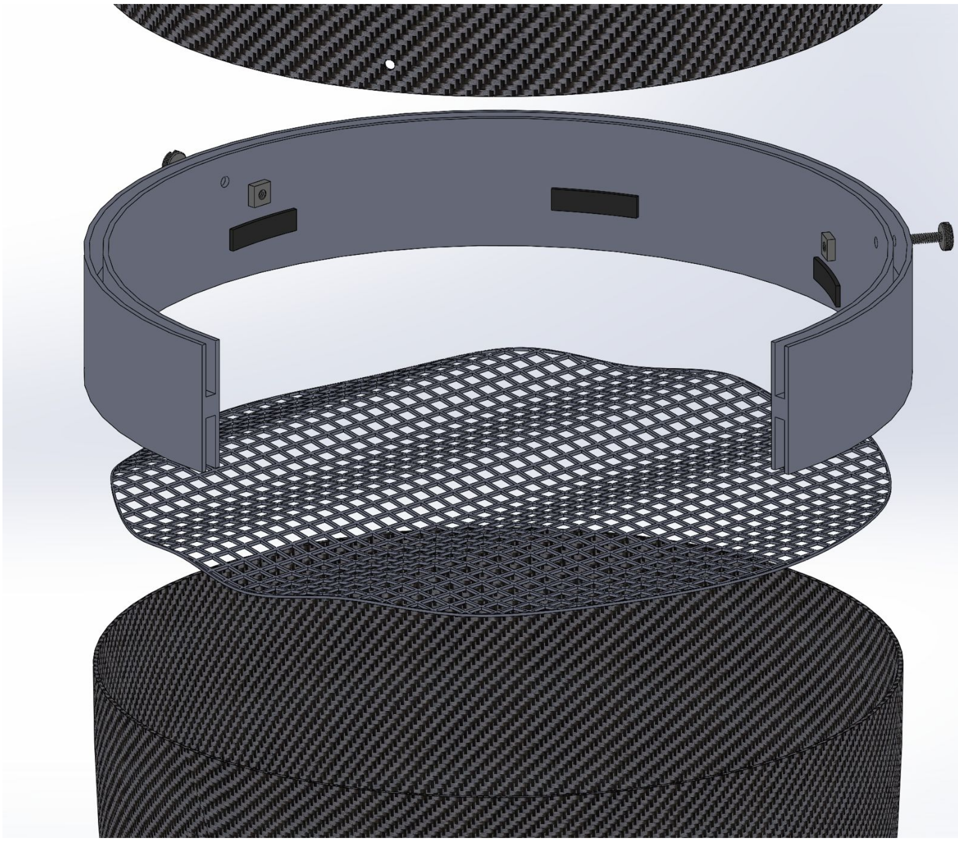


Figure 26. The stiffening ring assembly is shown with a section view revealing the attachment mechanism. Note: Reciprocating velcro strips not shown in view

7.2.2 Material Selection

The Bear Minimum canister aims to be the market's first fully composite canister. The new tongue and groove center stiffening ring will be made of composite allowing the entire canister to be lighter and elastic in nature. The canister can be broken into three main portions for material selection: the body, stiffening ring, and mold.

7.2.2.1 Canister Body

The Bear Minimum team explored two methods of creating the composite canister body using a carbon tooling mold. One method involved pre-preg composite laminate and the other was using a simple wet hand layup as noted in Figure 27.

The wet layup method was easy and simple to execute, but the quality of the part created was inferior to the prepreg part. The prepreg composite maintained a more even wall thickness of 0.055” with a circularity of 0.090” unlike the wet layup which had areas of overlapping layers or less than four layers of carbon. The more even wall thickness of the prepreg carbon allows for a higher strength and easier implementation with a stiffening ring groove.

The wet layup canister maintained a superior surface finish and lower weight due to excess resin being expelled into the fleece layer. Although the reduced weight is significant, the resin distribution of the wet layup is not as even as with prepreg. The prepreg thus, maintains a constant surface finish and look, even if it is not polished as the wet layup.

The team ultimately choose prepreg as the composite material of choice due to the ease of manufacturing and more repeatable results. Results from a decision matrix are shown in Table 18. Previously manufactured wet canister layups were more difficult to remove from the mold, causing permanent damage to the canisters upon removal.

Table 18. Decision matrix determining prepreg carbon fiber as the selected manufacturing material for the bear canister

Criteria	Wet Layup	Prepreg Layup
Strength	0	+
Manufacturing Fesability	0	+
Weight	0	-
Diameter Tolerances	0	+
Aesthetics	0	-
Cost	0	0
Sum of Positives	0	3
Sum of Negatives	0	2
Total	**0**	**1**

7.2.2.2 Stiffening Ring

Original design attempts to make the stiffening ring out of an injection molded plastic or short fiber composite were investigated; however, a prepreg carbon part was desirable. The tongue and groove stiffening ring can be made out of 18 layers of composite prepreg. Each composite layer is approximately 0.015” thick and can be shaped before being placed in the oven for curing. Prepreg carbon allows us to more accurately place the layers.

7.2.2.3 Mold and Canister Assembly

The stiffening ring grooves will be made using an aluminum three piece mold. The molds ring can be machined using CNC methods or by hand with a hand router [25].

7.2.3 Design Specific Safety Considerations

The safety hazard identification checklist identifies potential hazards pertinent to the Bear Minimum project. This list can be seen in Section 4.4 of this document under the Management Plan.

Our tongue and groove stiffening ring design maintains the same canister body as the previous design, but the material is changed from a polymer back to a composite laminate. The composite is similar to the body material, thus not introducing any new safety considerations for the new material.

- Regarding sharp edges on the canister: Sharp edges will still be present on the the new canister stiffening ring. Due to the four edges on the stiffening ring extra attention to covering or sanding down these sharp edges will be done.
- Regarding abnormal effort or physical posture during usage: The canister design will still be opened from the middle. The user will not be required to twist the canister to open it. This reduces the risk of stressing the user's' back muscles.
- Regarding environmental conditions such as humidity, cold & hot temperatures: The canister material is consistent and the container will only maintain 1-2% moisture. Allowing the canister to be homogenous throughout will reduce stress due to thermal expansion as the ring will expand with the canister halves. The tongue and groove will allow for slight ventilation in the case of pressurization.
- Regarding use in an unsafe manner: The canister can still be used unsafely and should be kept out of reach of small children. The exposed edges of the stiffening ring are also slightly sharp and caution should be used when handling. The bear minimum team does not recommend using the canister has a stool.
- Regarding other potential hazards: The canister body is still made of carbon fiber which can pose health hazards if the dust is exposed to the user. There are no additional other potential hazards from the new stiffening ring design.

7.2.4 Maintenance and Repairs

7.2.4.1 Maintenance

Maintenance of the canister body will be minimal to unnecessary. One disadvantage to composite parts is they experience wear over time. The bolts and nuts used to hold the canister together will not wear down as they are tougher than the canister walls. The user may need to monitor any surface finishes or internal sealant layers applied to the canister. These layers are used to improve the aesthetic appearance of the canister and prevent carbon dust from interacting with the canister contents.

7.2.4.2 Repairs

Composite laminates are very difficult and expensive to repair. In the unlikely case that the canister wall is punctured, cracked, or inoperable the user must either have the canister repaired or replaced. In the case of stiffening ring failure, the complex geometry would require a replacement part to be needed. For the canister halves, A post bond repair patch can be used to repair the crack or hole and strength the surrounding material. The repaired canister will not be of equal strength, but it will be usable. Instron testing has shown that the canister halves maintain up to approximately 85% of the original canister strength even with small cracks propagating from the edges.

7.3 Justification

7.3.1 Analysis Results

7.3.1.1 Hand Calculation Results

Because the canister separates in the middle, the most critical load case analyzed was a purely compressive load acting on the hoop of the canister in the middle. This is the load case is representative of the 100 lb drop test on the side of the canister. To model this, an equivalent static load to the impact load of 100 lb from 1 ft was calculated. This calculation involved work/energy and impact/momentum calculations. The velocity of the weight just before impact came out to be 8.02 ft/s. (Appendix B) The desired impact force depended on the time duration of the impact. From the drop test of last year's project, using the frames taken from the high speed camera, this time duration was approximately 0.1 s. This impact from last year's test is shown in Figure 28.

Figure 28. Side deflection is shown before and after the impact of approximately 0.1 s.

Appendix B shows the sample hand calculation for finding the impact force for a time of 0.1s. Because the design of this year's canister is very different than last year's design, this value for the impact time can only be used as a rough guideline. In Excel, impact time was plotted as an independent variable to find a range of impact forces the canister might experience. The plot is shown in Figure 29 below.

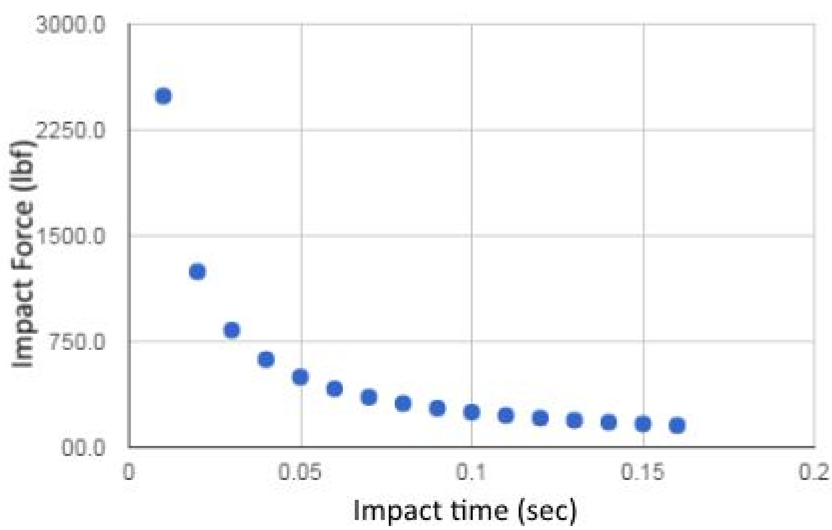


Figure 29. At the observed impact time of .1s from last year's project, the corresponding impact force is 249.1 lb.

At impact times lower than .025s, the relationship is severe. For this reason, the design should try to prolong the impact time. A future iteration could feature a three ply canister and stiffening ring to give the carbon less stiffness.

From these results, the stiffening ring was sized appropriately. At an impact time of 0.10s, using the impact time approximated from last year's impact test results, an impact force of 249.1 lb was computed using the curve of Figure 29. From the FEA analysis discussed above, a stiffening ring sized at 1.5 inches tall and the cross sectional dimensions shown in Figure 30, the part can support a compressive force of 371 lb which passes the 249.1 lb required load, yielding a factor of safety of 1.49 respectively.

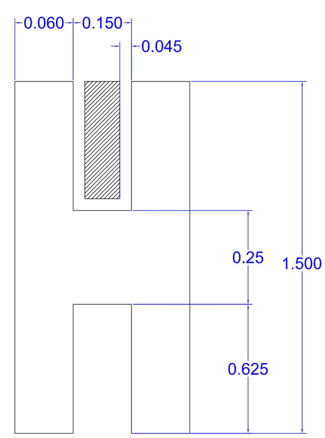


Figure 30. Finalized Stiffening Ring Cross Section Dimensions

The finalized cross sectional dimensions were selected from impact/momentum analysis and using multiples of 0.015 inches (thickness of a carbon ply). Making this multiples of 0.015 inches is due to manufacturing reasons discussed in section 8.2 of this report.

The reason why a smaller impact time was not used or a factor of safety was not applied to the calculations to be more conservative was because this calculation isolates the stiffening ring from the rest of the assembly and tests its compressive strength. That means that no load is transferred through the rings into the half canister bodies. This makes this analysis inherently conservative due the the fact that the stiffening ring will transfer loads very effectively due the continuous contact with the canister edges around the rims.

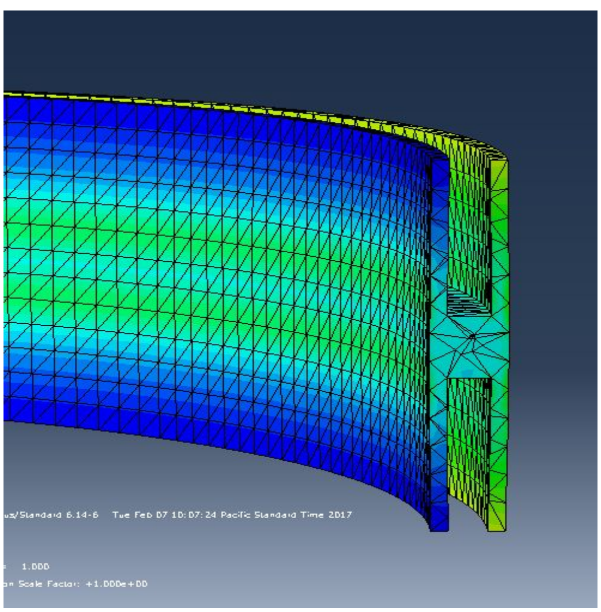
7.3.1.2 FEA Analysis

7.3.1.2.1 Stiffening Ring

Because finite element analysis had previously been performed on the bear canister halves and previous internal rings, it was not needed to perform FEA on those components again. Due to the new stiffening ring design, it was essential to validate the mechanical response. Thus, only the ring needed to be modeled to see how much of the 249 lb dynamic load it can handle (calculated from the impact analysis performed). The force on the model was 249 lb in the compressive direction (-U2 for top loading, +/-U1 or +/-U3 for side loading).

Below is a summary of the the FEA inputs used for the model in ABAQUS:

- Loading: 248 lbs. (-U2 for top loading, +/-U1 or +/-U3 for side loading
- BC: Fixed on stiffener side wall for side loading, fixed on stiffener center bottom for top loading.
- Mesh: 0.22 inches seed, tetrahedral



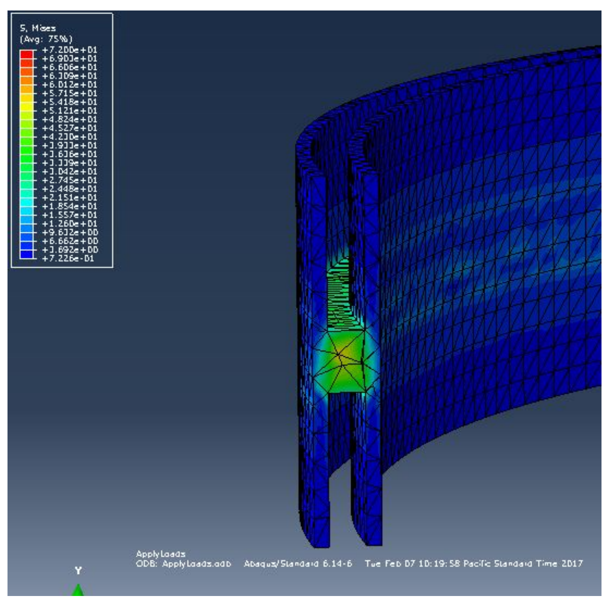


Figure 31. FEA von mises stress plots for side loading (left) and top loading (right). The stress safety factors of these tests were 1.80 and 1.49 respectively.

The FEA results in Figure 31 showed quite conclusively that the stiffening ring would not fail under the dynamic 249 lb load from the side or top of the canister. On the side loading case it was seen that the outer canister edge took the majority of the stress, which was in tension and the inside in compression. Tension is advantageous for composites due to their fibers being stronger in tension. For the top loading case it was seen that the center portion of the "H" shape was in high compression due to the small horizontal cross sectional area. This material was in compression which may help us align our fibers better.

Using the material specification sheet yield of 320 ksi, we can estimate the yield strength to be 233.7 ksi (based off of the FSAE strength data of 69.7% (Appendix H)). Using this value, it was calculated that there would be a safety factor of 1.80 for the side loading of the ring and 1.49 for the top loading of the ring. If the material was at 100% of it's material specification sheet then those safety factors would increase to 2.47 and 2.13, respectively.

7.3.1.2.2 Stress Concentrations Around the Drilled Holes

Stress concentrations around the holes are of concern when dealing with the top/bottom impact load case. When the weight is dropped on the top, a portion of the load will transfer to the pins which will load all three holes in shear. The worst case scenario, and an almost impossible occurrence, would be if all the load was focused directly on one pin. This load case was investigated.

From the FEA results in Appendix M performed on the half canister body, the maximum stress around the hole was 37.1 ksi. From the specificated yield strength of the twill weave carbon fiber of 320 ksi, the yield strength for our composite part is projected to be approximately 223.7 ksi. This is due to the 30.3% reduction of ultimate strength of prepreg carbon fiber parts laid up using Cal Poly's resources (Appendix H). Dividing the expected yield strength by the FEA results yields a maximum stress concentration factor of 6.03. A stress concentration factor of approximately 12 [26] can be expected for high modulus carbon/epoxy uniaxial composites. This number will be used as a rough guideline. This is because our carbon fiber is not uniaxial, it is a woven fabric meaning that the strength in the transverse direction is the same as the longitudinal direction. Because of these considerations, the stress concentrations around the drilled holes are considered to pass the engineering analysis.

7.3.2 Testing Results

Although the stiffening ring is designed to take the majority of external impact forces, it is important that the canister body contributes to taking a portion of the load. During the drop test, a 100 lb weight is to be dropped from one foot onto the side and top of the canister. The load absorbed by the stiffening ring will be the total dynamic force minus twice to load

supported by the canister halves. From this logic, it is essential we determine the load the canister halves can support to effectively size our stiffening ring.

An instron machine was the preferred method of choice for testing to produce a load-deflection curve of the canister half. The instron can easily provide the loads we needed and measure deflection up to the 0.0001” of an inch. In order to mount the canister to the instron we created a simple wooden jig that supported the canister and allowed the jig to attach to two aluminum mounting tabs for the instron as seen in the Figure 32 below.

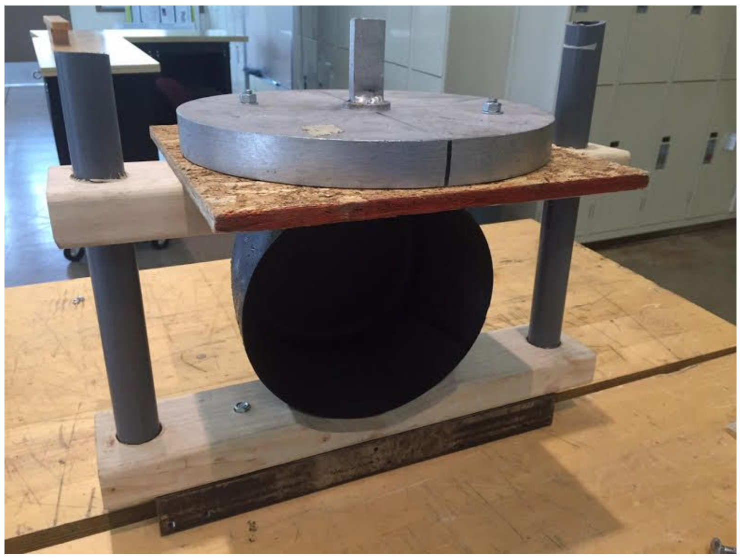


Figure 32. The testing jig created to test half canisters is shown. Two metal mounts are attached to wooden two by fours providing supports for the canisters. PVC piping allows the jig to move vertically.

The Instron machine allowed us to slowly increase the load and deflection and see the response from the canister half. The wooden two by four lumber pieces used had 12” diameter arc of a circle cut into them to allow the canister to be supported, but not roll out when loaded. We set the instron settings to a load gain of 100 per volt for load, and 0.2 per volt for deflection gain. The waveform used to modulate the canister up and down was set to -0.5 inch at a rate of 0.005 inches per second. The following results for the instron were collected and graphed in Figure 33 and Table 19 below.

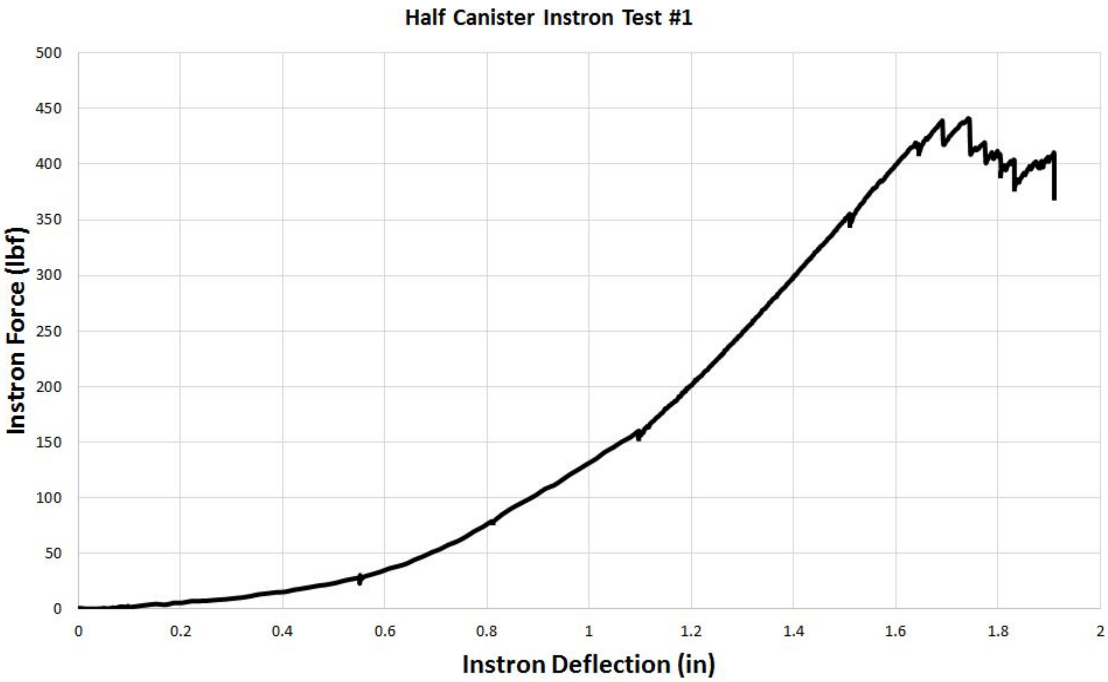


Figure 33. After post processing, the Instron compressive force was plotted over measured deflections for a half canister.

Table 19. Corresponding Instron compressive forces are shown at selected deflection values.

Instron Deflection (in)	Half Canister Force (lbf)
0	0
0.25	13.1
0.75	88.5
1.25	264.0
1.71	438.0

From the Instron results, we can see that although our canister is quite strong, taking a maximum force of 440 lb before yielding, it is not very stiff. The canister deflection was around 1.7 inches at it's yield criteria. The yielding at 1.71 inches indicated the first fiber failure. The ultimate strength of the canister was only 1 lb greater (441 lb) at 0.05 inches farther. From that

point on, the canister experienced multiple successive fiber failures, even when the load stopped increasing.

After the first run of the Instron, the canister had only minor damage done to it consisting of a couple fibers broken and hairline fractures. The second canister run yielded a maximum force of around 370 lb, approximately 86% of the first run. This shows that the canister is quite resilient and will work quite well even with some fiber damage.

The new stiffening ring design takes advantage of the flexibility and high strength of carbon fiber. The ring will be able to flex with the canister walls and not yield. In addition, more flexibility allows the impact time to be larger, thus reducing the force caused by decelerations. In the future we will test more stiffening ring geometries to optimize the weight and strength of the ring. If the ring is too stiff, we can reduce composite layers. Conversely, we can add additional composite plies or core materials to increase stiffness.

Testing was also carried out on a 3D printed prototype. The purpose of this prototype was to get a basic proof of concept. Because the strength, weight, and stiffness of the 3D printed part was much different than the anticipated strength, weight, and stiffness, testing the print in these categories would not provide good justification on corresponding design decisions. The 3D printed part shown with two half canisters is pictured in Figure 34.

Figure 34. The 3D printed prototype proved the design's attachment function. Note: the canister halves pictured were both manufactured as whole canisters, then cut down with a dremel; the height of the stiffening ring is .75 in while in the confirmation prototype, the height of the stiffening ring will be 1.5 in.

Even though strength, weight, and stiffness test results using the print were not a valid representation of the final design's characteristics, basic observations were made in these categories. The canister, using the printed stiffening ring, would hold a static weight of 165 lb of compression in the longitudinal direction. This was not the ultimate static load, just the weight of a student who was sitting on it as a stool (which is a load case we are expecting when taken backpacking). Also, this static loading proved how well the stiffening ring does as far as the attachment function of the design. Because the half canister's are contacted and supported at every point along the rim and are restricted in both directions by the grooves, the whole assembly feels very solid. The assembly feels like one rigid part which was the intention for the new design.

Additional design verification testing of our canister was the measurement of the canister dimensions. Original testing plans called for calipers to be used for dimension measurement. Due to availability of equipment and new training, it was decided a Coordinate Measuring Machine (CMM) would be the new method of measurement for the canister. The CMM is capable of measuring to the 1/10,000" of an inch. Using the manual touch off mode on the CMM touch probe was used to measure diameters around the canister. Figure 35 below shows the touch off points of the canister and their relative deviation from the nominal diameter. The image below shows that the mold is slightly ovular shaped and bends outwards at two of the ends.

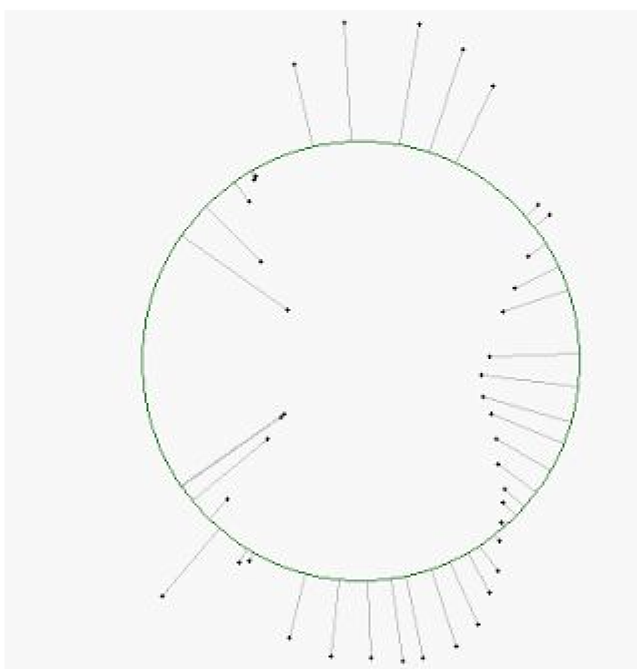


Figure 35. Touch-off points and deviation for CMM results on canister inner diameter are shown.

The results from the CMM machine allow for improvement to the design of the stiffening ring mold. The deviation in the canister mold and lip required a thicker slot in the stiffening ring. The results from the canister CMM are shown below in Table 20, with the maximum circularity of around 91 thousandths of an inch.

Table 20. Nominal canister diameters and circularity.

Canister Part	Measurement (in)
Inner Diameter	8.95901
ID circularity	0.09040
OD	9.06963
OD circularity	0.08162

7.3.3 Engineering Judgement

Design decisions which weren't able and/or necessary to have experimental, analytical, and/or numerical justification were assessed with the team members' engineering judgement. One such decision was the number and locations of the drilled holes in both the half canister body and the stiffening ring. Three holes evenly spaced 120° apart was selected. A common load case in the hoop direction, whether it is the compression test in the Instron, the drop test of 100 lb, a bear standing on it, or being dropped on a hard surface, is two opposing forces 180° inwards. By having two or four holes, the stress concentrations around the holes would be loaded simultaneously leading to a higher chance of failure. By having three holes spaced evenly around the hoop, this scenario will be avoided.

For procedure 2 of the manufacturing process (refer to Section 7.2.2), 10 layers of carbon fiber was selected to give the half canister body ample clearance when seated in the groove. Because the canister has curvature, a groove thickness equal to the canister wall thickness would cause interference. From the SolidWorks model, a 0.030 inch overlay due to the curvature was observed. This means the canister wall thickness could be thought of being 0.09 inches instead of the actual thickness, 0.06 inches. Adding 0.03 inches of tolerance to both sides of the canister yields a total groove thickness of 0.15 inches. This totals to 10 layers of carbon fiber thick. This assessment of the groove thickness was then inputted into Abaqus to verify the strength response (discussed in Section 7.3.1.1)

Prepreg carbon was selected as the material for many reasons. The specific strength of carbon fiber is ideal to meet the weight and strength specifications. Because the materials for the stiffening ring and the half canister bodies are the same, they whole canister will expand or contract equally when exposed to hygrothermal conditions. Also, the curing cycle for both parts will be the same, decreasing labor cost and manufacturing time. When ordering materials, only one carbon fiber type will be necessary to order also increasing the efficiency of operations when on a production level.

7.3.4 Feasibility and Possible Issues

The Bear Minimum canister will be the first almost completely carbon fiber canister on the market. This poses many feasibility concerns and potential issues down the road. These concerns range from cost all the way to the base material strength. Modern backpackers demand more from less and the Bear Minimum canister will be pushing the envelope of the material properties. The following are a culmination of concerns of the bear canister.

1. Composite fiber strength differing from specified values.

   Composite materials are difficult to work with by nature, There are many factors involved in the manufacturing processes such as fibers used, resin used, resin content percentage, porosity, cure cycle and time, and human error. The material specification sheet for our Cytec prepreg resin system list the canister having a fiber tensile strength of 320 ksi. Intuition leads us to believe our fiber strength will be considerably less than that due to manufacturing errors and uncertainty. Without proper material data of in-house manufacturing processes it is difficult to scale or offset our engineering calculations and simulation to reflect these manufacturing flaws.

   Fortunately data from the Cal Poly Formula SAE team was released to us allowing us to estimate the strength of our composite canisters. The FSAE composite samples were cured in the same composites room and autoclave as our canisters are manufactured in using similar resin systems with a fiber volume of 62%. This allows us to show structural similitude between the two. The Formula SAE data showed approximately that the fiber yield strength was 223.9ksi of the 320ksi of the manufacturer's data sheet. This yield percentage of 69.7% can be used for our models (Attachment H). This new fiber percentage yield shows that our carbon fiber strength of 320 ksi would also yield at 223.9 ksi and the resin at 420 ksi would yield at 292.7 ksi.

   The concern brought up with the carbon fiber strength is hoping that the canister fibers aren't strong enough and yield when in use. Ultimately, final manufacturing

methods will yield canisters with strength closer to 85%+ of the data sheet, but we should manufacture for worst case conditions or if some fibers are flawed in a portion of the canister.

2. Canister edges sticking out.

The second main concern of the stiffening ring design is the fact that the canister has two ring edges that stick out with the the new stiffening ring design. These edges are sharp and may either harm the user or break off. The manufacturing challenge here is to somehow soften those edges and sharp corners to allow them not to harm the user's backpack or skin. One possible method of protecting these edges is to dip the edges in wax to gain a small wax radius on the canister edges. This radius would be equal to the composite thickness to prevent interference between the tongue and groove latching system.

3. Thermal expansion of aluminum.

The aluminum parts needed for the stiffening ring mold are comprised of three sheets of aluminum in which the stiffening ring will be laid up on. Since we are using prepreg carbon fiber this requires that the aluminum mold halves be heated to 250°F to allow for curing of the composite. Due to the thermal expansion of aluminum, the dimension of the the middle aluminum ring used to dimension the groove of the the stiffening ring will expand and become larger. We can mitigate this expansion by one of two ways: 1) Decrease the aluminum ring thickness and allow it to expand into size, or 2) decrease increase the number of carbon layers to accept the slightly wider gap. The former being the more straightforward option because the thermal expansion of aluminum is known. If the aluminum expansion rate is 12.3E-6 inches per degree Rankine*1in (equivalent to a 1 degree fahrenheit change), then at 250°F the thermal expansion of aluminum would cause it to be 0.000276 inches larger, or approximately 2% of one layer of carbon. This expansion could be considered nearly negligible since we have much larger manufacturing tolerances to deal with.

4. Manufacturing the stiffening ring.

(See Section 7.2.2) There are ample things that could pose challenges during the manufacturing process. One such thing challenge is tolerancing the molds appropriately. This is very important because if the tolerancing is off, the vacuum bagging process will not be able to supply the right pressure to bond the layers of carbon well enough to create a structurally sound part. Another challenge will be drilling the holes. Because the bolts

will be going through three different surfaces, it is very important to have all three holes line up for each holes. Because the nut is the fastening method, and not something such as a press fit, this is not as much of a concern. Overall, if this manufacturing process is committed to and the part does not function as designed to, the mold will be a waste of time, money, and resources. This mold design does not allow for iterations of the stiffening ring such as changing dimensions or the number of plies.

7.4 Supporting Data

7.4.1 Bill of Materials

The bill of materials was relatively straightforward for this project. Only eight parts are required for the canister assembly. The full bill of materials can be seen below in Table 21. The assembly levels start at the finished canister, the final assembly. From there, it is broken down into its constituent parts: the half canister bodies (with and without holes), the stiffening ring assembly, and the elastic net. The stiffening ring assembly is then further broken down into its constituent parts: the ring itself, the nuts, velcro, and bolts.

Table 21. The total cost of materials per canister comes out to less than $92.23 considering the nuts, net, and velcro will be used for multiple canisters.

Bill of Materials								
Assembly Level	Part Number	Description			Vendor	Qty	Cost	Total Cost
0	0.0.0	Final Assembly			------	1		
1	1.1.0		Half Canister Body		Donated	1	$22.50	$22.50
1	1.2.0		Half Canister Body With Holes		Donated	1	$22.50	$22.50
1	1.3.0		Stiffening Ring Assembly		------	1	$23.69	$41.53
2	1.3.1			Stiffening Ring	Donated	1	$15.00	$15.00
2	1.3.2			Low Strength Steel Nut Pack 4-40	McMaster	3	$2.88	$2.88
2	1.3.3			Velcro® Brand Tape Strips	McMaster	1	$6.22	$6.22
2	1.3.4			18-8 Stainless Steel Knob 4-40 3/8" Long	McMaster	3	$5.81	$17.43
1	1.4.0		Elastic Net		OFS	1	$5.70	$5.70
	Total Parts	8				13	Grand Total	$92.23

7.4.2 Cost Analysis

The Bear Minimum funded by an external sponsor allowing us to have a budget of $2,000 USD. When designing any engineering part or system it is critical to keep costs in mind. For our project we are not as seriously concerned with pricing because the ultralightweight backpacking market is willing to pay a premium for composite or lightweight products. Despite the wealthy market, our sponsor has a goal of selling the canister at $500 USD for production.

In addition to this budget many materials and tools were supplied courtesy of the Cal Poly Human Powered Vehicle team. These supplies and tools include: prepreg carbon fiber, vinyl sheeting template material, and tools like drills, bits, and scissors. Additionally, during our initial prepreg and wet layup testing we had to purchase bagging materials and chemicals for both processes. Table 22 below summarizes the project costs as of 2/8/2017.

Table 22. Purchased Parts for the Bear Minimum Project are shown.

Purchased Part Costs	Supplier	Quantity	Total Cost
2x2 Twill Weave Carbon Fiber Prepreg (Cytec 5320-1 Resin System)	ACP Composites	1	688.29*
Low Strength Steel Nut Pack 4-40 of 100	McMaster-Carr	100	$2.81
18-8 Stainless Steel Knob 4-40 3/8" Long	McMaster-Carr	3	$5.88
3D printer Nylon Roll	Amazon.com	1	$23.85
LOCTITE Frekote NC-700 Gallon	ACP Composites		$118.00
Acetone 1 Gallon	Home Depot	1	$13.97
Plastic Sheeting 10'x100' 6mil	Home Depot	1	$59.98
Vinyl Sheeting for Templates	Home Depot	1	$9.98*
High Temp Vacuum Bag Connector Lock Ring	ACP Composites	1	39.95*
West Systems 105/109 Epoxy/Resin	The Craft, SLO	1	$60.00
* = Donation		**Total**	**$284.49**
		Total with Tax	$307.25

For manufacturing of each individual canister halves and also the future stiffening ring design the team had to purchase, or borrow many composite materials. Many of these are the bagging materials such as the breather, bleeder, vacuum bag, and release agents. Squeegees and

masking tape are also needed for manufacturing of prepreg carbon fiber. With tax included, manufacturing totals to about $93 overall as seen in the Table 23 summation below.

Table 23: Manufacturing Costs for the Bear Minimum Project are shown.

Manufacturing Costs	Supplier	Quantity	Total Cost
Yellow Vacuum Bag Sealant Tape Roll	Fibre Glast	1	$7.95
Breather Fleece - 5 Yard	Fibre Glast	1	$24.95
Polyester Peel Ply Yrd	Fibre Glast	1	$12.51
Vacuum Bag Film Strechlon 800 5yrd	Fibre Glast	1	$29.95
Squeegee	Fibre Glast	2	$1.80*
Painter's Masking Tape	Home Depot	2	$5.94
Latex Gloves 50 count	Home Depot	1	$4.47
Scissors	Home Depot	2	$11.96*
Tape Measure	Home Depot	2	$10.48*
Exacto Knife	Home Depot	2	$3.96*
Sand Paper 60 grit 9"x11"	Home Depot	1	$3.97*
20oz Carbon Fiber Tooling Fabric Mold	Fibre Glast	1	$60.45*
Hand Heat Gun	McMaster Carr	1	$31.69*
* = Donation		**Total:**	**$85.77**
		Total with Tax	**$92.63**

The majority of the test fixture building materials were purchasable from home depot for a minimal price of $20.55 excluding the cost of the Instron mounting plates. These plates were provided with the Instron to assist with mounting. A summary is shown in Table 24.

Table 24: Testing Costs for the Bear Minimum Project are shown.

Testing Costs	Supplier	Quantity	Total Cost
Construction Wood 2"x4"x96"	Home Depot	1	$2.69
Drywall Screws#6 1-1/4" 1lb pack	Home Depot	1	$6.47
PVC Pipe 1.25"x10'	Home Depot	1	$5.22
Gorilla Glue 2 Part Epoxy	Home Depot	1	$4.65
Aluminum Instron Mounting Plates	McMaster Carr	2	$0.00 *
* = Donation		**Total**	**$19.03**
		Total with Tax	$20.55

To date, the bear minimum project has been relatively inexpensive due to donated materials and available tools and equipment. We anticipate that half our purchases have yet to be made for this project. Eventually we will need purchase three aluminum plates for manufacturing the stiffening ring mold from. In addition we will need materials such as the velcro seen in Table 25 below in order to hold the restraining net in place. Overall, the bear minimum project is expected to only cost around $730 which is much below our allowed budget.

Table 25: Future Anticipated Parts for the Bear Minimum Project are shown.

Anticipated Parts	Supplier	Quantity	Total Cost
Velcro 1/2" x 5ft	McMaster-Carr	1	$6.22
Netting 1 sq yrd.	OnlineFabricStore.net	1	$5.70
Aluminum 6061 1.5" x 12" x 12"	McMaster-Carr	1	$114.58
Aluminum 6061 3/4" x 12" x 12"	McMaster-Carr	2	$159.88
* = Donation		**Total**	**$286.38**
		Total with Tax	$309.29
		Entire Project Cost	**$675.67**
		Entire Project Cost + 8% Tax	**$729.72**

In the future, Nick Hellewell expects to eventually mass manufacture and sell canisters to the general public. Additional costs needed for full scale production were considered. The first year will include the cost of capital investments (ovens, freezer for composites, and other general equipment). Labor, also seen in Table 26, is responsible for $280 of cost per canister. This is based off of an average yearly salary of $36,000 for a composite technician worker.

Table 26: Capital Investments and Labor Costs for the Bear Minimum Project are shown.

Capital Investments	Cost
Walk in Composite Oven	$8,000
Drill Press	$375
Vacuum Pump System	$750
Composites Freezer	$800
Total	**$9,925**
Labor Cost	**Cost**
Composite Technician 2x 8hr @ 36k/yr	**$280**

If we are to assume that 100 canisters are made per year (yielding around $50,000 income) then the price of one canister for the first year will be around $650 USD. This high price is due to the fact that capital investments must be paid off this first year. You can see the difference in total cost ($43,000 vs $33,000) between year one and year two in Table 27. Starting the second year and subsequent years, those capital investments will be paid off and the canister can sell for $499, right at our sponsor's goal price.

Table 27: Full Scale Production Costs for the Bear Minimum Project are shown.

100 Canisters Cost	First Year	Second Year +
Parts + Materials	$729.72	$729.72
Composite Material	$4,500	$4,500
Capital investments	$9,925	$0
Labor Cost	$28,000	$28,000
Total	$43,154.72	$33,229.72
Cost Per Canister	$431.55	**$332.30**
Retail Cost Per Canister (50% Markup)	$647.32	**$498.45**

The Bear Minimum team strives to meet the project goals. Our current plan will allow us to build and sell the canister for $500, manufacture a canister under 1.3lbs, and so far keeps us under our $2,000 product budget.

7.5 Drawings

To see the complete list of drawings and detail part and assembly drawing see Appendix K.

8 Project Plan

8.1 Design Verification

8.1.1 Overview

The design verification plan (DVP) was created to establish a process to test the finalized design. The full DVP can be seen in Appendix J. Each test was categorized as either a concept, structural, or confirmation test based on the relative order in which they needed to be conducted.

For example, conducting tolerance tests on the final product would be during the confirmation test stage while comparing shear strengths of various adhesives would be during the concept test phase. Each test was also categorized as a user, design, manufacturing, or environmental test. This was important because if a test fails, this category specified the source for the failure mechanism. The future test plan, Section 8.1.2, will discuss the specifics of each test, and will go over any foreseen problems.

8.1.2 Future Test Plan

In accordance to our design verification and testing plan we must validate our engineering design for the canister. Although we have already used the CMM and instron machines to test the canister additional testing must be done on future prototypes and also after the canister is finished to verify quality and dimensions, thus, some of the remaining tests as as follows:

1) Force-Deflection curve for the stiffening ring.

   Similar to the canister deflection curve on the instron, the stiffening design we manufacture should be tested on the instron machine to determine its strength and flexibility. We hope to achieve larger numbers than the canister strength, but lower numbers than the canister deflection. To conduct this test, fortunately, the testing jig from the half canister can be reused due to it having a similar diameter.

2) Tolerance check on CMM.

   Again, similarly to the canister halves, the stiffening ring must also be verified to have the correct tolerances. The stiffening ring tolerances are especially important because they mesh with the edge of the canister walls. This meshing allows the tongue and groove interface to make contact and help stiffen the canister assembly. Using the CMM machine again we can measure the stiffening ring inner and outer radii. Since the groove is extremely tiny, either the camera feature of the CMM will have to be used for tracking the edge, or we can measure the outer or inner diameters and add the thickness as an offset. The former being the more accurate option.

3) Canister hole alignment.

   The three alignment pin in the canister are used for aligning the canister halves together with the ring. If these holes aren't properly aligned, or 120° apart from each other this may cause issues with alignment or stress issues. Improper aligned holes will

cause wear on the edges as the threaded pins used will dig into the canister walls over time causing permanent damage. Secondly, if the holes are not the 120° apart then this will cause larger loads on the canister. The geometry of using three pins prevents any set of two pins from being loaded too much directly. We will be using hand tools and the CMM machine to verify hole alignment and position.

4) Porosity Verification.

As part of our material quality and verification it is essential that the fiberal volume and quality of the part is measured. Porosity verification will tell us how many voids or air pockets there are in the part. If the porosity percent is too large it will exponentially decrease the strength of our part. By using prepreg over wet layup methods we hope to make the canister body manufacturing more consistent and less reliant on the user. It is more beneficial to have a constant amount of porosity than to have a lower average percentage but a wide scatter in results. Porosity can be verified through non-destructive testing methods highlighted in section 2.6.2 non-destructive testing of this report.

5) Weight drop testing.

Our sponsor wants us to verify our bear canister design by dropping a 100 lb weight from 1 ft high on both the side and top of the canister. This simulates a bear stopping on the canister, as tested by the old SIBBG organization. Although this organization doesn't exist anymore, it is still beneficial for us to test our canister with this test as a basepoint and a comparison to the canister without the stiffening ring. The previous deflection maximum from the weight drop was 0.25”, recently our sponsor has removed this requirement to allow us to take advantage of the elastic and flexural properties that carbon fiber has to offer.

6) Final live bear testing.

Following the penultimate 100 lb weight drop test, the canister will be iterated to allow it to pass our final testing. To pass the live bear testing the canister will need to withstand 60 minutes in a bear cage. To prepare from this test the best canister will be submitted with all sharp edges removed and no edges larger than ⅛”. Upon successful passing of the live bear testing the canister will be certified for use in the backpacking community.

8.2 Design of the Manufacturing Process

8.2.1 Half Canister Body

The two half canister bodies will be manufactured similarly to the methods discussed in Section 5. Because we will only be manufacturing halves, only bottom half of the mold will be used. Two wet layups of a half canister have already been manufactured; however, the final confirmation prototype will be manufactured out of prepreg. The same layup procedure and stacking sequence will be used. Because the layup will now be open, a vacuum bagging process will be performed which will be simpler than the previously used bladder molding process. This is because more materials were necessary and pressure needed to be supplied to the oven for bladder molding. Because a second bottom mold will not be manufactured, the existing bottom mold will be used in two separate manufacturing processes to make the two halfs. During production, two molds would be supplied to the technician. Because evacuating the canister pre cure will supply the pressing force against the molds, the curing process will take place in the autoclave in the composites lab, not in the large oven. Only the differences in the manufacturing process were discussed in this section. For a complete description of the manufacturing process that will be used, see Section 5, then consider the changes noted above. Figure 36 shows materials needed for the vacuum bag lay up process. These were used during the previous wet layups and the prepreg procedure will be the same process except for the carbon used and lack of epoxy needed.

Figure 36. All required vacuum bagging materials are shown with the bottom mold, four sidewall carbon sheets, and four base carbon fiber sheets.

8.2.2 Stiffening Ring

The stiffening ring will be made out of 18 total sheets of prepreg carbon fiber. The layers will be wrapped inside of a female aluminum mold. The manufacturing process can be broken down into three distinct procedures. In these parts, prepreg strips will be laid up vertically building up the cross section as you see in Figure 37 from left to right. Table 28 gives more details of the manufacturing procedures.

Table 28. The manufacturing process for the stiffening ring can be broken down into three procedures. The table below gives more details on these procedures.

Procedure	Procedure 1	Procedure 2	Procedure 3
Number of carbon layers	4	10	4
Height of carbon strips (in)	1.5	0.25	1.5

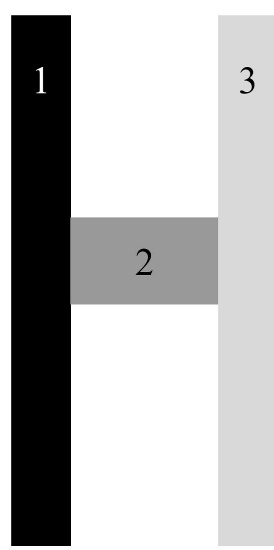


Figure 37. The cross section of the stiffening ring shows what section corresponds to which manufacturing procedure.

During procedure 1, the four layers of carbon will be pressed into the side wall of the centerpiece of the mold shown in Figure 38.

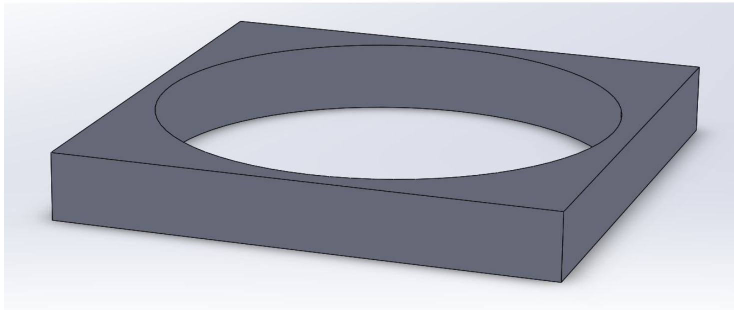


Figure 38. Four layers of prepreg carbon fiber will be laid up on the inside surface of the centerpiece of the mold.

After the first four layers are set in place, the base piece of the mold, shown in Figure 39, will be placed under the centerpiece.

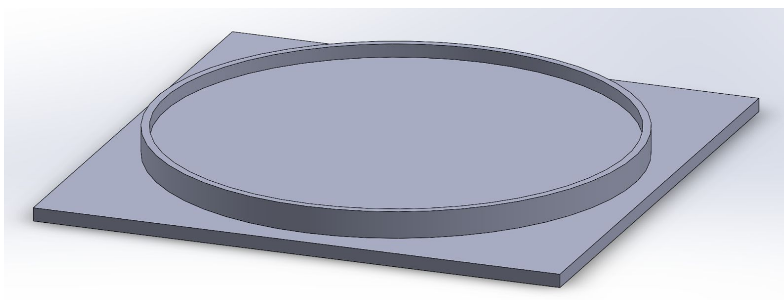


Figure 39. The mold centerpiece with the first four layers will be placed on top of the base piece shown. Then, ten layers will be pressed into the original four with the support of the protruding aluminum ring.

Referring to Figure 39, the upwards protruding ring on the base piece of the mold will fill the gap under the carbon of procedure 2 creating the bottom groove of the stiffening ring. Once the base piece has been fastened with bolts to the centerpiece, procedure 2 will be performed. The ten layers of ¼” tall strips of carbon will constitute the base of the grooves of the stiffening ring. Once the ten ¼” tall strips of carbon are set in place, the top piece of the mold, shown in Figure 40, will be placed.

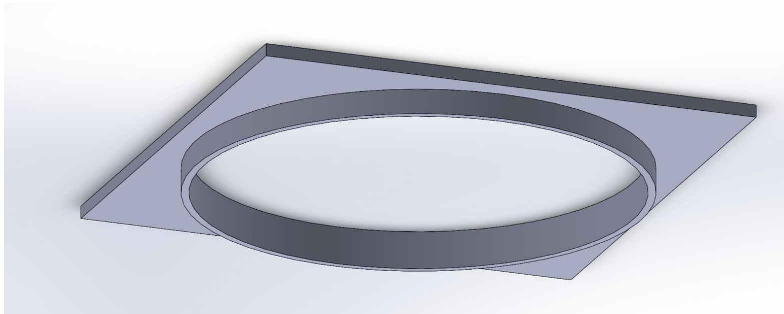


Figure 40. The top piece of the mold will go on last. The bottom protruding aluminum ring will sit on the top surface of the 10 layers of carbon. Once the top piece is secured, the last 4 layers of carbon will be pressed into the surface created by the inner surfaces of the protruding rings and the carbon.

Referring to Figure 40, the downwards protruding ring on the top piece of the mold will fill the gap above the the carbon of procedure 2. When the top piece of the mold has been fastened with bolts, procedure 3 will be performed. Another four layers will be pressed into the flush surface created by the base piece’s protruding ring, the carbon from procedure 2, and the top piece’s protruding ring. This procedure is similar to procedure 1. Once all carbon is pressed by hand into place and the mold is fastened, the complete mold, seen in Figure 41, will be vacuum bagged and cured with the same cure cycle for the half canister body. To finish the part, the three ⅛” through holes will be drilled into the ring at ¼” down from either edge.

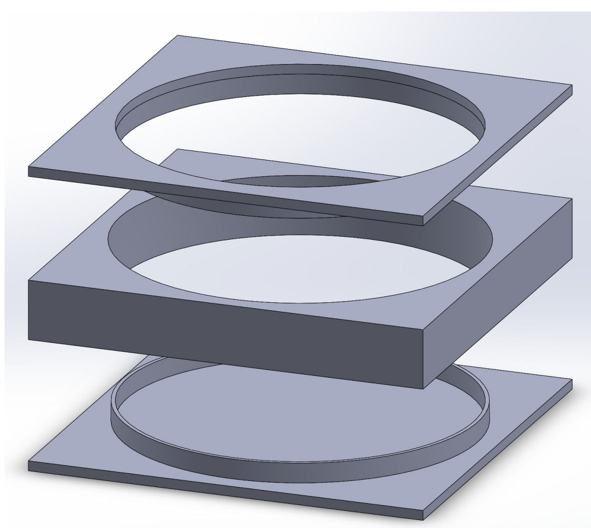


Figure 41. An exploded view of the mold shows how the three pieces will fit together during the layup process.

8.2.2.1 Canister Assembly

The groove of the stiffening ring without the through holes will be post bonded to the half canister without the three holes drilled through it via West Systems 105/109 slow cure epoxy and resin system. The nuts will be adhered with Gorilla Glue to the inside surface behind the drilled holes. All sharp edges will be sanded down and once tolerances are checked, the canister assembly will be complete.

8.2.3 Special Procedures

Upon completing the first operational ring, an iteration of the manufacturing process could include the embedment of the nuts within the carbon fiber. This would involve the last layer of carbon fiber to have appropriate markings of locations of the center of the nuts. Then, during the layup, the technician will slide the nuts into the carbon and inspect when the nuts line up with the pre marked locations. After cure, the drilled holes will go up to the last layer of carbon, but not through it. This way, the laminate will adhere the nut naturally and it will be a stronger bond. The canister will also be more aesthetically pleasing because the nuts will be hidden behind the fiber. The disadvantage of this would be more difficult manufacturing, and larger required tolerance due to the decreased accuracy from the manufacturing process.

The Velcro® brand tape strips will be the last thing to adhere to the stiffening ring and nylon net to complete the assembly. Six one inch long strips will be spaced out evenly around the rim of the stiffening ring half way down. Corresponding strips will be sewn into the nylon net evenly spaced. Future iterations could allow for smaller and fewer number of velcro strips on the netting and stiffening ring.

When laying up the canister halves and the stiffening ring, the carbon fiber strips will be laid up in an alternating fashion. For example, the start of the second strip of carbon fiber will be approximately 90° apart from the start of the first carbon fiber strip. This avoids having all ends of the carbon fiber strips at the same location post cure. Also, during the layup, a heat gun can be used on the low setting from approximately 8 inches to make the carbon fiber more tacky and malleable.

9 Manufacturing

9.1 Introduction

The manufacturing process was very similar to the manufacturing process described in Section 8.2. This section discusses the small differences, how the final parts of the canister assembly

were manufactured, manufacturing iterations, and recommendations for future manufacturing. Two final canister prototypes were manufactured: one light version weighing 1.3 lb and one more robust version weighing 1.7 lb. The only difference between the two canisters was the number of layers of carbon fiber laid when manufacturing them. The 1.3 lb canister was made with 3 layers of carbon fiber, and the 1.7 lb canister was made with 4 layers of carbon fiber. Because that is the only difference, the rest of the chapter will provide only one process assuming the 4-layered 1.7 lb canister is to be manufactured.

9.2 Canister Half

9.2.1 Mold

The mold used to manufacture the canister half was a modified mold from last year's canister mold. See Appendix K for more information about last year's canister mold. The mold consists of two parts: the mold base and the mold top support. Figure 42 shows the two mold parts.

9.2.2 Pre-Layup Process

By using the stencils provided, the carbon fiber was cut out from the roll. Four circles and four sidewalls were cut out. The mold release was applied to the mold. High-temperature FibRelease is recommended; however, any mold release can be used.

9.2.3 Laup Process

A sidewall cut out was laid in the mold first. It was important to press the carbon into the mold firmly to make the best quality product. A circle is then laid into the base of the mold. Overlap should be apparent when laying up the two pieces of carbon fiber. This process is continued for all four layers.

9.2.4 Post-Layup Process

The vacuum bag is made using the peel-ply and breather fabrics under the vacuum bag. Figure 42 shows a picture of a canister half after it has been vacuum bagged.

Figure 42. The part has been vacuum bagged and is ready for evacuation and curing.

The mold base is the same mold base used from last year's canister mold. The mold top support was made by cutting the top half of last year's canister mold to a height of two inches. This extra height allows for a reliable method to release the canister half from the mold. The process of releasing the part from the mold is as follows: (1) The mold top support is wedged off of the canister half. (2) Two 1" holes are drilled in the upper canister half where the mold top support was. These holes are across from one another. (3) A 1" steel bar is used to lever the canister half out of the mold base. The levering process is shown in Figure 43.

Figure 43. The canister is being levered out of the mold.

9.3 Stiffening Ring

9.3.1 Mold

The final mold used to manufacture the stiffening ring consists of seven parts: the mandrel, three tall spacing rings, and three short spacing rings. The middle mandrel was 3D printed out of Polycarbonate (printed by Parts Oven LLC), and the spacing rings were 3D printed out of ABS plastic. Figure 44 shows the stiffening ring mold.

9.3.2 Pre-Layup Process

9.3.2.1 Carbon Preparation

The stiffening ring requires a rectangular sheet of prepreg carbon fiber 30”x10”. A total of 16 strips will be cut out of this rectangle all with a length of 30”. Six of the strips will have a width of 1.25” and ten of the strips will have a width of .25”. A carbon fiber trimmer is highly recommended to make the cuts.

9.3.2.2 Mold Preparation

High temp FibRelease was applied to the mandrel. No other mold preparation procedures were carried out.

9.3.3 Layup Process

Three of the 1.25” strips are wrapped around the mandrel. It is important to wrap the layers with tension to provide better lamination between layers. After this step, it is encouraged to debulk under a vacuum overnight. After debulking, the ten .25” strips are to be laid up. They are to be oriented so .625” is above the stips and .325” is below them. Once the strips have been wrapped, the six spacing rings are to be placed. The three tall spacing rings are placed above the .25” strips and the three short spacing rings are placed below the .25” strips. The spacing rings are printed so .08” exists in between two adjacent sections. This allows for pressure to be exerted on the inner three 1.25” strips that have already been laid. The three-part spacing rings act as a clamp on the inner layers when vacuumed. It is encouraged to debulk overnight after this step. Figure 44 shows the stiffening ring at this step.

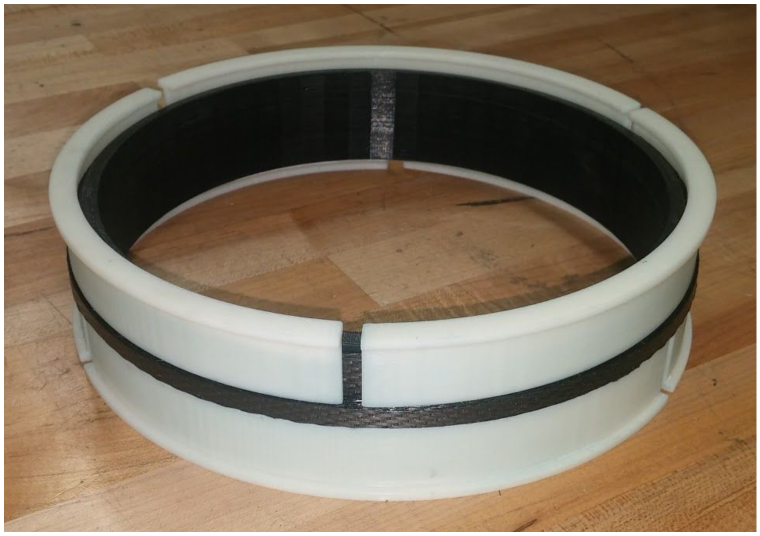


Figure 44. The spacing ring mold parts and the .25” carbon fiber strips create a flush outer surface. The final layers of the stiffening ring are ready to be laid up.

After debulking, the final three 1.25” strips are laid on the outermost surface created by the spacing rings and .25” strips and the assembly is ready to be cured. Figure 45 shows the stiffening ring evacuated and in the autoclave. To accommodate the relatively low glass transition temperature of the 3D printed molds, the assembly’s cure cycle is as follows:

- **Ramp up** oven to 200° F at a rate of 3°F per minute.
- **Hold** temperature at 200°F for 600 minutes (10 hours).
- **Ramp down** temperature at rate of 3°F per minute until 105°F.

Figure 45. The stiffening ring is ready for curing.

9.3.4 Post-Layup Process

Take the assembly out of the vacuum bag and remove the breather bag and peel-ply. Because of the Polycarbonate's higher coefficient of thermal expansion, the mandrel will contract more than the carbon during the ramp down and will slide out of the assembly with ease. To get the ABS spacing rings out of the part, the assembly (excluding the mandrel) is submerged in an acetone bath. After five days, the ABS will have fully dissolved in the acetone leaving the carbon fiber stiffening ring. Figure 46 shows the ring being cleaned of ABS as the acetone dissolves it.

Figure 46. The acetone bath can be seen in the background. The stiffening ring grooves are being scraped to increase efficiency of the acetone dissolving process.

It is recommended to scrape as much ABS out of the part every day with a thin metal tool such as a screwdriver. It is also recommended to let the carbon fiber stiffening ring dry for at least three days to regain its hardness. After the ring has dried, three holes are drilled at 120° apart from one another 5/16” from the top (refer to stiffening ring drawings for clarification). Once the holes have been drilled, the stiffening ring is sanded and sprayed with one layer of clear coat for aesthetics.

9.3.5 Manufacturing Iterations

Four stiffening rings were manufactured. Descriptions about each are below.

- Stiffening Ring #1: The entire mold was manufactured out of polycarbonate. The spacing rings of the mold were one piece instead of broken up into three pieces. After curing Stiffening Ring #1, the spacing rings never came out of the part. Because the molds never released, ABS printed molds were designed for Stiffening Ring #2 with the plan of dissolving them with acetone. Also, the inner wall of the stiffening ring did not get ample pressure. The carbon fibers making up the inner wall were delaminating. The spacing rings of the mold were designed to be split up into three pieces to provide a clamping action on the inner wall. Figure 47 shows Stiffening Ring #1 being laid up.

Figure 47. Stiffening Ring #1 mid layup is shown.

- Stiffening Ring #2: The changes mentioned above were implemented in Stiffening Ring #2. After the cure and acetone bath, the ring was too small. Stiffening Ring #3 was then designed to have a larger diameter.

- Stiffening Ring #3: The diameter of the mandrel was enlarged by wrapping tape around it. Figure 48 shows the mandrel after it was enlarged. The nuts were also implemented into the layup. Figure 49 shows the nuts before the cure. Nuts in the layup proved to pose more problems than they solved, so this was abandoned in Stiffening Ring #4.

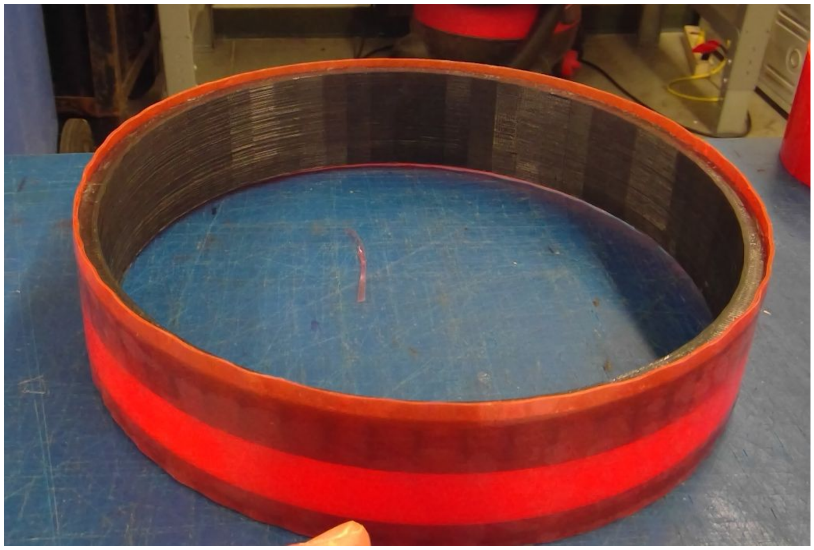


Figure 48. The enlarged mandrel is shown.

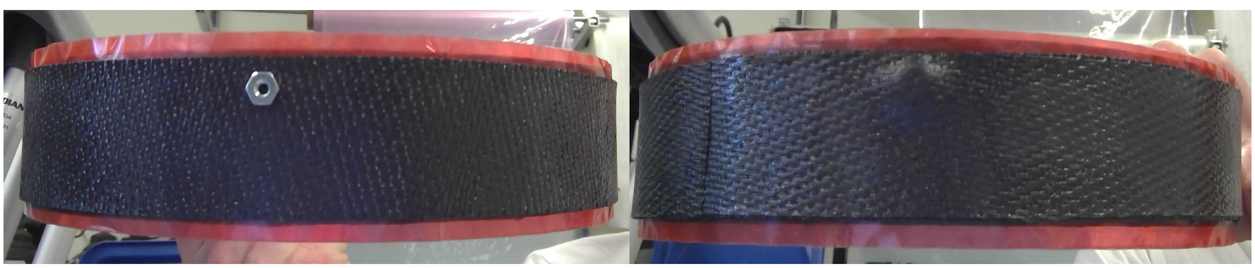


Figure 49. Nuts were implemented into the layup for Stiffening Ring #3. (Left) The nuts were placed after the first two layers were laid, and (right) the second two layers were then laid over them.

- Stiffening Ring #4: The nuts were not implemented into Stiffening Ring #4. See sections 9.3.1-9.3.4 for more details about the manufacturing of Stiffening Ring #4.

9.3.6 Recommendations for Future Manufacturing

Depending on 3D printer capabilities, the middle mandrel could be printed out of ABS or any other type of plastic. If the acetone-bath removal method is used to dissolve the spacing rings, the spacing rings should be printed out of ABS. Another option is to print the spacing rings out of PVA or PLA plastic and dissolve them post-cure in water.

10 Design Verification & Testing

Rama

Include (but not limited to):

1. Test descriptions with photos
2. Detailed results
3. Specification verification checklist or DVPR

10.1 Instron Testing

Instron testing is an effective way to evaluate the strength of a sample using simple equipment. Typically an instron compression machine is used to determine the elastic modulus of a material or the stress-strain curve. For our canister, due to the complex nature of the composite material and non-optimal material (the prepreg carbon weave was donated due to it's expired nature) it was more useful, and easier, to obtain a load-deflection curve. A strain deflection curve would require the use of strain gauges and additional complex monitoring equipment. The last critical reason for choosing to develop a load-deflection curve over a stress-strain curve was that we had a jig for holding the canister parts in the instron already made from previous instron testing. The instron testing description and details can be seen earlier in section 7.1 of this report.

10.1.1 Canister Half

10.1.1.1 Strength Test: 4-Layer Canister Half

In section 7.1 of this report an initial four layer thick walled canister was tested to failure to show the maximum force a half canister can withstand. Although the stiffening ring is designed to take the majority of the load, the half canisters can be used to reinforce the ring. Additionally, we wanted to see the canister load at 0.25" and 0.5" inches deflection. Referenced below in Figure 50 is the previous instron testing results for reference, with a maximum load of 438 lbf.

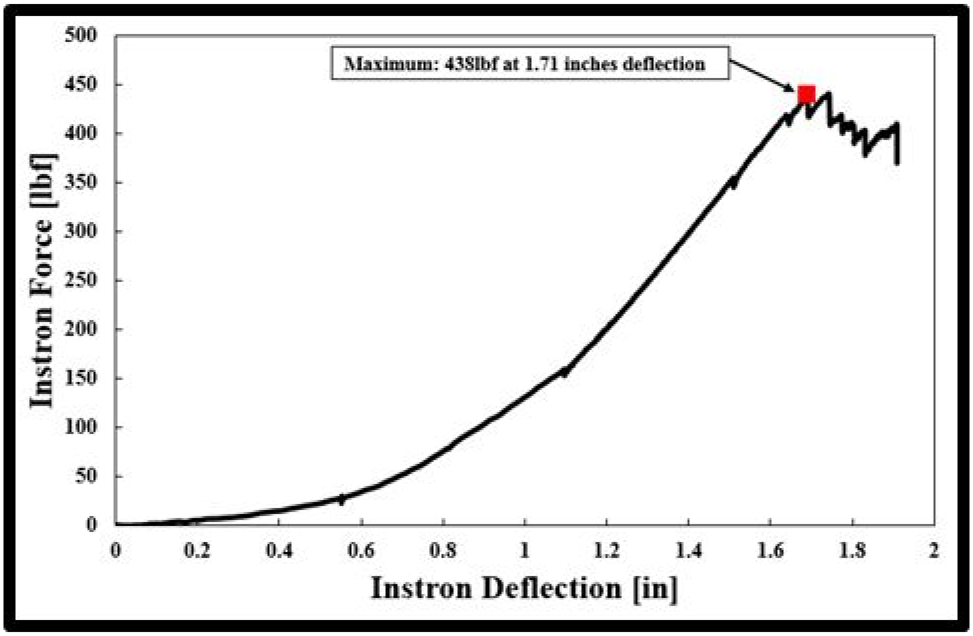


Figure 50. Original Instron Half Canister of a Four-Layer 5 hour cure

10.1.1.2 Stiffness Test: 5-Hour Cure vs 12-Hour Cure

Previously, it was decided that a wet carbon fiber weave was inferior to the prepreg carbon fiber weave due to it's ease of manufacturing and repeatability. It was also shown that the wall thickness of the prepreg composite was more uniform. Our second test was to compare the strength of a longer cure cycle versus a shorter one. Our Cytec 5320-1 prepreg resin system has a recommended cure cycle time of 3 hours (5 total with ramp and cool down). On the other hand our 3D printed mandrel mold has a glass transition temperature of 200F meaning that our autoclave oven needs to be decreased by 50F. Standard practice is to increase cure time by one hour for every 10F decrease, yielding an 8 hour cure cycle. We increased this cycle to 10 hours for good measures and with ramp and cooldown it is 12 hours.

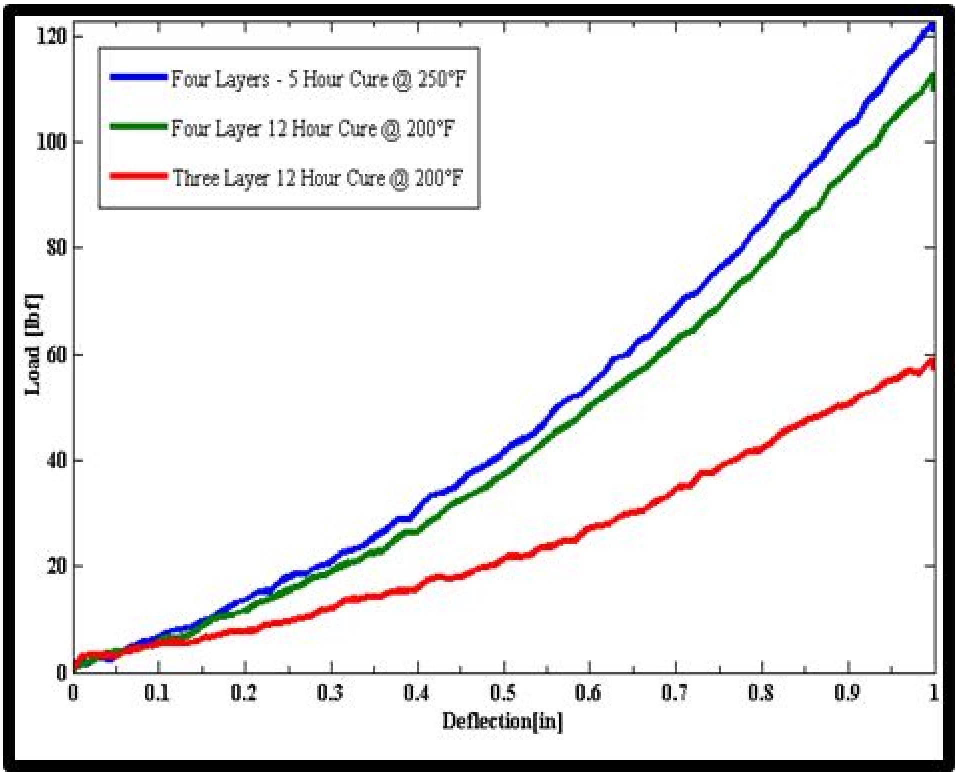


Figure 51. Instron Results from Various Cure Cycle Times

On the instron we tested both a 5 hour cure and 12 hour cure cycled canister halves to compare the effect of increasing the cure time. The previous Figure 51 shows that for our four layer sample, the 12 and 5 hour cures had similar load-deflection curves, with the 5 hour cure being 11% higher at 1 inch of deflection. For smaller deflections, closer to what the canister would experience out in the field, the load difference at 0.25inches was less than a 1 lbf difference. This showed that the cure cycle makes less than <5% difference for our small angle deflections. Using our small angle assumption for small deflections, we can linearize the stiffness curve around the origin. The canister is approximately 67 lbf/inch for small deflections up to 0.25inch, showing that our canister acts like a spring for small deflections.

10.1.1.3 Stiffness Test: 3-Layer Canister Half vs 4-Layer Canister Half

The red line in the figure also shows the three layered canister half load deflection curve which showed the huge increase in stiffness going from a three layer to a four layer canister. At one inch of deflection the three layered canister half was approximately 50% of the four layer canister. Although the stiffness is much less, it can be justified by the 0.4 lbf decrease in weight. The three layer canister was only cured at the 12 hour cure cycle since it was often cured simultaneously with the stiffening ring. The three layer, 12 hour cure, canister half reached a maximum load of 60 lbf at 1 inch. Using the 11% increase in stiffness from the four layer

canister trials, we can estimate that a 5 hour cure for the 3 layered canister would be able to to take approximately 66 lbf.

10.1.2 Canister Assembly

10.1.2.1 Stiffness Test: 1.3 lbs Canister Assembly vs 1.7 lbs Canister Assembly

Our canister assembly consists of the two canister halves and the stiffening ring. We chose to test the full assembly as it a better representation of the entire canister than just the stiffening ring alone. Our target goal for this project was not met by our original 4-layered 1.7lb canister so a second iteration of 1.3lbs and three layered wall was made which was lighter and had a slightly less thick stiffening ring.

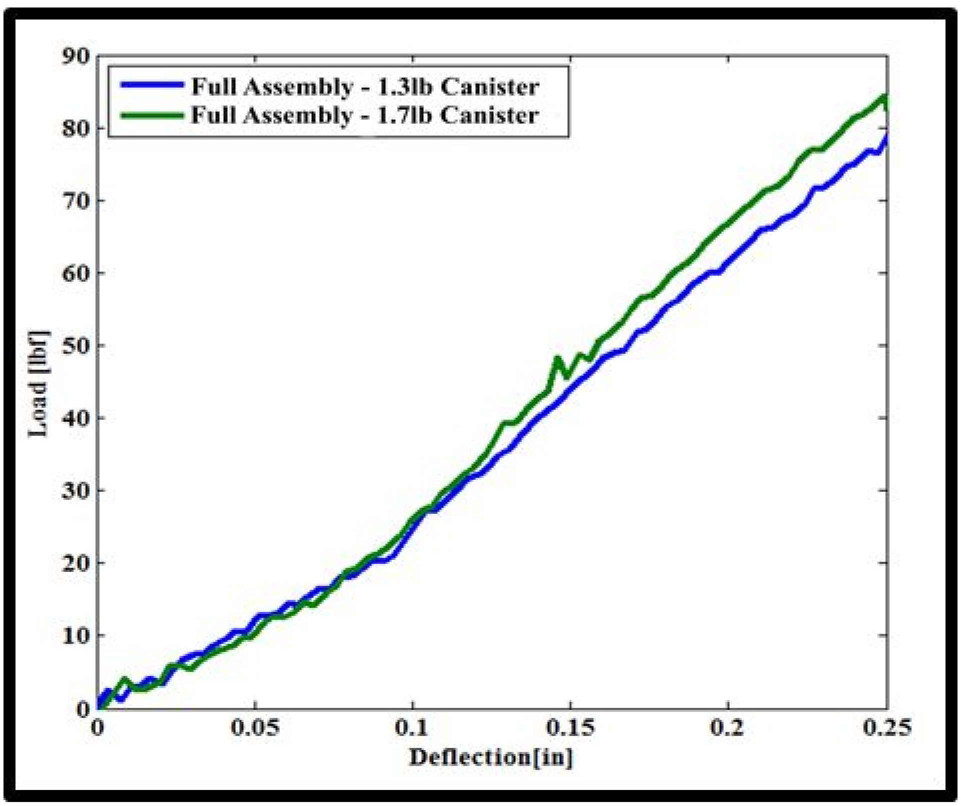


Figure 52. Full Assembly Instron Stiffness Comparison of Light and Heavy Canisters

The results of our test in Figure 52 corroborated our hypothesis that the 1.7lb assembly featuring more layers on the ring and halves would be the stronger of the two. Surprisingly, the 1.7lb assembly was only slightly stiffer than the 1.3lb assembly. We believe that the acetone bath had significantly softened the 1.7lb stiffening ring. Residual moisture in the rings significantly reduces their stiffness to the point that even simple inspection by hand can notice a large difference. After thorough drying for multiple days the rings return to their initial strength. The

bear minimum team found the 1.7lb stiffening ring was not fully dry at the time of the test which may have reduced its strength slightly.

10.2 Drop Testing

10.2.1 Introduction

A series of drop tests were carried out to simulate an equivalent dynamic load exerted by a bear. When the agency existed, the SIBBG required canisters to pass 100 lb top and side drop tests from 1 ft high for canister certification. As a precedent, these two drop tests were chosen to test the 1.3 lb and 1.7 lb Bear Minimum bear canisters. See Section 10.2.2 for the full drop test setup, procedure, and safety information. Sections 10.2.3 and 10.2.4 discuss each test performed. These descriptions are categorized by a thumb-screw locking mechanism, a threaded rod locking mechanism, or an epoxy bond. The thumb-screw locking mechanism refers to the locking mechanism proposed in the final design description (refer to section 7.2). The threaded rod locking mechanism and epoxy bond were alternative locking mechanisms tested for the side drop test only. The intent of these alternatives was to verify whether each canister would pass with a different locking mechanism. The three types of locking mechanisms are shown side by side in Figure 53 before the 100 lbs was dropped.

Figure 53. (Left) The 1.7 lb canister is shown with the thumb screw locking mechanism. (Middle) The 1.3 lb canister is shown with the epoxy bond. (Right) The 1.7 lb canister is shown with a threaded rod through the canister secured by three washers and a nut on both sides.

A failing grade was given to any canister that showed any fiber failure, delamination, or part separation.

10.2.2 Drop Testing Plan

10.2.2.1 Introduction & Objective

The SIBBG (Sierra Interagency Black Bear Group) used to conduct drop testing on bear canister to validate their strength and resilience in the case a bear applies a compressive load to the canister outside. The SIBBG ceased its existence in the late 2013's but provided a good basepoint for impact testing. The drop test in particular provides a good introduction to live bear testing. Previous canisters such as the BearVault have been tested in similar ways as seen in the following story:

> "During the autumn and winter of 2002/2003, BearVault made several prototypes which were impact-tested by the Sierra Interagency Black Bear Group (SIBBG). By May 2003, we had a canister that was ready for the ultimate test: a trial stint with Fisher, the 560 pound black bear at the Folsom Zoo. Fisher, with his massive bulk and powerful jaws, had sent many designers back to the drawing board. It turned out, that is exactly what he did to this early BearVault design as well. The SIBBG required the canister to last one full hour – but after just 8 minutes, Fisher had torn into the canister, and claimed his tasty reward of meat, peanut butter and jelly."

10.2.2.2 Goals

Similar to the SIBBG testing criteria, we are going to test the canister by dropping a 100lb weight from one foot high onto both the side and top of the canister. Although SIBBG had a maximum deflection requirement of 0.25", given carbon fiber's unique elastic properties we are not limiting our deflection requirement. A successful canister will pass both the side and top drop tests without fracturing, fraying, or yielding. This result is desirable to improve the lifecycle and structural integrity of a canister. A structurally compromised canister may not withstand subsequent bear attacks.

10.2.2.3 Schematic:

The following schematic in Figure 54 shows our testing setup which consists of the canister inside a plexiglass enclosure, high speed camera, and 100lb weight tied to a pulley system.

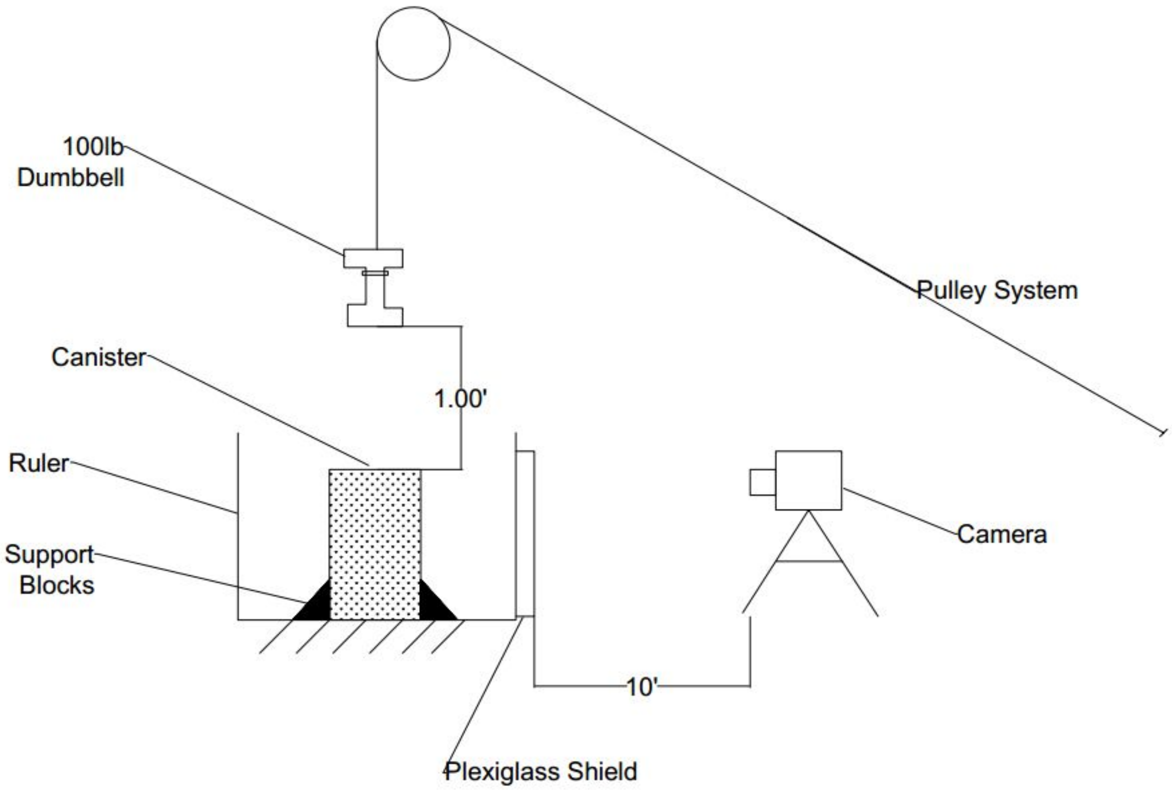


Figure 54. Schematic of Drop Testing Apparatus

10.2.2.4 Equipment and Specifications:

- 150lb+ rated rope
- 150lb+ rated pulley
- 100lb Weight and Platform
- 2 foot+ long ruler
- Plexiglass sheet
- Cinder Blocks For barrier
- Restraining wood block
- Video Camera (High speed Preferred)
- Base mounting restraint

10.2.2.5 Preparation

- Base and Enclosure:

The canister will be enclosed inside of a heavy duty plastic container to prevent lateral movement and stray debris. The camera-facing edge will be removed and a transparent plexiglass sheet placed in the cutout. (This will allow the camera picture to be clear and the lens protected). Inside the enclosure the canister will be placed in the center with restraining blocks or books placed on the side to prevent sliding of the canister out of the camera frame. The restraining blocks will not prevent the canister from deflecting or changing shape, just preventing slippage. A ruler will be adhere to the enclosure base to allow for a scale and weight vertical alignment.

- Camera:

The high speed camera will be placed a safe distance from the test apparatus (10ft) and the focus zoomed in on the plexiglass display. It will be run a few seconds before the drop to allow the operator to move a safe distance away. A secondary mobile camera will also take video for additional footage.

- Pulley System:

The pulley system is responsible for hoisting the 100lb weight and platform to the required height of 1 foot (relative) to the top of the canister. The ruler will allow for vertical alignment

10.2.2.6 Safety and Risks

Special safety precautions are needed in this test due to a large mass being dropped. The mass needs to be contained when it is impacted by a safety enclosure. The enclosure built of cinder blocks also ensures that the canister or any fragments do not fly out and injure the operators or an expensive camera. Special attention to the order of operations is needed. All personnel involved in the drop test must be out of range of the impact before the weight is dropped. Safety glasses will be worn at all times.

10.2.2.7 Procedure

After mounting the pulley to a the vertical support a rope will be attached through a clovehitch knot to the dumbbell. The canister will then be placed into the encasement with the supporting blocks. The high speed camera placed 10 feet away and angled at the subject impact zone. The weight will be lifted to one foot high by the primary person. The secondary person will verify the correct height. The secondary person will then start the camera and move to a safe distance away. The primary person will then drop the weight and is responsible for stopping the camera(s).

The test will be repeated on the side and top of canister. Four tests in total will be conducted: two on a canister with three layers of wall thickness, and two on a thicker four layered wall canister.

10.2.2.8 Pass/Fail Criteria

A successful canister will be deemed "passing" if it maintains the criteria described in Table 29.

Table 29. Pass Criteria for Drop Testing to be met

Pass Criteria
-No composite fiber yield -No permanent deflection. (Elastic Regime) -No carbon fraying -No carbon fracture -No dents or cavities greater than ⅛" -Weight dropped directly vertically **All Criteria MUST be met to PASS**

10.2.3 Four Layer 1.7lb Canister

10.2.3.1 Top Drop Test #1: Thumb-Screw Locking Mechanism

Figure 55 shows the 1.7 lb canister during the impact. The canister passed the top drop test. Because the canister featured the thumb-screw locking mechanism, top drop tests were not performed with the epoxy bond or threaded rod locking mechanisms.

Figure 55. The top drop test impact with the 1.7 lb canister is shown.

10.2.3.2 Side Drop Test #1: Thumb-Screw Locking Mechanism

The 1.7 lb canister with the thumb-screw locking mechanism failed the side drop test. Figure 56 shows the canister during the impact, and Figure 57 shows a close up view of the failure.

Figure 56. The side drop test impact with the 1.7 lb canister is shown. The bolt hole is shown shearing during the impact.

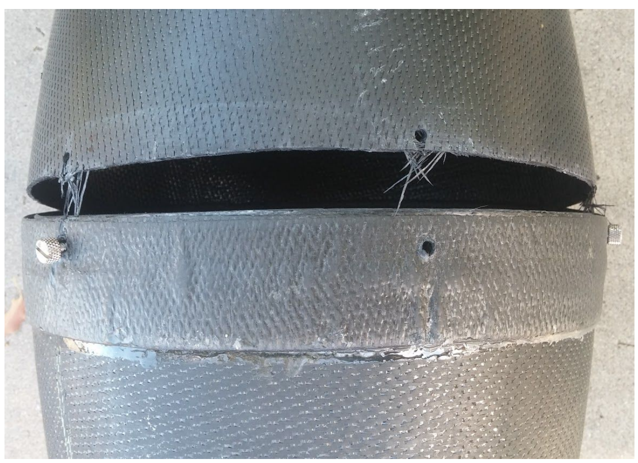


Figure 57. A close up view of the failure is shown. Four of the six bolt holes sheared during the side impact.

The fiber failure under the bolt holes was due to shear stress concentrations around the bolt holes. This stress around the bolt holes was larger than anticipated due to the impact time of approximately .0083 seconds compared to the expected impact time of 0.10 seconds. This failure was a design failure. Further FEA is required to determine how much stress the carbon fiber experiences around the bolt holes from the shorter impact time and appropriate adjustments to

the design should be made. Depending on the amount of support necessary, steel washers implemented into the layup could be a sufficient course of action.

10.2.3.3 Side Drop Test #2: Epoxy Bond

Figure 58 shows the 1.7 lb canister during the impact. As seen in the figure, the epoxy bond failed on impact.

Figure 58. The side drop test impact with the 1.7 lb canister and epoxy bond is shown. The epoxy bond failed during the impact as seen in the image.

The intent of the epoxy was to create a permanent bond between the canisters. However, the impact force was large enough to break the adhesion. All of the individual parts of the canister were intact; the canister assembly only experienced part separation. Because the carbon fiber did not delaminate or break, the test result was ruled plausible. If a locking mechanism was designed to keep the parts together, the 1.7 lb canister would pass the side drop test.

10.2.3.4 Side Drop Test #3: Threaded Rod Locking Mechanism (Hand-Tightened)

A threaded rod locking mechanism was created by drilling holes through the middle of the ends of the canister. A threaded rod with three different sizes of washers and a two nuts on each end were used to secure the assembly. Figure 59 shows the locking mechanism:

Figure 59. The threaded rod locking mechanism is shown. Three different sized washers were used on each end to diminish the stress concentration.

The canister failed the side drop test due to part separation. The impact and failure is shown in Figures 60 and 61, respectively.

Figure 60. The side drop test with the 1.7 lb canister and hand-tightened threaded rod locking mechanism is shown. Part separation is visible.

Figure 61. After the impact, the canister half was not fully seated in the stiffening ring.

Similarly to Side Drop Test #2, the failure was only part separation; all carbon fiber remained intact. This supports the conclusion that if a new locking mechanism could successfully keep the assembly together, then the 1.7 lb canister would pass the side drop test.

10.2.3.5 Side Drop Test #4: Threaded Rod Locking Mechanism (Wrench-Tightened)

After the canister assembly showed part separation in the Dise Drop Test #3, the nuts on both ends were tightened with a wrench and the canister was tested again. Figure 62 shows the 1.7 lb canister during the impact.

Figure 62. The side drop test with the 1.7 lb canister and wrench-tightened threaded rod locking mechanism is shown. Part separation is visible.

Similarly to Side Drop Test #3, the non-adhered canister half separated from the stiffening ring. It is important to note the gap between parts was smaller as seen in Figure 62 when compared to Figure 60. This was due to the added extra compression from tightening the nuts with the wrench. The canister also failed the test due to fiber failure and delamination at one location on the non-adhered canister half. Figure 63 shows this failure.

Figure 63. The canister half failed at the seam of the layup. This failure does not contradict the analysis completed during the design phase, because the design of the part did not take into account the extra pre-loading from tightening the nuts.

10.2.3.5.1 Failure Analysis: Canister Half Fiber Failure and Delamination

This failure would be classified as a design failure. The failure would occur again if the same test was repeated. Comparing this result to the results from Side Drop Test #3, the reason why the canister half experienced fiber failure and delamination was because of the initial added compression the washers exerted on the canister ends from tightening the nuts with the wrench. Because of this pre-loading, the stress on the ends of the canister was greater than in Side Drop Test #3 causing the canister half to fail. The reason why the canister half failed at the filleted edge was because of the layup procedure. The filleted edge was where the sidewall layers overlapped the bottom layers, or the seam in the layup. That is why the delamination and fiber failure occurred here. If the final locking mechanism features an initial compressive load on the canister, the structural design of the canister half needs to be revisited to make it stronger.

10.2.3.6 lb Canister Conclusion

As mentioned earlier, the feasibility of the 1.7 lb canister was decided to be plausible. Because there were not any part failures during the side drop test (excluding Drop Test #4), it can be concluded that if a locking mechanism was to be designed to keep the assembly together during impact, the canister would pass the top and side drop tests.

10.2.4 Three Layer 1.3lb Canister

10.2.4.1 Top Drop Test #1: Epoxy Bond

Figure 64 shows the 1.3 lb canister during the impact. The canister passed the top drop test.

Figure 64. The top drop test impact with the 1.7 lb canister is shown.

10.2.4.2 Side Drop Test #1: Epoxy Bond

The epoxy bonded 1.3 lb canister failed the side drop test. The stiffening ring experienced fiber failure, and the canister half experienced fiber failure and delamination. The epoxy bond also broke causing part separation. Figures 65, 66, and 67 show the impact, the stiffening ring failure, and the canister half failure, respectively.

Figure 65. The impact is shown. The fiber failure of the stiffening ring can be seen in this image.

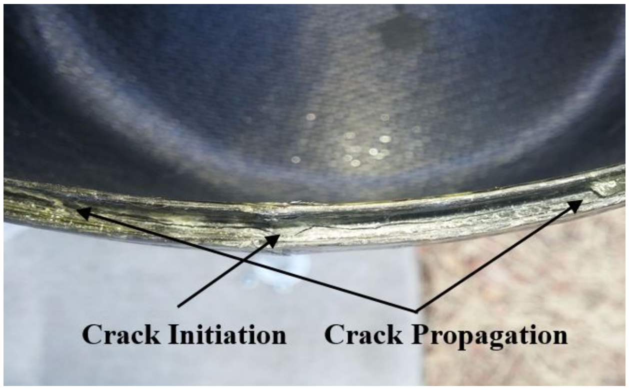


Figure 66 and 67. The stiffening ring failure is shown from the top view (left) and the front view (right).

10.2.4.2.1 Failure Analysis: Stiffening Ring Failure

The stiffening ring failure can be categorized as a design failure, specifically a failure within the design of the manufacturing process. As a result of the current vacuum bagging manufacturing process, wrinkles on the outside edge of the stiffening ring formed. The wrinkles were then sanded down after the cure, breaking the continuous carbon fibers. This location, where the wrinkles got sanded down, was where the part failed. The sanded-down wrinkle is visible in Figure 68. The bolt hole also added a stress concentration at this location on the stiffening ring. It is recommended that the manufacturing process is to be altered to get rid of the wrinkles, and to move the drilled holes off of the sanded-down wrinkles.

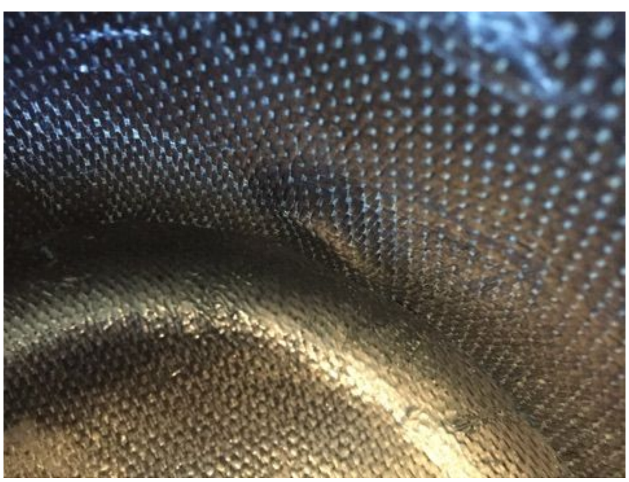
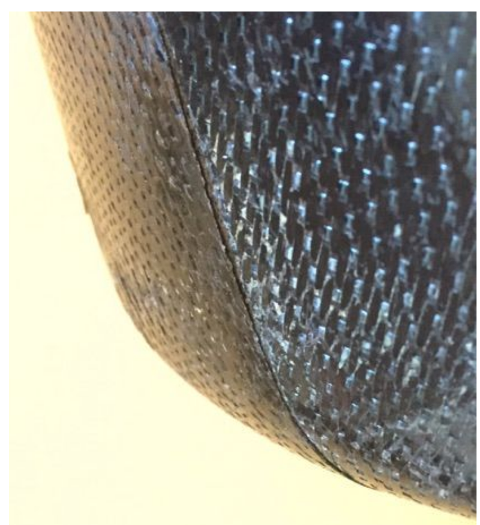



Figure 68. The canister half failure is shown from the inside (left) and from the outside (right). The location of the failure was on the seam of the sidewall of the canister half.

10.2.4.2.2 Failure Analysis: Canister Half Failure

Manufacturing was accountable for the canister half failure. The failure would not necessarily occur again if the same test was repeated. The other canister half was manufactured using the same methods, and it did not fail. This means the 3-layer prototype canister half has a 50% failure rate. After speaking with Real Carbon Inc., a professional composite manufacturing company, a reasonable failure rate is 25% for prototypes going through testing. If the sample size was increased, a more accurate failure rate could be assigned to this part.

10.2.4.3 lb Canister Conclusion

The feasibility of the 1.3 lb canister design was decided to be inconclusive. This is because the first failure for the canister assembly was the epoxy breaking. When the epoxy failed, the load path was broken meaning the dynamic load was unable to be transferred from the point of impact, the stiffening ring, into both canister halves and then back through the stiffening ring. Because of this, there is a chance that the broken load path caused the sequential stiffening ring and canister half failures. Further side drop testing of the 1.3 lb canister is required to determine the feasibility of the 1.3 lb canister.

11 Full Scale Manufacturing Analysis

In anticipation for future full scale manufacturing the Bear Minimum team consulted with four senior industrial engineering students in the IME 443 class at Cal Poly. The following students were responsible for investigating the feasibility, cost, and process flow for manufacturing: Wicky Woo, George Merida, Alyssa Leventis, and Jesse Yap. The initial goal was to design for a manufacturing rate of 5,000 units per year, or approximately 20 units each day for 250 yearly working days.

After discussing the process flow for creating a canister the following key step blocks were discovered and a process flow was created in Figure 69.

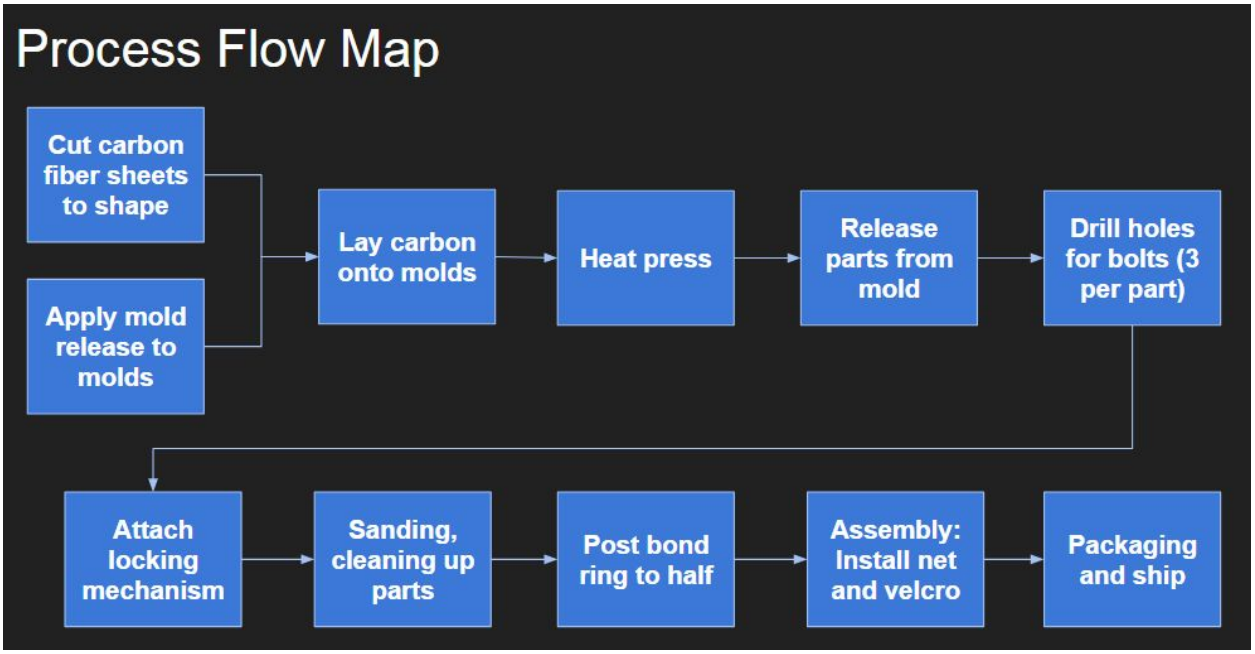


Figure 69. Manufacturing Key steps

Regarding the materials needed in the process, the three key parts are the carbon fiber, molds, and final assembly (ring and two halves).

Material Flow:

- Raw Carbon Fiber: Freezer → Carbon Fiber Prep → Carbon Fiber Laying
- Molds: Mold Prep → Carbon Laying → Hydraulic Press → Assembly Prep
- Finished Parts: Locking Mechanism → Ring → Final Assembly and Packaging

To achieve the material flow the raw carbon fiber, molds, and assembly require 12 steps spanning 3.83 hours (230 minutes total). These steps are highlighted in Table 30 in the order they occur.

Table 30. Operations list for Bear Canister Production

Operation		Time(mins)
10	Cut carbon fiber sheets to shape	10
11	Apply mold release	10
12	Lay carbon onto molds	45
20	Hydraulic heat press	75
21	Release from mold	15
30	Drill holes	5
31	Attach locking mechanism	10
32	Sanding and cleanup	30
40	Post bond ring to half	10
41	Cleanup	10
42	Assembly of net and velcro	5
50	Packaging and ship	5
	Total cycle time	230

The total time divided by the number of operations yielded an average time of 20 minutes per station. The following departments are needed to achieve the following process flow without bottlenecking. The following departments and quantities were identified:

1. Carbon Fiber Prep
2. Mold Prep
3. 3x Carbon Fiber Laying
4. 4x Hydraulic Pressing
5. Assembly Prep
6. 2x Locking Mechanism Assembly
7. Ring Assembly
8. Final Assembly and Packaging

The following schematic in Figure 70 shows the layout of the manufacturing assembly giving a 2:3 depth to width ratio of the building. Departments related to the same material flows were put near each other to promote productivity and less transportation time between steps.

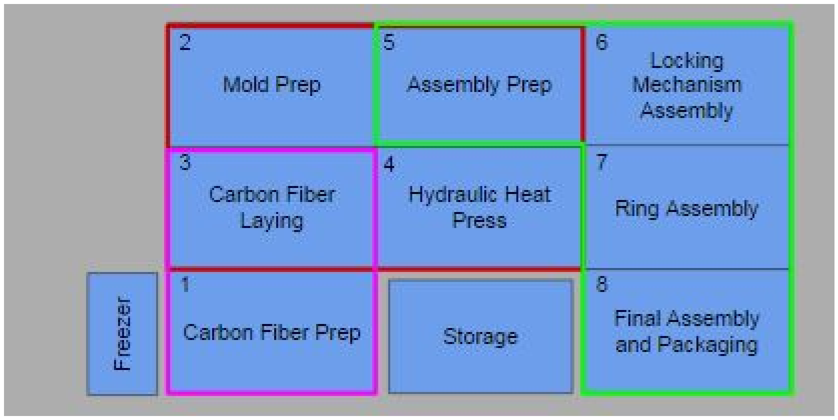


Figure 70. Layout of Department Stations in a Manufacturing Space

Operating the facility will take a total of 10 laborers to run the facility, 3 of them are highly skilled for more critical steps and require a higher hourly rate. The total labor cost is $285,000 per year as seen in Table 31 .

Table 31. Labor Needed for 5,000 units per year

Labor Type	**Hourly Rate**	**Yearly Cost**	**Quantity**
Skilled	$23	$46,000	3
Unskilled	$10.50	$21,000	7
Total labor cost per year		**$285,000**	

The stations will need various storage chests, cutting machines, and presses to process listed in Table 32 below. The freezer is used to store raw carbon, and the presses are used to quickly cure the canister halves.

Table 32 Equipment Needed for 5,000 units per year

Item	Cost	Supplier	Quantity
Chest Freezer (6' Width)	$550	Sears	1
Die Cutting Press	$3,000	Tippmann	1

Hydraulic Heat Press	$5,000	Ebay	4
Drill Press	$3,400	Max Tool	1
Half Mold	$8,000	Nick's Estimate	8
Ring Mold	$2,500	Nick's Estimate	4
Silicone	$889	MC Silicone	60 kg
Workbenches (60"x30", 96"x36")	$190, $320	Global Industrial	10
Total initial investment	**$103,869**		

Total cost for manufacturing will be -$425k first year and -$323k for subsequent years to account for a fixed labor cost and material cost for each canister. The full final powerpoint presentation can be seen in Appendix N below.

12 Conclusion

The Bear Minimum project has spanned two years and two complete senior project design cycles. This year's senior project was a continuation aimed at designing the lid for the last year's canister. We had a small team of only two people requiring us to be very organized, scheduled, and proactive in our work.

Following the design process we started the year with the ideation phase which involved creating many different ideas for opening structures, mechanisms, and locations. After selecting a middle opening design using channel push points we found that the parts were too flimsy to be feasible. We went back to the drawing board and created our H-Channel, double tongue-and-groove locking mechanism which is structurally sound. The H cross section mimics an I-beam giving the canister excellent radial stiffness and rigidity.

Overall our project was a monumental success as we successfully redesigned the canister to open from the center and improve the radial rigidity which was the major design weakness. Our design also allows the tongue and groove interface to make contact around the entire rim. We succeeded in overcoming manufacturing challenges such as mold removal, insufficient lamination and removing spacers. We innovated by using cheap 3D printed rings as the spacers which we successfully melted out. Additional successes include an innovative two material, 7

piece mandrel mold for the stiffening ring and making two iterations: 1.3lbs and 1.7lbs respectively.

The lighter 1.3lb canister passed the top drop test, but did not pass the side test due to delamination crack propagation inside the stiffening ring.

The heavier 1.7lb canister passed the top drop test, but also didn't pass the side drop test. We believe that it plausibly could pass in the future if the locking mechanism between the canister halves and the ring is better reinforced. Failure in our testing was always observed at this interface, but never in the actual stiffening ring or halves which leads us to believe the canister design is plausible.

In comparison to our original project specifications we successfully passed most of our target specifications in Table 33. Most of the geometry requirements were met and also quality of the weave. Weight was also achieved, but drop testing was not. We did not submit the canister for live bear testing.

Table 33. Original Specification Sheet Comparison

Category	#	Specification	Target	Tolerance	Risk	Verification
Part Geometry	1	Internal Volume	650 in^3	Min	L	PASS
	2	Size (Length x Diameter)	11" x 9"	+/- 0.25"	L	PASS
	3	Total Weight	1.3 lb_f	Max	M	PASS
	4	Lid Weight	0.20 lb_f	Max	M	N/A
	5	Largest gap diameter	0.25"	Max	M	PASS
Quality Control	6	Diameter of the opening in canister body	6.5"	+/- 0.25"	L	FAIL
	7	Void volume fraction	5%	Max	M	N/A
Operation	8	Torque necessary to open canister	5.1 ft-lb_f*	Max	L	PASS
Forces and Torques	9	Weight dropped during the drop test from 1 ft high	100 lb_f	Min	H	FAIL
Safety	10	Filleted edge radius	0.125"	Min	M	PASS
	11	Removable parts sizes (choking hazard)	1.75" x 1"	Min	L	PASS
Motion	12	Time to remove latched lid	30 sec	Max	L	PASS

Production and Quality	13	Amount of weave distortion on exterior (normalized by surface area)	15%	Max	H	PASS
	14	Time in live contact with bear (according to SIBBG Certification)	60 min	Min	H	N/A
Cost	15	Total cost	$2,000	Max	M	PASS

The manufacturing process for our final canister was not optimized but we successfully lead a team of students to investigate short cure cycles and the costs.

The Bear Minimum team would like to extend our thanks to the following people for providing technical excellence, manufacturing assistance, and project support:

- **Project Sponsor:** Nick Hellewell
- **Senior Project Advisor:** Peter J. Schuster
- **Professors:** Joseph Mello (ME) , Xuan Wang (IME), Sthanu Mahadev (ME), Eltahry Elghandour (ME)
- **Technical Experts:** George Leone,
- **Students:** Eli Rogers (ME) , Mel Boonya-ananta (ME), Wicky Woo (IE), Alyssa Leventis (IE), Jesse Yap (IE), George Merida (IE)
- **Other:** Mechanical Engineering Shops, Parts Oven LLC.

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Appendices

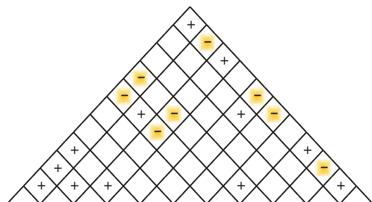
A. Quality Function Deployment (QFD) Chart
B. Hand Calculations
C. Drawings of Nine Selected Designs
D. Layout Drawings of Selected Top and Middle Opening Designs
E. Design Hazard Identification Checklist
F. Gantt Chart
G. Case Study: Composite Manufacturing Processes
H. Formula SAE Carbon Fiber Testing Data
I. Budget Sheet
J. Design Validation Report (DVP)
K. CAD Drawings
L. Specifications Sheets
M. Case Study: Bear Canister Finite Element Analysis (FEA)
N. Case Study: Industrial Engineering Full Scale Manufacturing Study
O. Operator's Manual

Appendix A: QFD - House of Quality
Project:
Revision: 1
Date: 10/25/16

Correlations	
Positive	+
Negative	−
No Correlation	

Relationships	
Strong	●
Moderate	○
Weak	▽

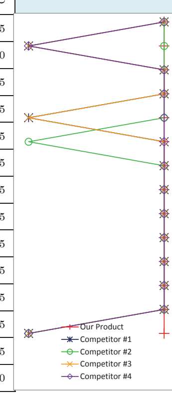
Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼



WHO: Customers

NOW: Current Product Assesment - Customer Requirements

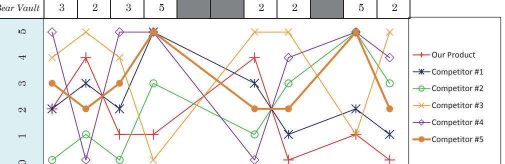
							Column #	1	2	3	4	5	6	7	8	9	10	11							
							Direction of Improvement	▲	▼	◇	▲	▼	▼	▼	▼	◇	▼	▼							
Row #	Weight Chart	Relative Weight	Nick Hellewell	Avid Lightweight Backpacker	Avid Backpacker	Maximum Relationship	WHAT: Customer Requirements (explicit & implicit) / HOW: Engineering Specifications	Internal Volume [in^3]	Total Mass [lb_m]	Size (L [in] x D [in])	Size of Opening (D [in])	Max gap size (diameter [in])	Maximum time for lid removal [s]	Mass to Volume Ratio [lb_m/in^3]	Price to Volume Ratio [$\$/in^3$]	Smallest fillet radius	Void fraction	Cost	**Bear Minimum Bear Canister**	Competitor #1: *Bearikade Weekender*	Competitor #2: *Garcia Backpacker's Cache*	Competitor #3: *Hunny Canister Bear Necessities*	Competitor #4: *Counter Assault*	Competitor #5: *Bear Vault*	Row #
1		9%	10	9	8	9	[Volume of at least 650 in^3]	●	○	●	○			●	○	▽		○	5	5	0	5	5	5	1
2		9%	10	9	7	9	[Maximum weight of 1.6 lb_m]	○	●	○	▽			●		▽	▽	●	5	0	0	5	0	0	2
3		8%	10	6	8	9	[Maximum sale price of $500]	○	●	○			▽	●	●		▽	●	5	5	5	5	5	5	3
4		10%	10	10	10	9	Hand needs to fit in lid opening	▽		○	●								5	5	5	5	5	5	4
5		8%	6	8	8	9	No extra tools required for opening			▽	○		●					▽	5	0	0	5	0	5	5
6		9%	10	8	8	9	Strong enough for 100 lb_f drop test	○	●	○	○			○		○	○	▽	5	5	5	0	5	5	6
7		3%	10	0	0	9	Lid needs to be a structural element		●	▽	●	○		▽		○	○	○	5	5	5	5	5	5	7
8		9%	10	8	8	9	No gaps in canister larger than .25 in		▽	▽		●					▽	▽	5	5	5	5	5	5	8
9		8%	6	8	8	9	Lid removal must take less than 30 s			▽	○		●					▽	5	5	5	5	5	5	9
10		5%	5	5	5	9	Lid must go through testing				▽		○				●	○	5	5	5	5	5	5	10
11		10%	10	10	10	9	Lid must be able to lock		▽	▽	▽		●					▽	5	5	5	5	5	5	11
12		6%	5	10	2	9	No sharp protruding edges			○		▽				●	▽	▽	5	5	5	5	5	5	12
13		6%	10	3	5	9	No choking hazards			●	▽								5	5	5	5	5	5	13
14		3%	10	0	0	9	Total project cost under $2000		▽	▽				▽	○	○	●	●	5	0	0	0	0	0	14



	1	2	3	4	5	6	7	8	9	10	11
HOW MUCH: Target	650 [in^3]	1.6 [lb_m]	11 [in] x 9 [in] (L x D)	6.5 [in] (D)	.25 [in]	30 [s]	.01875 [lb_m/in^3]	.83 [$\$/in^3$]	.25 [in]	[4%]	$500
Max Relationship	9	9	9	9	9	9	9	9	9	9	9
Technical Importance Rating	166.5	299.5	294.5	243.2	91.58	249.8	261	106.5	111	135	271.8
Relative Weight	7%	13%	13%	11%	4%	11%	12%	5%	5%	6%	12%
Weight Chart											

Current Product Assesment - Engineering Specifications

	1	2	3	4	5	6	7	8	9	10	11
Our Product	2	4	1	1			4	0		1	0
Competitor #1: *Bearikade Weekender*	2	3	2	5			3	1		2	1
Competitor #2: *Garcia Backpacker's Cache*	0	1	0	3			1	3		5	3
Competitor #3: *Hunny Canister Bear Necessities*	4	5	4	0			5	5		1	5
Competitor #4: *Counter Assault*	5	0	5	5			0	4		5	4
Competitor #5: *Bear Vault*	3	2	3	5			2	2		5	2



Column #	1	2	3	4	5	6	7	8	9	10	11

Appendix C: Hand Calculations (1/2)

Clamped Circle Stress | 10/20/16 | Ramz Adajian | 1

Impact Force: 100 lbm weight from 1 ft onto surface of 6.5" Diameter circular clamped plate. Max deflection is 0.25"

$m = 45.35$ kgs (100 lbm) $\quad \nu_{zz} = 0.497$

$h = 0.309$ m (1 ft)

$V_{impact} = 2.44$ m/s

$KE = \frac{1}{2} m v^2 = (\frac{1}{2})(45.35 kg)(2.44 m/s^2)$

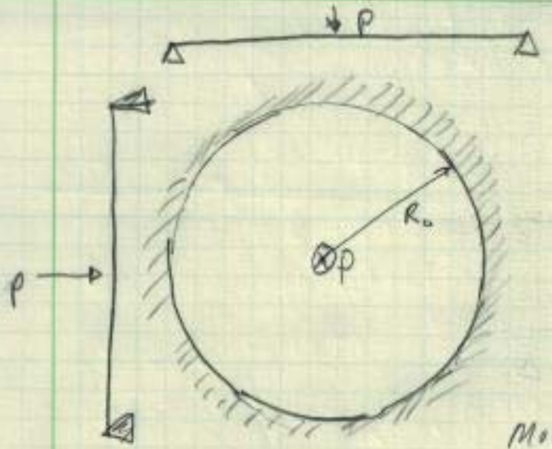
$\rightarrow KE = 135.49 J$

From Work Energy relationship with max impact deflection of 0.25 in or 0.00635 m

$\rightarrow$ Force, avg $= 21,337 N \cdot \frac{1 lbf}{4.44 N} = 4797$ lbf

$$\text{Pressure} = F/A = \frac{4797 lbf}{\pi(\frac{1}{2}(6.5''))^2} = \boxed{225.9 psi}$$

Appendix C: Hand Calculations (2/2)



Displacement of center to not exceed 0.25 in under 226 psi pressure avg load. Fixed statically all around. Calculate Modulus needed if $\nu \approx 0.497$ 3/8" plate, $R_o = 3.25$". Calculate max stress and make sure not exceeded.

Displacement: Max @ center, $r = 0$

$$w(r) = \frac{p r_o^4}{64D}\left[1 - \left(\frac{r}{r_o}\right)^2\right]^2$$

$$@\ r = 0 \quad w(0) = \frac{p r_o^4}{64D}$$

$$M_{max} = M_r(0) = M_\theta = \frac{p r_o^2}{16}(1 + \nu)$$

Max stress @ center of plate at the depth

$$\sigma_{max} = \frac{6}{h^2} M_{max} = \frac{3(1+\nu) p r_o^2}{8h^2}$$

Appendix C: Canister Internal Pressure Calculation

Bear Minimum Senior Project - Team #28

```
%California Polytechnic State University, San Luis Obispo
%Rama Adajian
%11/11/16

clc
clear
close all
global Tmax
```

GLOBAL VARIABLES

```
%Tmax is the Glass Transition temperature of the epoxy.
Tmax = 325 %[Degrees F]
```

INITIAL CONDITIONS STP @ 70 Degrees F

```
n1 = 0.405 %[moles]
T1 = 72 %[Degrees F]
P1 = 14.7 %[Psi]
V1 = 600 %[Cubic Inches]
```

SECONDARY CONDITIONS @ INCREASED TEMPERATURE

```
n2 = 0.405 %[moles]
V2 = 600 %[Cubic Inches]
T2 = [5:10:Tmax]' %[Degrees F]
```

CALCULATING SECONDARY PRESSURE FROM IDEAL GAS LA

```
for i = 1:length(T2)
    P2(i,1) = T2(i)
    P2(i,2) = ((T2(i)+459)/(T1+459))*P1
end
```

Temperature	Internal Pressure	Internal Pressure
°F	PSIA	ATM
5	12.8	0.87
15	13.1	0.89
25	13.4	0.91
35	13.7	0.93
45	14.0	0.95
55	14.2	0.97
65	14.5	0.99
75	14.8	1.01
85	15.1	1.02
95	15.3	1.04
105	15.6	1.06
115	15.9	1.08
125	16.2	1.10
135	16.4	1.12
145	16.7	1.14
155	17.0	1.16
165	17.3	1.18
175	17.6	1.19
185 **DRY Epoxy Glass Transition Temp**	17.8	1.21
195	18.1	1.23
205	18.4	1.25
215	18.7	1.27
225	18.9	1.29
235	19.2	1.31
245	19.5	1.33
255	19.8	1.34
265	20.0	1.36
275	20.3	1.38
285	20.6	1.40
295	20.9	1.42
305	21.2	1.44
315	21.4	1.46
325 **WET Epoxy Glass Transition Temp**	**21.7**	**1.48**

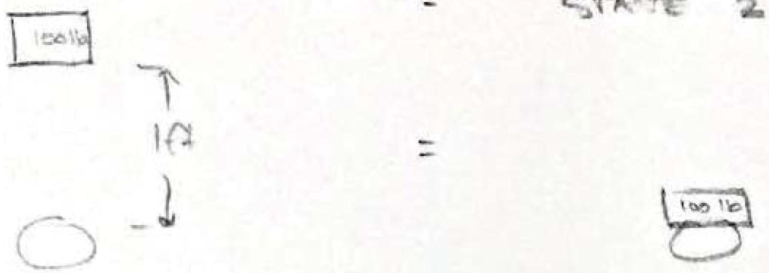
Ring Design Analysis (Load Case) 2/2/17

From Instron Testing: $P_{max} =$ lb

Drop Test equivalent static load calc: $P_{eq} = 249$ lb

assume: impact occurs in .1 s.

STATE 1 = STATE 2



$$\cancel{m}gh = \frac{1}{2}\cancel{m}v^2$$

$$v = \sqrt{2gh}$$

$$v = \sqrt{2(32.2\ ft/s^2)(1 ft)}$$

$$v = 8.02\ ft/s$$

$$(mv)_1 + \int F\,dt = \cancel{(mv)_2}$$

$$-mv + \int_0^t P_{eq}\,dt = 0$$

$$P_{eq}\,(.1s - 0s) = mv$$

$$P_{eq} = \frac{\frac{(100\ lb)}{(32.2\ ft/s^2)}(8.02\ ft/s)}{(.1s)}$$

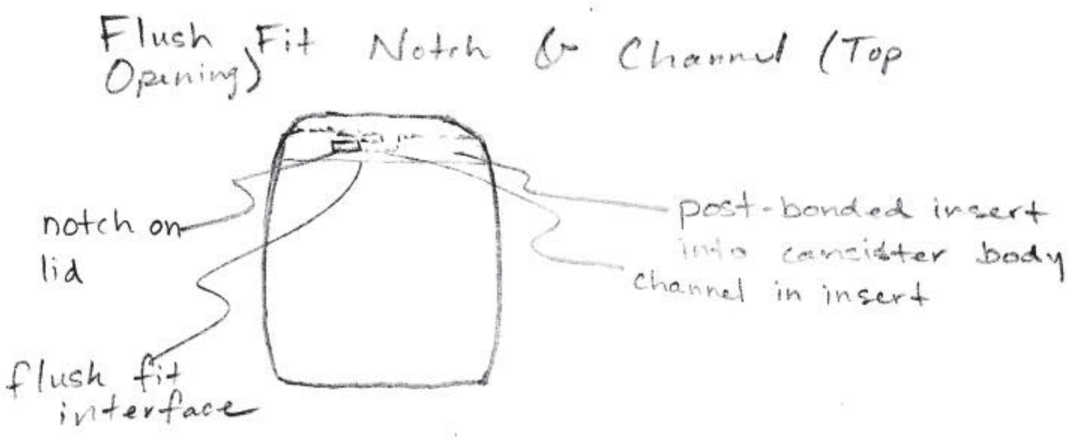
$$\boxed{P_{eq} = 249\ lb}$$

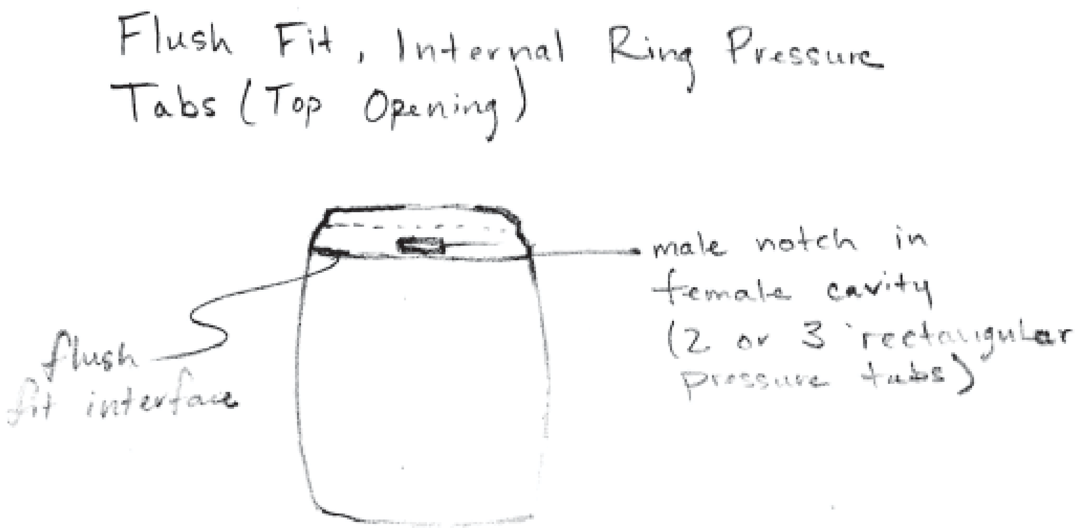
CDR
Design Analysis: Load Case

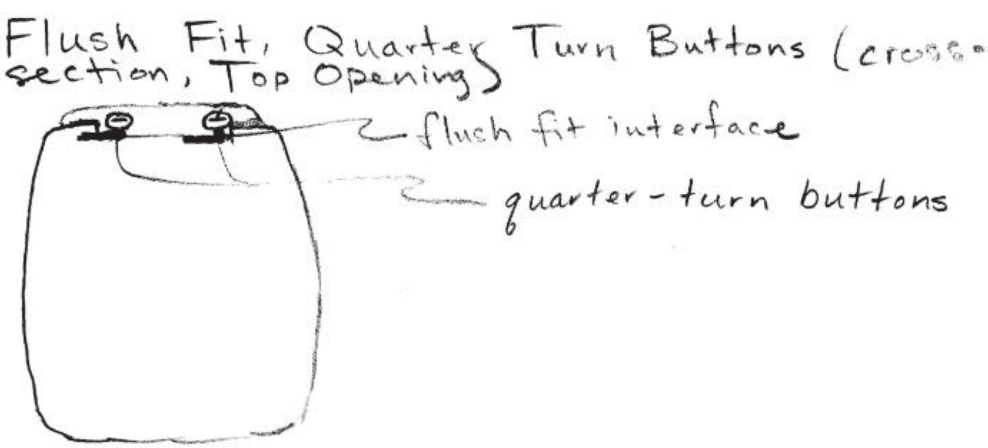
Equivalent Force Rings must contribute: $P_{ring} =$

$$P_{ring} = P_{eq} - P_{max}$$

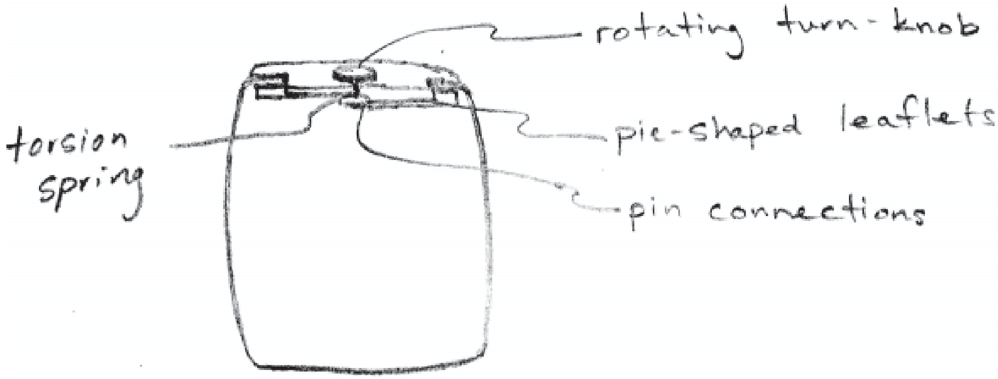
Appendix D: Drawings of Nine Selected designs



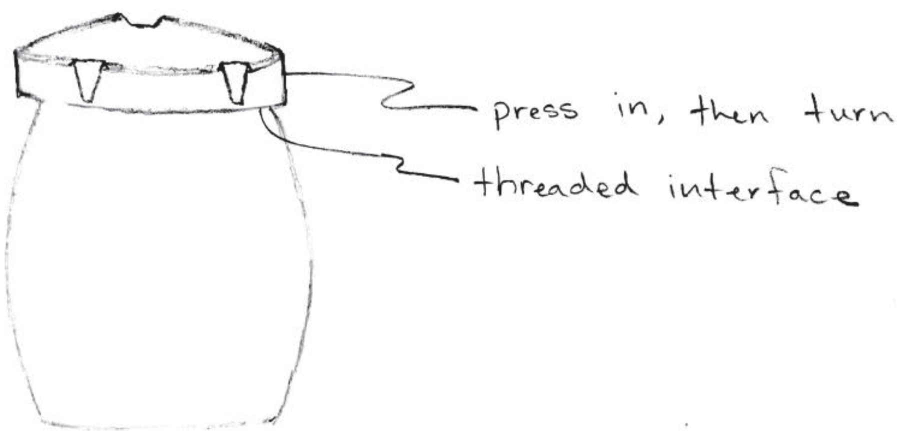




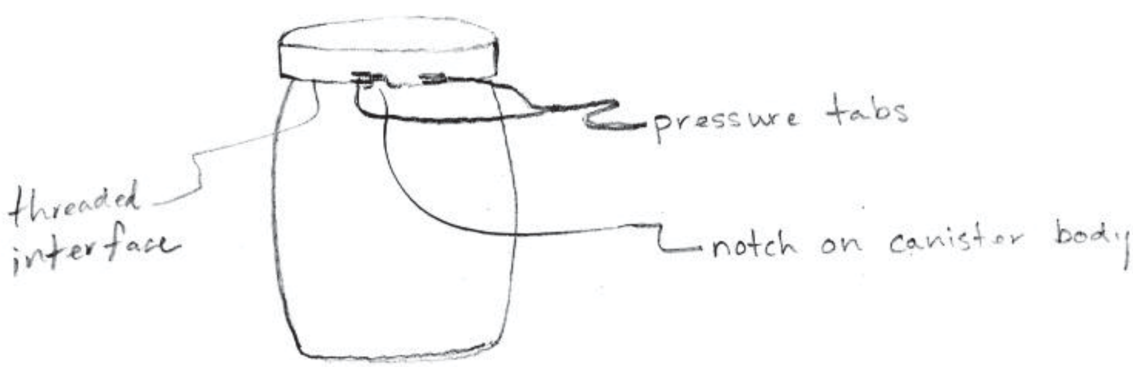
Flush Fit, Rotating Spring Loaded Leaflets (cross-section, Top Opening)



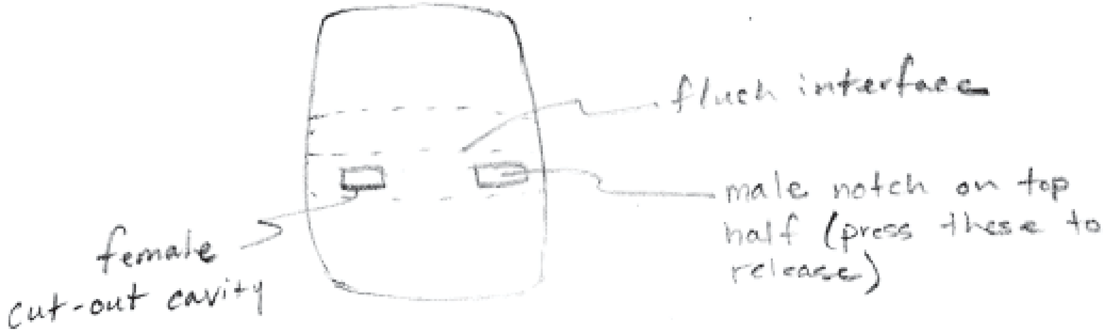
Threaded Fit, Pill Bottle Side-Pressure Release (Top Opening)



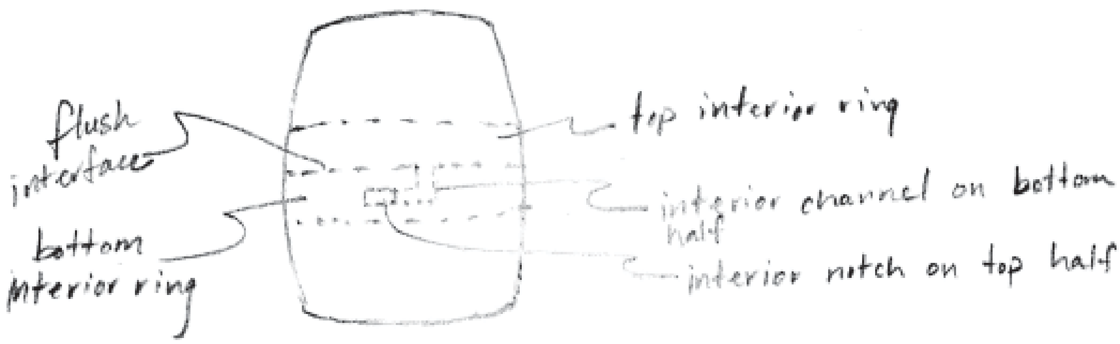
Threaded Fit, Pressure Tabs (Top Opening)



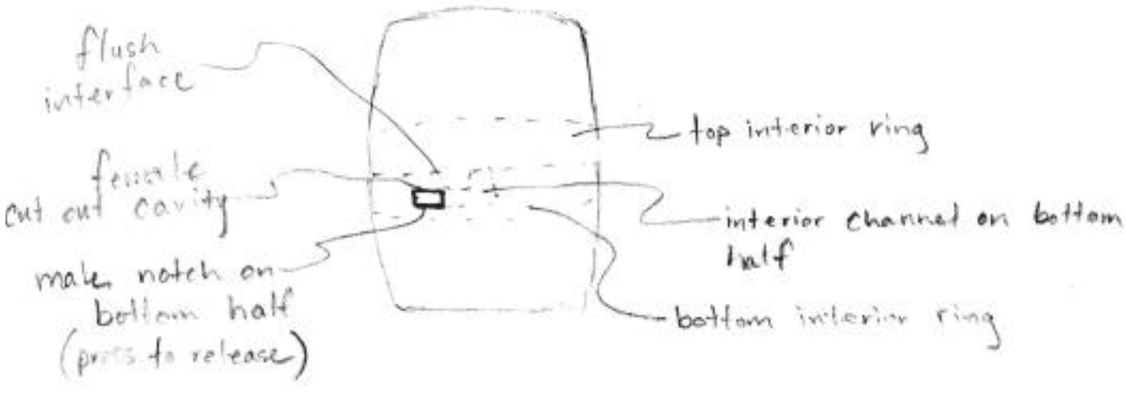
Flush Fit, Internal Ring Pressure Tabs (Middle Opening)



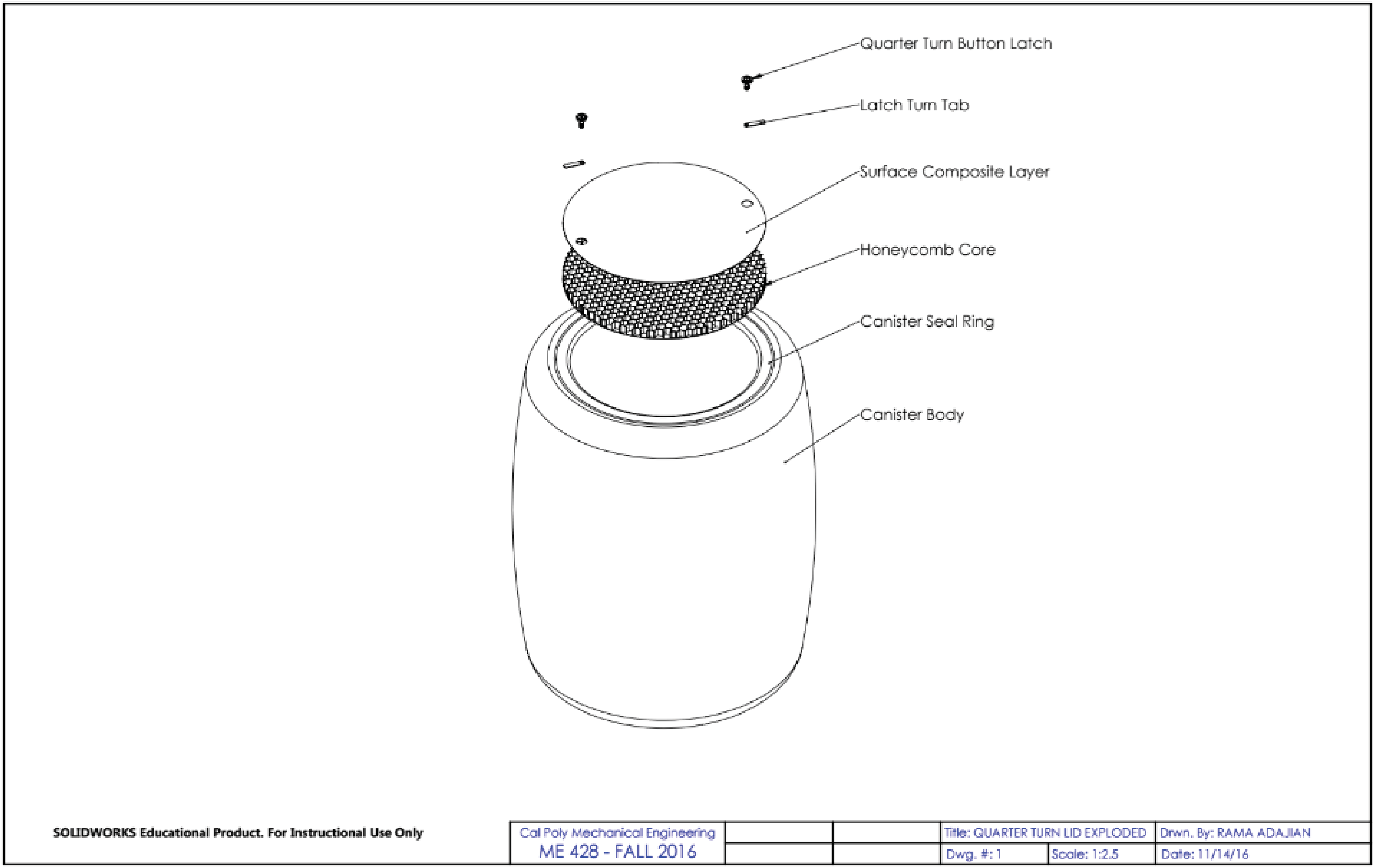
Flush Fit, Notch & Channel (Middle Opening)



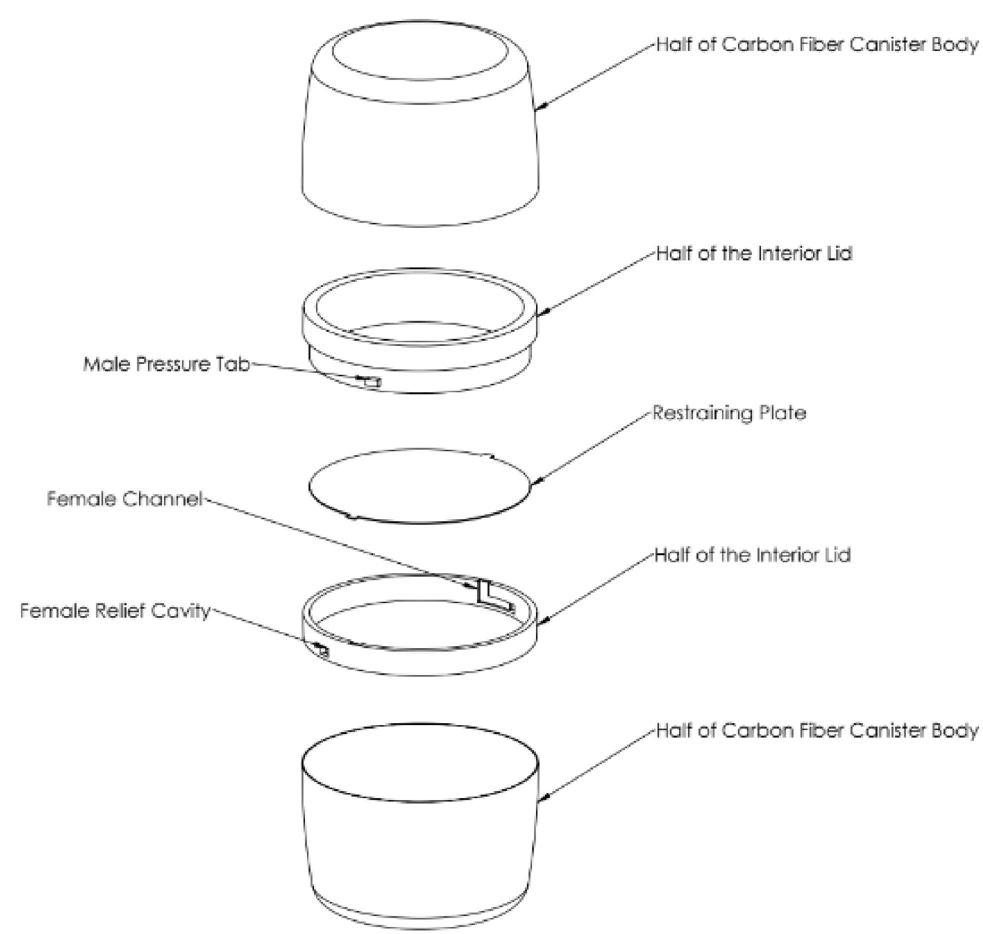
Flush Fit, Internal Ring Pressure Tabs with Channel (Middle Opening)



Appendix E: Layout Drawings (1/2)



Appendix E: Layout Drawings (2/2)



Cal Poly Mechanical Engineering	Lab Section: 02	Assignment #	Title: Middle Opening Design		Drwn. By: Adam Eisenbarth
ME 429 - Fall 2016	Dwg. #: 1	Layout Drawing	Date: 11/10/16	Scale: 1:4	Chkd. By: Rama Adajian

Appendix F: Design Hazard Identification Checklist

ME 428/429/430 Senior Design Project 2016-2017

DESIGN HAZARD CHECKLIST

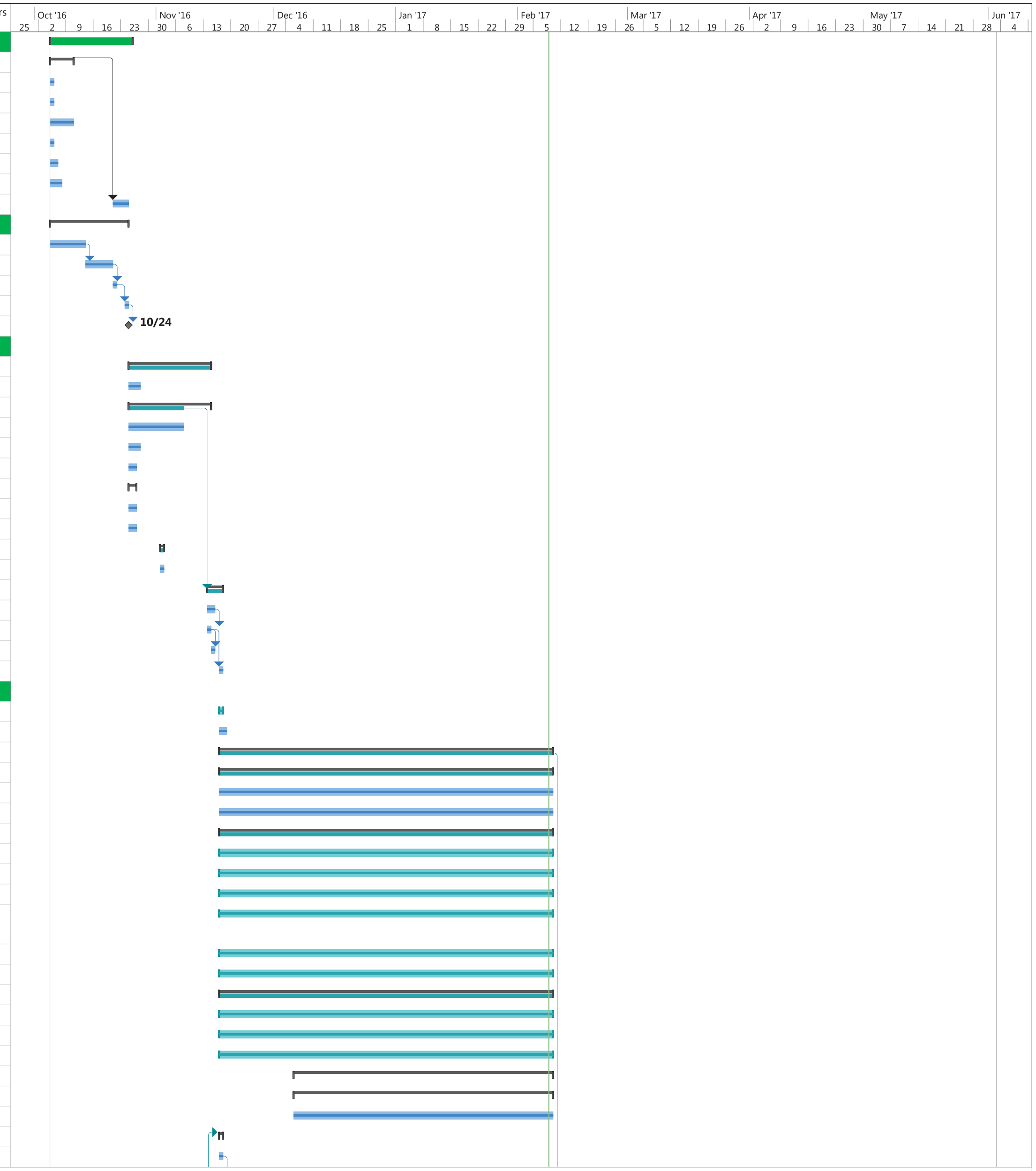
Team: #28 Bear Minimum Advisor: Nick Hellewell

Y	N	
☐	☑	1. Will any part of the design create hazardous revolving, reciprocating, running, shearing, punching, pressing, squeezing, drawing, cutting, rolling, mixing or similar action, including pinch points and sheer points?
☐	☑	2. Can any part of the design undergo high accelerations/decelerations?
☐	☑	3. Will the system have any large moving masses or large forces?
☐	☑	4. Will the system produce a projectile?
☐	☑	5. Would it be possible for the system to fall under gravity creating injury?
☐	☑	6. Will a user be exposed to overhanging weights as part of the design?
☑	☐	7. Will the system have any sharp edges?
☐	☑	8. Will any part of the electrical systems not be grounded?
☐	☑	9. Will there be any large batteries or electrical voltage in the system above 40 V?
☐	☑	10. Will there be any stored energy in the system such as batteries, flywheels, hanging weights or pressurized fluids?
☐	☑	11. Will there be any explosive or flammable liquids, gases, or dust fuel as part of the system?
☑	☐	12. Will the user of the design be required to exert any abnormal effort or physical posture during the use of the design?
☑	☐	13. Will there be any materials known to be hazardous to humans involved in either the design or the manufacturing of the design?
☐	☑	14. Can the system generate high levels of noise?
☑	☐	15. Will the device/system be exposed to extreme environmental conditions such as fog, humidity, cold, high temperatures, etc?
☑	☐	16. Is it possible for the system to be used in an unsafe manner?
☑	☐	17. Will there be any other potential hazards not listed above? If yes, please explain on reverse.

For any "Y" responses, add (1) a complete description, (2) a list of corrective actions to be taken, and (3) date to be completed on the reverse side.

Description of Hazard	Planned Corrective Action	Planned Date	Actual Date
Sharp edges on part	(1) Sanding of edges (2) use of rubber or soft material to cover edges	On all Carbon based parts and manufactured assemblies	
Physical strain when loading canister and its contents	(1) Latches open very easily under light force (2) Ergonomically placed for hands	Add with final assembly June 2017	
Toxic release agent material used	(1) Use respirators and gloves when applying frekote (2) Use wax or water based release agents	December 2016. On second prototype canister	
System susceptible to pressure, heat, and moisture	(1) Use epoxies which have a glass transition temperature outside of range if left in the sun (2) Avoid exposing core material that is susceptible to moisture to the open air (3) Ensure that the canister can hold an internal pressure of 18PSIA if internal air was heated, expanded, and	11/4/16	Items 1 and 3 confirmed
Small child could get trapped inside	(1) Warning label to keep out of reach of children (2) Warning label to not use as stool unless lid is securely attached to assembly	Add with final assembly June 2017	
Carbon dust is an irritant	(1) Add liner material to carbon to prevent wear and dust from being released	Add with final assembly June 2017	

ID	WBS	ID	Task Name	Duration	Start	Finish	Predecessors
1	**1**	**1**	**Phase 1 - Proposal Phase**	**15 days**	**Wed 10/5/1(**	**Tue 10/25/16**	
2	**1.1**	**2**	**Draft Writing & Research**	**4 days**	**Wed 10/5/1(**	**Mon 10/10/1(**	
3	1.1.1	3	Define Scope of Project	1 day	Wed 10/5/16	Wed 10/5/16	
4	1.1.2	4	Customer Requirements	1 day	Wed 10/5/16	Wed 10/5/16	
5	1.1.3	5	Research Manufacturing Techniques	4 days	Wed 10/5/16	Mon 10/10/16	
6	1.1.4	6	Basic Hand Calculations	1 day	Wed 10/5/16	Wed 10/5/16	
7	1.1.5	7	Quality Function Deployment (QFD)	2 days	Wed 10/5/16	Thu 10/6/16	
8	1.1.6	8	Three Brainstorming Sessions	3 days	Wed 10/5/16	Fri 10/7/16	
9	1.2	9	Final Proposal Editing	2 days	Fri 10/21/16	Mon 10/24/16	2
10	**2**	**10**	**Phase 1b - Manufacture Prototype Canister Body**	**14 days**	**Wed 10/5/1(**	**Mon 10/24/1(**	
11	2.1	11	Gather and Process Raw Materials	7 days	Wed 10/5/16	Thu 10/13/16	
12	2.2	12	Canister Layup	5 days	Fri 10/14/16	Thu 10/20/16	11
13	2.3	13	Canister Curing	1 day	Fri 10/21/16	Fri 10/21/16	12
14	2.4	14	Canister Removal From Mold and Polishing	1 day	Mon 10/24/1	Mon 10/24/16	13
15	2.5	15	Project Proposal Due	0 days	Mon 10/24/1	Mon 10/24/16	14
16	**3**	**16**	**Phase 2 - Preliminary Design Phase**	**18 days**	**Tue 10/25/1(**	**Thu 11/17/16**	
17	**3.1**	**17**	**Draft Writing**	**15 days**	**Tue 10/25/1(**	**Mon 11/14/1(**	
18	3.1.1	18	Revisions From Proposal	3 days	Tue 10/25/16	Thu 10/27/16	
19	**3.1.2**	**19**	**Add New Sections to Proposal**	**15 days**	**Tue 10/25/1(**	**Mon 11/14/1(**	
20	3.1.2.1	20	Pugh & Decision Matricies	10 days	Tue 10/25/16	Mon 11/7/16	
21	3.1.2.2	21	CAD Modeling	3 days	Tue 10/25/16	Thu 10/27/16	
22	3.1.2.3	22	Process Descriptions	2 days	Tue 10/25/16	Wed 10/26/16	
23	**3.1.3**	**23**	**Proof Of Concept Prototyping**	**2 days**	**Tue 10/25/1(**	**Wed 10/26/1(**	
24	3.1.3.1	24	Top Opening Design Prototype	2 days	Tue 10/25/16	Wed 10/26/16	
25	3.1.3.2	25	Side Opening Design Prototype	2 days	Tue 10/25/16	Wed 10/26/16	
26	**3.1.4**	**26**	**Meet with Sponsor**	**1 day**	**Wed 11/2/1(**	**Wed 11/2/16**	
27	3.1.4.1	27	Make edits to report from sponsor	1 day	Wed 11/2/16	Wed 11/2/16	
28	**3.2**	**28**	**Final Revisions**	**4 days**	**Mon 11/14/1**	**Thu 11/17/16**	**19**
29	3.2.1	29	Proofreading and Peer Editing	2 days	Mon 11/14/1	Tue 11/15/16	
30	3.2.2	30	Create Presentation	1 day	Mon 11/14/1	Mon 11/14/16	29
31	3.2.3	31	Present Presentation to Class	1 day	Tue 11/15/16	Tue 11/15/16	30
32	3.2.4	32	Preliminary Design Review Due	1 day	Thu 11/17/16	Thu 11/17/16	30
33	**4**	**33**	**Phase 3 - Critical Design Phase**	**62 days**	**Thu 11/17/1(**	**Fri 2/10/17**	
34	4.1	34	Meet with Sponsor for PDR Feedback	1 day	Thu 11/17/16	Thu 11/17/16	
35	4.2	35	Choose Between Top and Side Opening	2 days	Thu 11/17/16	Fri 11/18/16	
36	**4.3**	**36**	**Detailed Design Phase**	**61 days**	**Thu 11/17/1(**	**Thu 2/9/17**	
37	**4.3.1**	**37**	**Center Ring**	**61 days**	**Thu 11/17/1(**	**Thu 2/9/17**	
38	4.3.1.1	38	Ideate Possibilities	61 days	Thu 11/17/16	Thu 2/9/17	
39	4.3.1.2	39	Wet layup test halfs of canister	61 days	Thu 11/17/16	Thu 2/9/17	
40	**4.3.1.3**	**40**	**Select Design**	**61 days**	**Thu 11/17/1(**	**Thu 2/9/17**	
41	4.3.1.3	41	3D Printed Prototype	61 days	Thu 11/17/16	Thu 2/9/17	
42	4.3.1.3	42	Cost Analysis	61 days	Thu 11/17/16	Thu 2/9/17	
43	4.3.1.3	43	Material considerations	61 days	Thu 11/17/16	Thu 2/9/17	
44	4.3.1.3	44	Theoretical strength of common composite manufacturing techniques	61 days	Thu 11/17/16	Thu 2/9/17	
45	4.3.1.3	45	Determine number of lock points and some not locking	61 days	Thu 11/17/16	Thu 2/9/17	
46	4.3.1.4	46	CAD Design	61 days	Thu 11/17/16	Thu 2/9/17	
47	**4.3.2**	**47**	**Retaining Plate or Net**	**61 days**	**Thu 11/17/1(**	**Thu 2/9/17**	
48	4.3.2.1	48	Ideate Possibilities	61 days	Thu 11/17/16	Thu 2/9/17	
49	4.3.2.2	49	Select Design	61 days	Thu 11/17/16	Thu 2/9/17	
50	4.3.2.3	50	CAD Design	61 days	Thu 11/17/16	Thu 2/9/17	
51	**4.3.3**	**51**	**More Detailed Stress Analysis**	**48 days**	**Tue 12/6/16**	**Thu 2/9/17**	
52	**4.3.3.1**	**52**	**Learn FEA and Hand Calcs for composites**	**48 days**	**Tue 12/6/16**	**Thu 2/9/17**	
53	4.3.3.1	53	Learn FEA laminate Modeling	48 days	Tue 12/6/16	Thu 2/9/17	
54	**4.4**	**54**	**Report Writing**	**1 day**	**Thu 11/17/1(**	**Thu 11/17/16**	**71**
55	4.4.1	55	CDR Report Writing	1 day	Thu 11/17/16	Thu 11/17/16	



Project:
Bear Minimum Gantt Chart
Gantt Revision: Thu 2/9/17

Task	Summary	Inactive Milestone	Duration-only	Start-only	External Milestone
Split	Project Summary	Inactive Summary	Manual Summary Rollup	Finish-only	Deadline
Milestone	Inactive Task	Manual Task	Manual Summary	External Tasks	Progress

Manual Progress

ID	WBS	ID	Task Name	Duration	Start	Finish	Predecessors
56	4.4.2	56	CDR Report Editing	1 day	Thu 11/17/1(	Thu 11/17/16	
57	4.4.3	57	CDR Presentation Writing	1 day	Thu 11/17/1(	Thu 11/17/16	55
58	4.4.4	58	Critical Design Report (CDR) Due	1 day	Thu 11/17/1(	Thu 11/17/16	
59	5	59	Phase 3b - Design Final Iteration & Optimization	30 days	Thu 2/9/17	Wed 3/22/17	
60	**5.1**	**60**	**Final Design Optimization**	**30 days**	**Thu 2/9/17**	**Wed 3/22/17**	
61	5.1.1	61	Max Deflection Analysis	10 days	Thu 2/9/17	Wed 2/22/17	
62	5.1.2	62	Number of Mounting Points	2 days	Thu 2/9/17	Fri 2/10/17	
63	5.1.3	63	Fillet Stress Concentration Analysis	10 days	Thu 2/9/17	Wed 2/22/17	
64	5.1.4	64	Weight verses Strength Optimization	10 days	Thu 2/9/17	Wed 2/22/17	
65	**5.2**	**65**	**Research**	**30 days**	**Thu 2/9/17**	**Wed 3/22/17**	36
66	**5.2.1**	**66**	**Manufacturing Research**	**30 days**	**Thu 2/9/17**	**Wed 3/22/17**	
67	5.2.1.1	67	Manufacturing Considerations of Stiffening Ring	30 days	Thu 2/9/17	Wed 3/22/17	
68	**5.2.2**	**68**	**Materials Research**	**30 days**	**Thu 2/9/17**	**Wed 3/22/17**	
69	5.2.2.1	69	Injection Molding Feasibility (As needed)	14 days	Thu 2/9/17	Tue 2/28/17	
70	5.2.2.2	70	Research Short Fibers and Materials	14 days	Thu 2/9/17	Tue 2/28/17	
71	**5.3**	**71**	**Manufacture Second Round of Prototypes**	**38 days**	**Mon 1/30/1**	**Wed 3/22/17**	
72	5.3.1	72	Lead Time: Order Parts	14 days	Mon 1/30/17	Thu 2/16/17	
73	**5.3.2**	**73**	**Build Concept Prototype**	**7 days**	**Mon 1/2/17**	**Tue 1/10/17**	
74	5.3.2.1	74	Manufacture in 3D print or layup	5 days	Mon 1/2/17	Fri 1/6/17	
75	5.3.2.2	75	3d possible ring design	2 days	Mon 1/2/17	Tue 1/3/17	
76	5.3.2.3	76	Combine 3D printed part and rims	2 days	Mon 1/2/17	Tue 1/3/17	
77	**5.3.3**	**77**	**Build Structural Prototype**	**8 days**	**Mon 1/2/17**	**Wed 1/11/17**	
78	5.3.3.1	78	Build Finalized Rings	5 days			
79	5.3.3.2	79	Finalize carbon base	2 days			
80	5.3.3.3	80	Adhere rings to base	1 day			
81	**5.3.4**	**81**	**Build Confirmation Assembly**	**14 days**	**Mon 1/2/17**	**Thu 1/19/17**	
82	5.3.4.1	82	Build Retaining Ring	1 day			
83	5.3.4.2	83	Build Structural Ring	5 days			
84	5.3.4.3	84	Build Cansiter Body	2 days			
85	5.3.4.4	85	Adhere Assembly parts together	2 days			
86	5.3.4.5	86	Tolerance Inspection	2 days			
87	5.3.4.6	87	Clearcoating and surface processing	2 days			
88	6	88	Project Update Report	0 days	Thu 3/16/17	Thu 3/16/17	
89	7	89	Phase 4 - Testing Phase	34 days	Thu 3/16/17	Tue 5/2/17	65
90	**7.1**	**90**	**Stage 1 Testing**	**0 days**	Thu 2/9/17	**Thu 2/9/17**	
91	7.1.1	91	CMM tolerance Verification	0 days	Thu 2/9/17	Thu 2/9/17	
92	**7.2**	**92**	**Stage 2 Testing**	**34 days**	Thu 3/16/17	**Tue 5/2/17**	
93	7.2.1	93	Body Stress Strain Testing	0 days	Thu 2/9/17	Thu 2/9/17	
94	7.2.2	94	Center Ring Stress Strain Testing	1 day	Thu 3/16/17	Thu 3/16/17	
95	**7.3**	**95**	**Stage 3 Testing**	**34 days**	Thu 3/16/17	**Tue 5/2/17**	
96	**7.3.1**	**96**	**Drop Test**	**34 days**	Thu 3/16/17	**Tue 5/2/17**	
97	7.3.1.1	97	Test Plan				
98	7.3.1.2	98	Test Jig	2 days			
99	7.3.2	99	Tolerance Verification				
100	7.3.3	100	Porosity Verification Testing	7 days			
101	7.3.4	101	Puncture Testing	4 days			
102	7.3.5	102	Live Bear Testing	21 days			
103	8	103	Hardware and Safety Demo	0 days	Tue 5/2/17	Tue 5/2/17	
104	9	104	Phase 5 - Build Final Canister	24 days	Tue 5/2/17	Fri 6/2/17	
105	9.1	105	Manufacturing	14 days			
106	9.2	106	Final Verification	10 days			
107	9.3	107	Project Expo Prep	24 days			
108	9.4	108	Submit for Live Testing	24 days			
109	10	109	Project Expo and Final Report Due	0 days	Fri 6/2/17	Fri 6/2/17	

Project:
Bear Minimum Gantt Chart
Gantt Revision: Thu 2/9/17

Task | Split | Milestone | Summary | Project Summary | Inactive Task | Inactive Milestone | Inactive Summary | Manual Task | Duration-only | Manual Summary Rollup | Manual Summary | Start-only | Finish-only | External Tasks | External Milestone | Deadline | Progress | Manual Progress

Case Study: Composite Manufacturing Processes

Technical Report
November 18, 2016

ME 412
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Table of Contents

1 Background and Report Overview

1.1 Overview

The investigation of composite manufacturing processes was limited to three processes. The selected processes will be for thermoplastic and/or thermoset composites only. This is because the purpose of this technical report is to investigate manufacturing options available at California Polytechnic State University for a senior project. The senior project is to design a carbon fiber ultralight bear canister for ultralight backpack camping. Because the project is only looking into composites with polymeric matrices, due to availability and resources on campus, only thermoset and thermoplastic composite manufacturing processes will be considered. Thermoset and thermoplastic composites refer to the type of matrix in the composite, the load bearing component. The classification system of a composite matrix is seen in Figure 1.

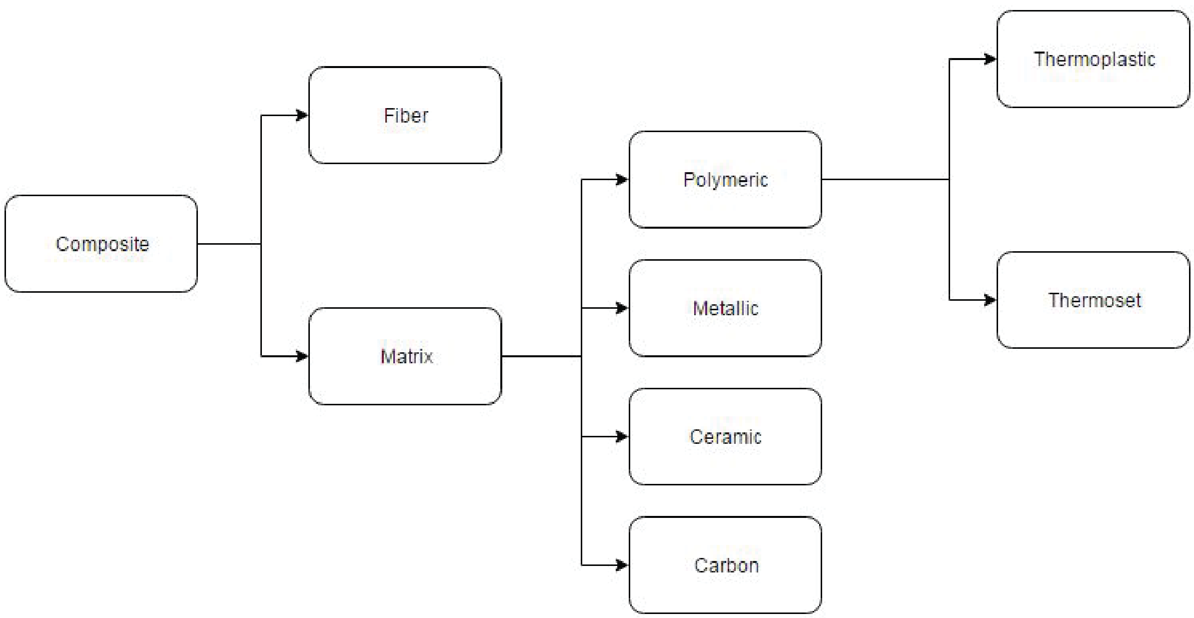


Figure 1. The flowchart shows where thermoplastic matrices appear in a breakdown of a generic composite. Note that only the elements along the path to thermoset and thermoplastic matrices have been broken down into subelements.

A thermoset composite matrix refers to a matrix that cures at a lower temperature than thermoplastics. To give an insight into some of the characteristics of metallic, ceramic, and carbon matrices, they are all considered only for high-temperature applications in an increasing temperature order. This gives perspective to the low temperatures that a thermoset matrix will experience during curing relative to some other composite matrix options. When curing, the thermoset matrix undergoes polymerization and cross-linking with the aid of a hardening agent and heating. Once the curing process is

complete, the result is irreversible, which is not the case for thermoplastics. Thermoplastics can be reheated, giving the composite flexibility similar to before the initial cure. When an already cured thermoset matrix composite is reheated at temperatures near the curing temperature (typically around 250-300°F), the resin does not melt, but it decomposes thermally. The most commonly used thermoset matrix materials are polyesters, epoxies, polyimides, and vinyl esters. [13]

Within thermoset manufacturing processes, there are an abundance of various manufacturing processes. Depending on the application, certain manufacturing processes have advantages over others. The two thermoset manufacturing processes that will be investigated will be vacuum bagging and bladder molding. The thermoplastic manufacturing process that will be investigated will be injection molding. These are three very common manufacturing processes which are all capable of being completed with Cal Poly's resources. The methods will be described in detail, pros and cons will be looked at, and the various processes will compared to the one another.

1.2 Senior Project Brief Background

The senior project for which this case study is based on, is currently in the last phase of the preliminary design stage. The product of interest is a composite bear canister attempting to weigh under one pound. An initial design of the canister has been completed which lays out the functions of the canister and also gives a rough idea of how each part will interface with the rest of the design. Note that the detailed design of the project has not been completed. However, the design is at a far enough stage to conduct a case study on manufacturing techniques for each part of the assembly. The proposed design of the canister assembly can be seen in Figure 2.

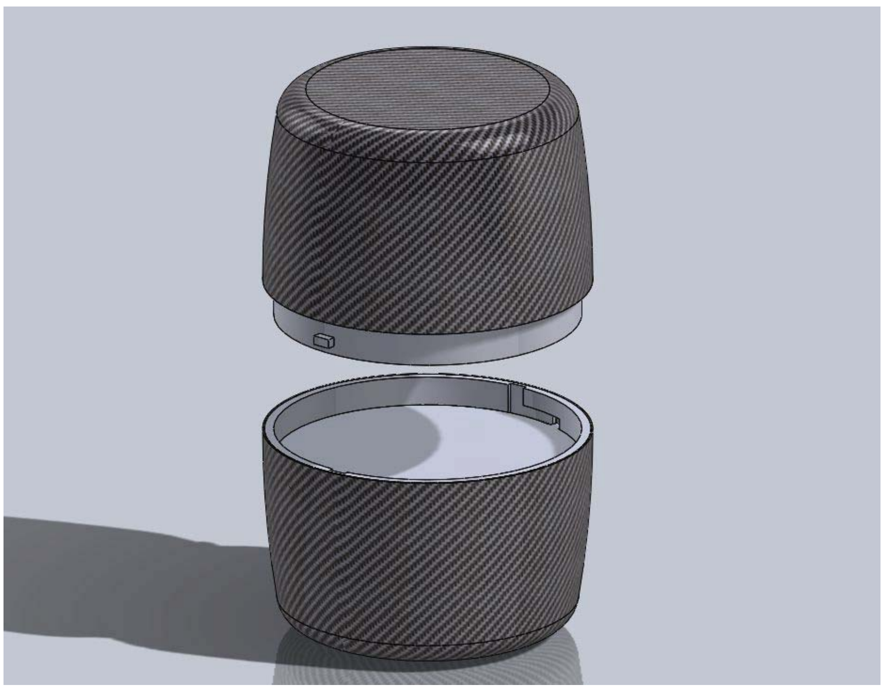


Figure 2. A rendering in SolidWorks was completed for the preliminary design of the ultralight bear canister.

An exploded layout drawing can also be seen in Appendix A. The layout drawing clearly shows all of the parts in the assembly and how they will fit together. There are two functions of the canister for which this report is concerned with. They are (1) how the two halves of the canister will attach to one another and (2) how the two halves of the canister will lock with one another. The preliminary design, as seen in Figure 2, will achieve these two functions. The mechanism responsible for the attachment and locking of the canister is seen in Figure 3, and a description of the operation will be discussed in the next paragraph.

Figure 3. The parts responsible for the attaching and locking mechanism are shown. These parts will pose challenges during the manufacturing stage of the design process.

Two protruding male pressure tabs on the top half of the canister will be compressed in the normal direction and will then enter the L shaped channel. There will be interference between the channel and the pressure tabs. The user will rotate the pressure tabs until they reach the cavities at the end of the channel. Because the cavities are cut to a greater depth than the L shaped channel, the pressure tabs will snap into the cavities providing the locking feature of the canister. To open the canister, the pressure tabs will be pressed in, and the reverse motion will take place.

The brief description of the design and operation of the canister was merely introduced to give a background before delving deeper into the study of possible manufacturing techniques for the parts. It is important to understand how to canister operates

2 Study of the Manufacturing Techniques

2.1 Overview

For this attachment and locking mechanism to operate with minimal difficulty and effort, the manufacturing of the parts has to be precise. For example, if the pressure tabs don't exhibit the contours accurately, the fit in the channels and cavities will not be adequate. This proposes a challenge because capturing sharp contours is more difficult to achieve when using composite materials versus other materials. The vacuum bagging, bladder molding, and injection molding manufacturing processes will be discussed in sections 2.2, 2.3, and 2.4, respectively. The discussion will assess how effective each process is at capturing sharp contours.

2.2 Vacuum Bagging

2.2.1 Overview

Vacuum bagging manufacturing utilizes an evacuated bag to pull a composite part onto the desired mold shape. Because the part is being pulled around the mold, the mold is a positive mold. The cure cycle takes place with the vacuum still in place so the part can become rigid around the mold. Creating an airtight seal is a difficult task; many different components are required during the setup phase to achieve this. A common setup system for a vacuum bagging process is shown in Figure 4.

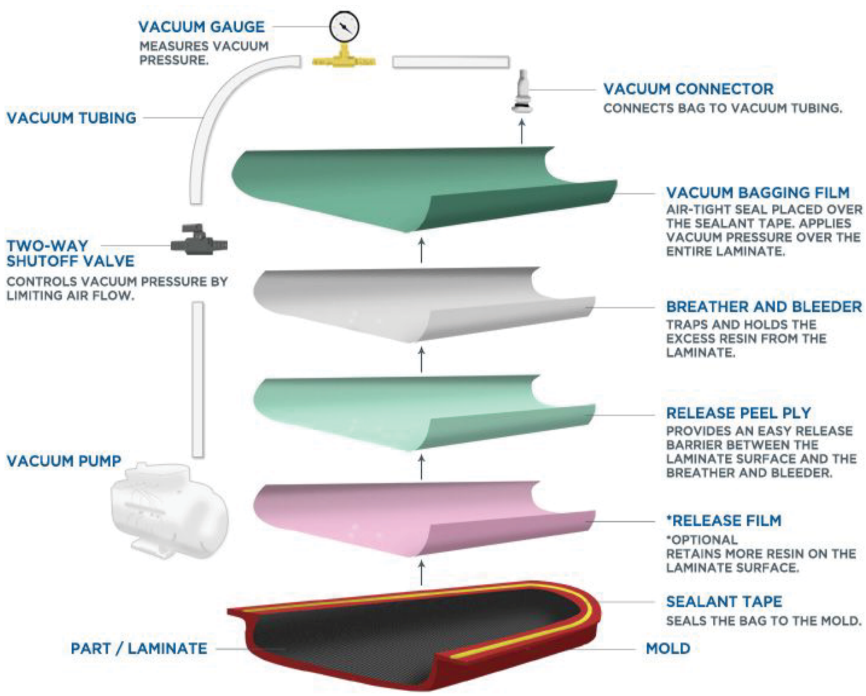


Figure 4. A typical vacuum bagging layer composition shows the required materials and orientation of the layers [2].

2.2.2 Advantages

By evacuating the system, the plies consolidate which significantly reduces voids as the matrix goes through its chemical curing stages. The vacuum also lessens the likelihood of the fiber orientation to shift during curing [1] [2]. Arguably the most important advantage of using a vacuum bagging manufacturing process is the capability of optimizing the fiber-to-resin ratio. The fiber-to-resin ratio is important because it gives the composite part its strength and stiffness characteristics. The fibers do not display rigidity when in the textile state. Also, thermosetting resins, like epoxies, are quite brittle if cured without reinforcement. If the resin makes up the majority of the laminate, the laminate will display properties more representative of the resin. If too little resin exists, places where the fibers are dry will cause weak spots. Vacuum bagging allows for a desired fiber-to-resin ratio by having the fibers saturated with resin and “squeezing out” excess resin. With the use of an autoclave, the pressure can be vamped up to two or three times atmospheric creating an even larger pressure difference. [2] By optimizing the fiber-to-resin ratio, the strength to weight ratio of the laminate improves; without unnecessary resin in the part, the composite will be lighter.

2.2.3 Disadvantages

There is an asterix next to the word optimize when talking about the fiber-to-resin ratio. There are many factors which determine what that ratio will end of being for the composite part. These factors are often hard to control such as the amount of resin used at the beginning. If the fibers are saturated with no excess resin, the fiber-to-resin ratio will be more desirable from a strength-to-weight ratio perspective than if the fibers are saturated and there is extra resin. Another factor deals with the timing of the vacuum pressure being applied. Other disadvantages come into play when looking at the logistical side of the process. When the excess resin is removed, resources are wasted. On large-scale projects, a larger labor team is required to take care of the layup. The layup process has a time limit, especially if the resin cures at temperatures around room temperature. [3]

2.2.3 Effectiveness to Capture Contours

For vacuum bagging, capturing contours effectively does not have a yes or no answer. The ability to do this depends on the location of the contours, the geometry relative to the rest of the part, and the laminate material and ply number and orientation. For example, if sharp contours are protruding out of a convex surface, such as the pressure tabs off the internal ring of the bear canister, the contours are capable of being captured effectively. There will be some fillet effect at the base of the sharp edge. During research, the capability for vacuum bagging to capture complex geometries was not discussed much. Figure 5 shows an example of how capable a vacuum bagging manufacturing process is for capturing contours. It is suffice to say that capturing contours using this process is neither an advantage or a disadvantage.

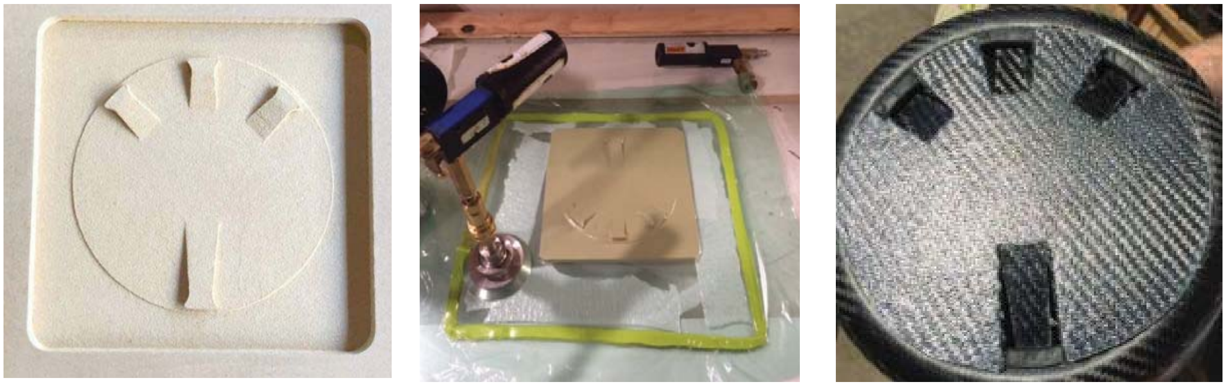


Figure 5. (Left) The sample mold is shown. Capturing the sawtooth contours of the four components on the part will be observed. (Middle) The vacuum bag layup is shown. (Right) The composite part features distinct contours. The results show that protruding contours from a part can be captured effectively using a vacuum bagging technique [6].

2.3 Bladder Molding

2.3.1 Overview

Bladder molding is a viable option when a composite part is manufactured using a negative mold. A negative mold consists of a cavity in which the composite material, pre-cure, is placed into and pressed to fit the cavity as best as possible. A bladder, typically made of silicone, or another elastomer, is then placed inside the cavity and composite. Air pressure is supplied to the bladder inflating it like a balloon. This pressure creates a force which further presses the composite piece into the mold, creating a better part according to the desired shape. The part is then cured in this manner to give the composite its rigidity, strength properties, and stiffness properties. For the senior project, the canister body was manufactured using a bladder molding process. A photo taken after the curing process, but with the bladder still in the mold is shown in Figure 6.

Figure 6. The green bladder was made of silicone. Pressure was applied through a sealing device (photo is after device was taken off) to press the carbon fiber into the mold.

2.3.2 Advantages

Unlike vacuum bagging, bladder molding does not involve removal of resin. This can be both an advantage and a disadvantage. From the viewpoint of being wasteful of money and resources, this is an advantage. To make a part with an appropriate fiber-to-resin ratio (about 60% [2]), the option of using a prepreg composite material is an option. Prepreg composites have the resin pre-impregnated into the fiber textile. When a prepreg composite is used, the fiber-to-resin ratio can be selected when ordering your composite material. Most preprerg composites contain around a 65% fiber-to-resin ratio [4]. Because the part is being pressed into Other advantages include: “Bladder molding is used for parts that either have complex geometry, strict cosmetic requirements, tight outside tolerances or a combination of all three.” [16]

2.3.3 Disadvantages

A disadvantage to bladder molding is the mold manufacturing process is more complex than other typical thermoplastic manufacturing processes, often increasing the time and money invested in the project. For a consistent pressure forcing the part against the mold, a bladder which accurately represents the shape of the part is required. This might suggest the means for a custom professionally made bladder meaning a more expensive manufacturing process.

2.3.4 Comparison to Vacuum Bagging

Because bladder molding is pressing the part into the mold versus pulling the part around the mold, the outside of the part is either up firmly against the mold or the inside is up against the mold, respectively. This means that the surface finish for a bladder molding manufacturing process will most likely be better. Also, due to this fact, manufacturing is the little to no need for post processing your part.

The selection of either using vacuum bagging or bladder molding is not based on the surface finish or amount of post-processing. These are just byproducts of which process is selected. When choosing between the two, vacuum bagging versus bladder molding is dependent on the application. When a hollow part is desired, bladder molding is preferable to fill the cavity of the negative mold. For a part with convex and protruding geometries, vacuum bagging is effective to capture the shape: the main determining factor is the geometry of your part. Another consideration is the type of mold you are using. Depending on what resources are available, one of the two mold types, positive or negative, might not be available.

2.3.5 Effectiveness to Capture Contours

According to Rock West Composites, bladder molding is an effective way to capture composite contours. The reason why is because a lot higher pressures can be achieved during a bladder molding process (at pressures around 100 psi) than vacuum bagging. This allows the composite part to be pressed up firmly against contours in the mold. For the senior project at hand, capturing the contours of the attachment-locking mechanism may be achievable with a bladder molding process. The challenges faced, if this process is selected, would be the molding manufacturing. Most likely the mold manufacturing process would go as such: a negative mold would be made from HDF. A positive plaster mold would be made from the cavity in the HDF. A third step in the mold process would be made from tooling carbon fiber to create another female mold. Once this female mold is created, the bladder molding process would be an option.

2.4 Injection Molding

2.4.1 Overview

Injection molding composite parts is very similar to injection molding plastic parts. The procedures are the same; the only difference is in the fact that composites are used for composite injection molding. Typically, short fiber thermoplastic composites, such as chopped glass fibers with nylon, are used [7]. It is also common to combine the short fiber composites with an injected mold plastic process. This creates a part with a lower strength to weight ratio; however, is a great method for increasing accuracy and decreasing cost. A schematic showing the injection molding process is shown in Figure 7.

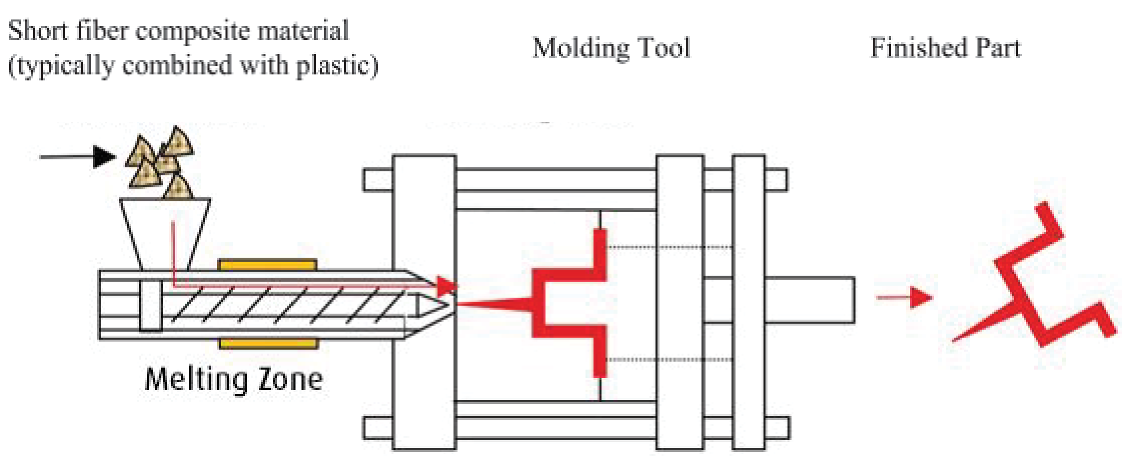


Figure 7. The composite (-plastic combination typically) goes through a similar process as plastic injection molding where the part is heated to allow formation and shaped around a tool.

2.4.2 Advantages

For commercial applications, injection molding composite parts have a competitive price per part. When the scale is not quite at commercial, the cost of the manufacturing the molds has a higher impact, therefore meaning it is more expensive per part. Also, at a commercial scale, parts have the ability to have very high production rates. Another important advantage is the high levels of precision which are possible with injection molding. The use of short fiber composites can be advantageous or disadvantageous depending on the function of the part. This is discussed more in section 2.4.3.

2.4.3 Disadvantages

The one main disadvantage for injection molding short fiber thermoplastic composites is the lower strength and stiffness characteristics when compared to plies of long fibers. Because the short fibers are randomly oriented and short, the anisotropic material will not give as strong of a mechanical response as long fiber composites. This is very important depending on the application. If the direction and magnitude of the load being applied is known, then injection molding with short fiber composites may not be strong enough for the job. With that being said, the randomly oriented short fibers can also work to the part's advantage. If the loading direction is unknown or is in multiple directions, the short fibers can respond in a more consistent manner with respect to the orientation of the loading.

Another very important disadvantage to a short fiber injection mold manufacturing process is the high potential for void formation. In a study discussed in *Void Formation In Short-fiber Thermoplastic Composites,* voids tend to nucleate at fiber ends, and their content depends on processing conditions, fiber concentration, and fiber length [9]. In an injection molding process the presence of voids can be decreased by cooling the material under pressure. Another factor playing an important role in void formation is the cooling rate. After the injection mold process, the melt is cooled, and external surface layers solidify first, which leads to internal voiding [9]. To decrease the effects, slower cooling rates can be implemented in the process.

2.4.4 Comparison to Vacuum Bagging Manufacturing and Bladder Molding Manufacturing

Injection molding can capture contours better than the other two processes. Because thermoplastic short fiber composites are used instead of thermosets, the composite part will be less strong and less stiff in the loading direction. In a randomly loaded case, the thermoset with the short fiber composites will respond better mechanically. Injection molding will create a part that is heavier due to the typical combination of the composite with plastic. All of these are important considerations when selecting a composite manufacturing process for a given application.

2.4.5 Effectiveness to Capture Contours

Out of the three manufacturing processes looked into, injection molding is the most effective for capturing contours. Complex shapes can be captured to a high degree of accuracy. Figure 8 shows an example of a parts where sharp contours are captured effectively by an injection molding process.

Figure 8. Geometries of most shapes and sizes are capable of being produced with an injection molding manufacturing process [8].

3 Conclusion

For the senior project attachment-locking mechanism, an injection molding process would be the best choice. To enable the canister to operate will optimum functionality, the sharp contours will be necessary to capture. Injection molding gives this option. The strength of the parts would be jeopardized; however, because the parts are internal to a strong canister body, the strength is not too much of a concern. Future challenges include: making the parts lightweight with the plastic-short fiber composite combination, minimizing cost for a non -commercial application, and manufacturing the molds for the injection molding process.

4 References

[1] Staff. "Fabrication Methods." The Online Magazine of High Performance Composites and Composites Technology : CompositesWorld. N.p., n.d. Web. 18 Nov. 2016.

[2] "Learning Center - Vacuum Bagging Equipment & Techniques for Room-Temp Applications." Fibre Glast. N.p., n.d. Web. 18 Nov. 2016.

[3] "Vacuum Bagging Process." Vacuum Bagging Process - German Advanced Composites.

N.p., n.d. Web. 18 Nov. 2016.

[4] "Learning Center - About Prepregs." Fibre Glast. N.p., n.d. Web. 18 Nov. 2016.

[5] "Bladder Molding." Bladder Molding - Manufacturing Processes - Custom. N.p., n.d. Web. 18 Nov. 2016.

[6] Rogers, Eli, Naveen Beasly, Cory Wilson, and Donald Wood. Ulta-Light Bear Canister. Tech. N.p.: n.p., n.d. Print.

[7] "Injection Molding : CompositesWorld." Injection Molding : CompositesWorld. N.p., n.d. Web. 18 Nov. 2016.

[8] "Services | Composite Injection Molding | Plastiques Gagnon." Plastiques Gagnon. N.p., n.d. Web. 18 Nov. 2016.

[9] Vaxman, A.; Narkis, M.; Siegmann, A.; Kenig, S. (1989). "Void formation in short-fiber thermoplastic composites". Polym Compos. 10: 449–453. doi:10.1002/pc.750100609.

List of Drawings and Specification Sheets of Ordered Parts

1.0.0 - Exploded Final Assembly

- 1.1.0 - Half Canister Body
- 1.2.0 - Half Canister Body with Holes
- 1.3.0 - Stiffening Ring Assembly
    - 1.3.1 - Stiffening Ring
    - *1.3.2 - Low Strength Steel Nuts 4-40
    - *1.3.3 - Velcro® Brand Tape Strips
    - *1.3.4 - 18-8 Stainless Steel Knob 4-40 ⅜" Long
- 1.4.0 - *Elastic Net

2.0.0 - Exploded Stiffening Ring Mold Assembly

- 2.1.0 - Top Piece of Mold
- 2.2.0 - Centerpiece of Mold
- 2.3.0 - Base Piece of Mold

3.0.0 - Half Canister Mold

*Ordered parts

FORMULA SAE TESTING DATA 2016-2017

Material Testing - 10/04/2016									
Fiber Type: M46J	Unidirectional 12k		Cure Temp:		265 °F		Fiber Volume:		62 %
Resin System: TC250			Cure Pressure :		75 psi		Fiber Areal Weight:	0.00035	lb/in^2
Factor*:	0.48		Cure Pressure :		13 psi		Fiber Density:	0.0647	lb/in^3
Elastic Properties									
Experiment Number	1	2	3	4	5	6	7	**Average**	**SI units**
E1	29.72	29.17	34.52	24.24	30.13	27.63	25.99	**28.771429 msi**	**198372 MPa**
E2	-	3.05	0.8	0.75	0.81	-	-	**0.7866667 msi**	**5423.88 MPa**
G12	0.49	0.47	0.59		0.45	0.45	0.42	**0.4783333 msi**	**3297.99 MPa**
G23	-	-	-	-	-	-	-	**0.2103387 msi**	**1450.23 MPa**
v12	0.21	0.22	0.16	0.25	0.32	0.14	0.28	**0.2257143 -**	**0.22571 -**
v23	-	-	-	-	-	-	-	**0.87 -**	**0.87 -**
Flex Modulus	24.04	21.25						**22.645 msi**	**156132 MPa**
Failure Properties									
e1t	7447	7588	8261.2	8028.8	7659.2	7908	8127	**7859.9714 με**	**7859.97 με**
e2t	-	-	2988.61	2569.1	4328	-	-	**3295.25 με**	**3295.25 με**
e1c	-	-	-	-	-	-	-	**3807.1737 με**	**3807.17 με**
e2c	-	-	-	-	-	-	-	**1596.1367 με**	**1596.14 με**
e12	4796	26253	24378		26508	25679	17795	**24122.66 με**	**24122.7 με**
F1t	221.4	221.4	274.1	192.3	229.4	218.7	210.2	**223.92857 ksi**	**1543.93 MPa**
F2t	-	-	2.62	2.26	3.76	-	-	**2.88 ksi**	**19.8569 MPa**
F1c	-	-	-	-	-	-	-	**108.4654 ksi**	**747.843 MPa**
F2c	-	-	-	-	-	-	-	**1.395 ksi**	**9.61819 MPa**
F12	2.22	7.93	10.26		8.01	7.35	7.1	**8.13 ksi**	**56.0544 MPa**
ILSS	9.04 9.13	9.54 9.45	9.33 10	9.34 10	8.95 10.24	9.31	8.65	**9.415 ksi**	**64.9142 MPa**
Flex Strength	164.8	152.2						**158.53 ksi**	**1093.03 MPa**
Physical Properties									
Thickness (calculated)								**0.008687 in**	**0.22065 mm**
Thickness (@ 75 psi)								**0.007974 in**	**0.20254 mm**
Thickness (@ 13 psi)								**0.0114896 in**	**0.29184 mm**
Density								**0.066 lb_m/in^3**	**####### kg/m^3**
Abaqus								**1.72E-04 lb_f*s^2/in^4**	**1.84E-03 ton/mm^3**

*: Compression Reduction Factor from Datasheet by comparing tensile and compressive strength properties

Notes:
Exp A seems like low failure load for 45 test
Exp D has weird noise at high loads for 45 test
For E2/F2/e2t testing: Cure Temp. 250°F - 90 min hold / Pressure 13 psi
G23 not tested - data from datasheet

Bear Minimum Budget Sheet

Purchased Part Costs	Supplier	Quantity	Total Cost
2x2 Twill Weave Carbon Fiber Prepreg (Cytec 5320-1 Resin System)	ACP Composites	1	688.29*
Pull Out Dowel Pin 18-8 SS 1/4"Dx1/2"L	McMaster-Carr	3	$10.47
3D printer Nylon Roll	Amazon.com	1	$23.85
LOCTITE Frekote NC-700 Gallon	ACP Composites		$118.00
Acetone 1 Gallon	Home Depot	1	$13.97
Plastic Sheeting 10'x100' 6mil	Home Depot	1	$59.98
Viynl Sheeting for Templates	Home Depot	1	$9.98*
High Temp Vacuum Bag Connector Lock Ring	ACP Composites	1	39.95*
West Systems 105/109 Expoxy/Resin	The Craft, SLO	1	$60.00
* = Donation		**Total**	**$286.27**
		Total with Tax	$309.17

Manufacturing Costs	Supplier	Quanity	Total Cost
Yellow Vacuum Bag Sealant Tape Roll	Fibre Glast	1	$7.95
Breather Fleece - 5 Yard	Fibre Glast	1	$24.95
Polyester Peel Ply Yrd	Fibre Glast	1	$12.51
Vacuum Bag Film Strechlon 800 5yrd	Fibre Glast	1	$29.95
Squeegee	Fibre Glast	2	$1.80*
Painter's Masking Tap	Home Depot	2	$5.94
Latex Gloves 50 count	Home Depot	1	$4.47
Scissors	Home Depot	2	$11.96*
Tape Measure	Home Depot	2	$10.48*
Exacto Knife	Home Depot	2	$3.96*
Sand Paper 60 grid 9"x11"	Home Depot	1	$3.97*
20oz Carbon Fiber Tooling Fabric Mold	Fibre Glast	1	$60.45*
Hand Heat Gun	McMaster Carr	1	$31.69*
* = Donation		**Total:**	**$85.77**
		Total with Tax	**$92.63**

Testing Costs	Supplier	Quanity	Total Cost
Construction Wood 2"x4"x96"	Home Depot	1	$2.69
Drywall Screws#6 1-1/4" 1lb pack	Home Depot	1	$6.47
PVC Pipe1.25"x10'	Home Depot	1	$5.22
Gorilla Glue 2 Part Epoxy	Home Depot	1	$4.65
Aluminum Instron Mounting Plates	McMaster Carr	2	$0.00 *
* = Donation		**Total**	**$19.03**
		Total with Tax	$20.55

Anticipated Parts	Supplier	Quanity	Total Cost
Minature 6" Hook Pin	McMaster-Carr	6	$24.36
Netting 1 sq yrd.	OnlineFabricStore.net	1	$5.70
Aluminum 6061 1.5" x 12" x 12"	McMaster-Carr	1	$114.58
Aluminum 6061 3/4" x 12" x 12"	McMaster-Carr	2	$159.88
* = Donation		**Total**	**$304.52**
		Total with Tax	$328.88

Entire Project Cost	**$695.59**
Entire Project Cost + 8% Tax	**$751.24**

Capital Investments	Cost
Walk in Composite Oven	$8,000
Drill Press	$375
Vacuum Pump System	$750
Composites Freezer	$800
Total	**$9,925**

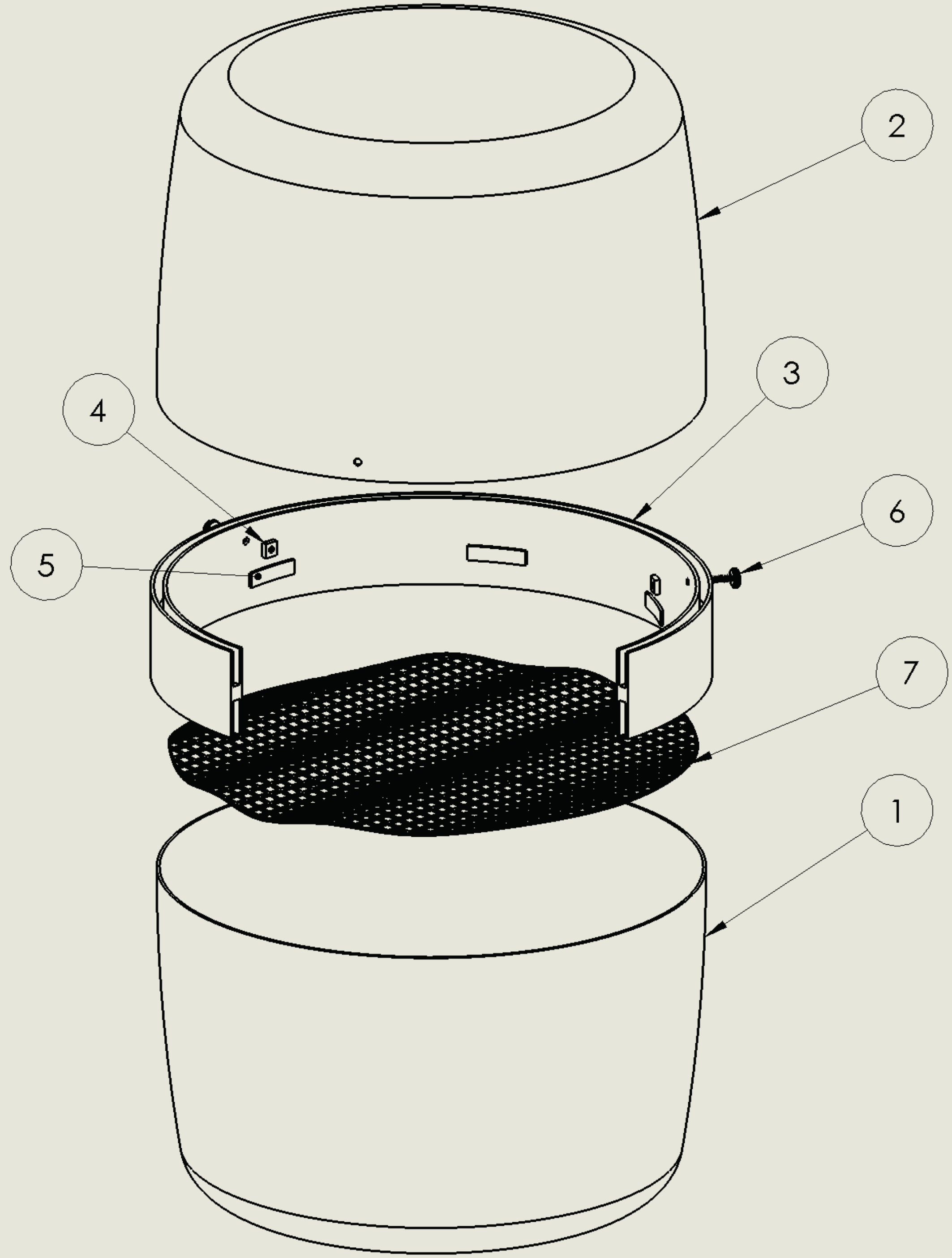
Labor Cost	Cost
Composite Technician 2x 8hr @ 36k/yr	$280

100 Canisters Cost	First Year	Second Year +
Parts + Materials	$751.24	$751.24
Composite Material	$4,500	$4,500
Capital investments	$9,925	$0
Labor Cost	$28,000	$28,000
Total	$43,176.24	$33,251.24
Cost Per Canister	$431.76	**$332.51**
Retail Cost Per Canister (50% Markup)	$647.64	**$498.77**

Group 28 - Bear Minimum - Design Validation Plan and Report

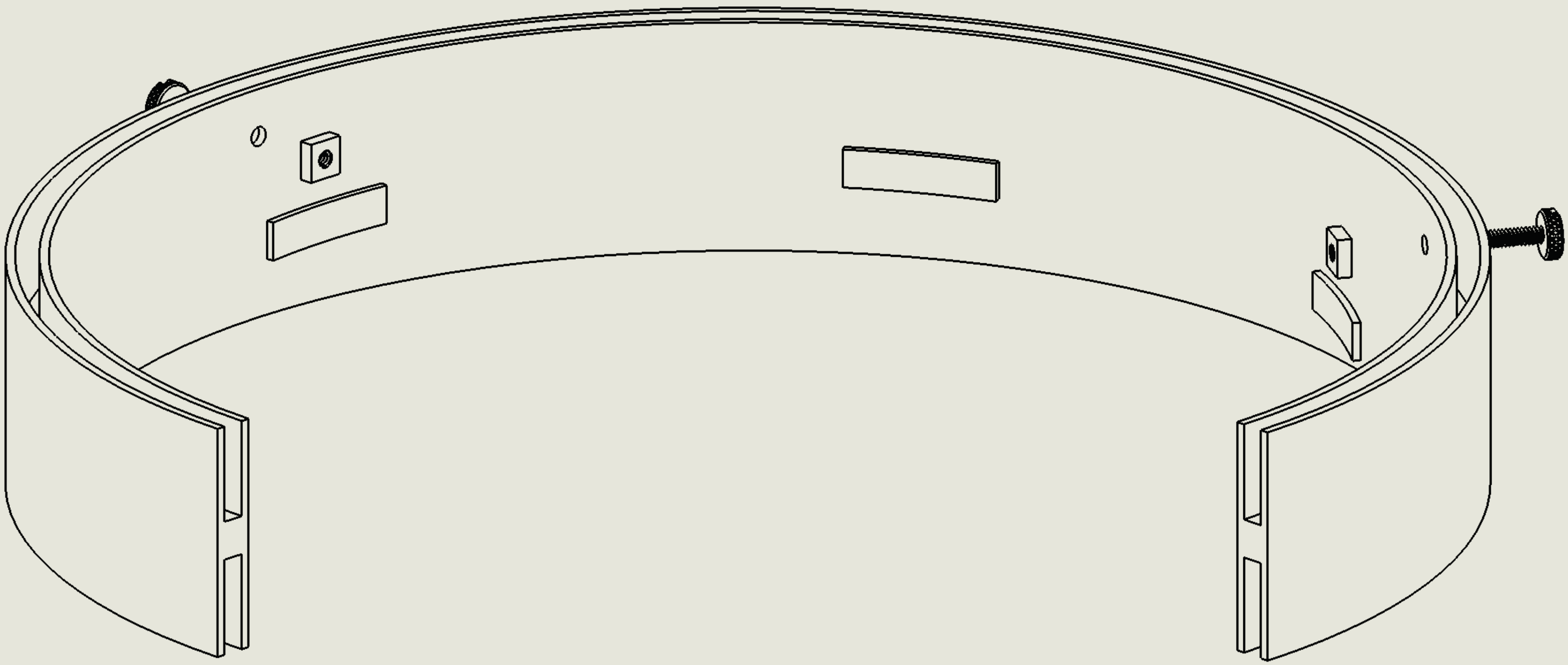
TEST PLAN / TEST REPORT

Item No	Specification or Clause Reference [1]	Test Description [2]	Materials/Equipment	Location	Acceptance Criteria [3]	Notes	Test Responsibility [4]	Test Stage [5]	Samples Tested: Quantity	Samples Tested: Type [7]	Timing: Start date	Timing: Finish date	Test Results: Test Result [6]	Test Results: Quantity Pass	Test Results: Quantity Fail	Notes (Assigned engineer)
1	**DSN:** Force-deflection test for a carbon-fiber half canister	Compression testing to record the elastic response of the canister. Testing until plastic deformation would be preferrable to get the limits of the elastic regime	Inston Model 1331, test fixture	Composites Lab	Results will be used to get a stress-strain curve	If ample canister halves are produced, compression tests could go until failure		2 - Structural	1	Carbon Fiber	2/3/2017	2/3/17	Failure Load: 439 lb Failure Deflection: 1.71 in	0	1	The part was tested until failure.
2	**DSN:** Ring and canister half adhesion must be strong enough to stay bonded when experiencing a load representative of a bear attack	Adhesive pullout strength tests: the two materials being tested will be fully adhered using the adhesion product of choice. An external hook or pulling device will be attached to one of the materials and pulled until bond breaks	Inston Model 1331, clamps, force gauge, material, measuring tape, latching to sample ring (tiedown ring)	Composites Lab	Results will be compared to loads representative of a bear and also other adhesives for the same two materials	All considered materials for the rings will be tested with the twill weave carbon fiber. This will be a main consideration when selecting the material for the rings		2- Structural				W17 - W7				
3	**DSN:** Force-deflection test for the male and female rings	Compression testing to record the elastic response of the canister. Testing until plastic deformation would be preferrable to get the limits of the elastic regime	Inston Model 1331, test fixture	Composites Lab	Results will be used to get a stress-strain curve	If ample test rings are produced, compression tests could go until failure		2 - Structural				W17 - W7				
4	**MFG:** Holes in half canister body are not in line with holes in stiffening ring	Post anlysis by inspection: using calipers to measure and verify the tolerance between the notches and channel openings is within acceptable design tolerance	Calipers for measurement verification	n/a	Must be within acceptable tolerances (which will be determined later)	Design tolerances must be determined accurately before testing		3 - Confirmation				S17 - W3				
5	**MFG**: Interference between canister body and groove does not allow attachment	Post anlysis by inspection: using calipers to measure and verify the tolerance between the notches and the channels is within acceptable design tolerance	Calipers for measurement verification. Sandpaper	n/a	Must be within acceptable tolerances (which will be determined later)	Design tolerances must be determined accurately before testing		3 - Confirmation				S17 - W3				
6	**MFG:** Carbon does not conform to mold shape	Post anlysis by inspection to verify canister has conformed to mold shape.	Calipers for measurement verification	n/a	Visual inspection shows no noticable dips, unconformities, or flaws with accordance to the mold	Visual inspection will be completed by multiple engineers to verify results		3 - Confirmation				S17 - W3				
7	**ENV:** Bear strikes canister							3 - Confirmation				S17 - W5				
8	**ENV:** Bear jumps on canister	Drop test of 100 lb from 1 ft high on top and bottom and various sides	High speed camera, weights, measuring tape, distance backdrop or reference sheet for high speed, safety equipment, rope or string to drop weight with.	On campus labs	No cracks, delamination, or bursting, max deflections must be less than 0.25"	be determined before testing with heavy weights. A high speed camera might be desired to analyze mechanical response of canister		3 - Confirmation				S17 - W5				
9	**ENV:** Bear rolls canister off cliff							3 - Confirmation				S17 - W5				
10	**MFG:** Large porosity	Acid digestion test to check composite void content/ Porosity	Acid, scale for sample weight, lid, eye protection, oven or paper towels to dry sample, calipers to measure diminsions (ensure relatively equal sample densities). Composite samples of various number of layers	Composites Lab	Void content less than 4%	Materials for burn test must be aquired. Safety procedures must be determined before testing with hazardous materials		3 - Confirmation				S17 - W5				
11	**USR**: Drop or Puncture accidently	Drop weighted canister in random orientations onto various rocky and rough surfaces	Metal Hole punch device. Camera, material samples, measuring tape, backpack for transportation	On a local trail or rocky surface	No cracks, delamination, or bursting, max deflections must be less than 0.25"	Proper wieght of in canister must be determined with a liberal factor of safety		3 - Confirmation				S17 - W5				
12	**ENV:** Live bear test	The final confirmation prototype will be filled with food and tested with a live bear for one hour of exposure	Black/Brown/Grizzly Bear	San Diego Zoo or Yellowstone	Canister must not fail during testing time period	Final test		3 - Confirmation				S17 - W5				



ITEM NO.	PART NUMBER	PART NAME	QTY.
1	1.1.0	Half Canister Body	1
2	1.2.0	Half Canister Body With Holes	1
3	1.3.1	Stiffening Ring	1
4	1.3.2	Low Strength Steel Nuts	3
5	1.3.3	Velcro Brand Tape Strips	6
6	1.3.4	18-8 Stainless Steel Knob 4-40 3/8" Long	3
7	1.4.0	Elastic Net	1

Cal Poly Mechanical Engineering ME 428/429/430 - 2016/17	Part #: 0.0.0	Title: Canister Assembly	Drwn. By: Adam Eisenbarth
		Date: 02-06-2017 Scale: 1:5	Chkd. By: Rama Adajian

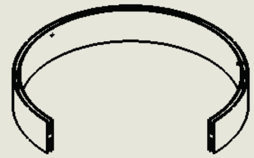


Cal Poly Mechanical Engineering ME 428/429/430 - 2016/17	Part #: 1.3.0	Title: Stiffening Ring Assembly	Drwn. By: Adam Eisenbarth
		Date: 02-06-2017 | Scale: 1:1	Chkd. By: Rama Adajian

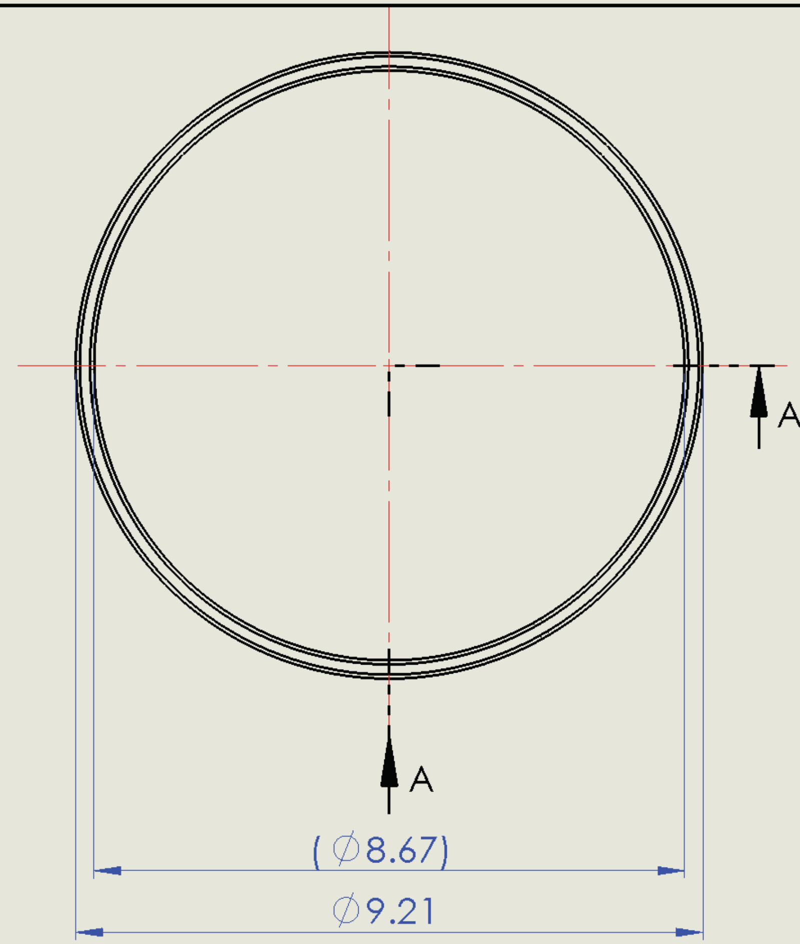
NOTES

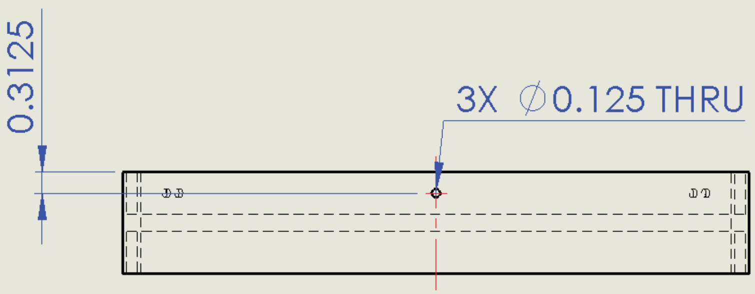
UNLESS OTHERWISE SPECIFIED:

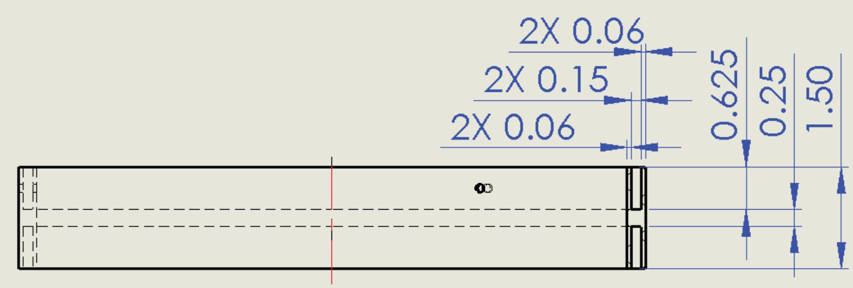
1. ALL DIMS. IN INCHES
2. TOLERANCES:
   - X.XX = ±.03
   - X.XXX = ±.03
   - X.XXXX = ±.03
   - ANGLES = ±2°
4. MATERIAL: 3K 2X2 TWILL WEAVE CARBON FIBER FABRIC, 5.9 OZ
5. FOUR LAYERS OF CARBON WILL BE LAID UP TO COMPRISE THE 0.06" WALL THICKNESSES FOR THE GROOVE. 10 LAYERS OF CARBON WILL BE LAYERED TO COMPRISE THE 0.15" GROOVE THICKNESS (EACH CARBON LAYER IS .015" IN THICKNESS).
6. STACKING SEQUENCE: $[0]_{4T}$ FOR WALLS, $[0]_{10T}$ FOR GROOVE BASE
7. SEE MANUFACTURING PROCEDURE FOR LAYUP INSTRUCTIONS
8. VACUUM BAG LAY UP
9. CURE WITH HONEYWELL HC 900 OVEN. RAMP UP OVEN TO 250° F AT A RATE OF 4°F PER MINUTE. HOLD TEMPERATURE AT 250°F FOR 180 MIN. RAMP DOWN TEMPERATURE AT RATE OF 4°F PER MINUTE UNTIL 130°F.
9. SAND SHARP EDGES AND DRILL .25 IN HOLES AFTER CURING CYCLE
10. HOLES ARE EVENLY SPACED AT 120°



SCALE 1:8

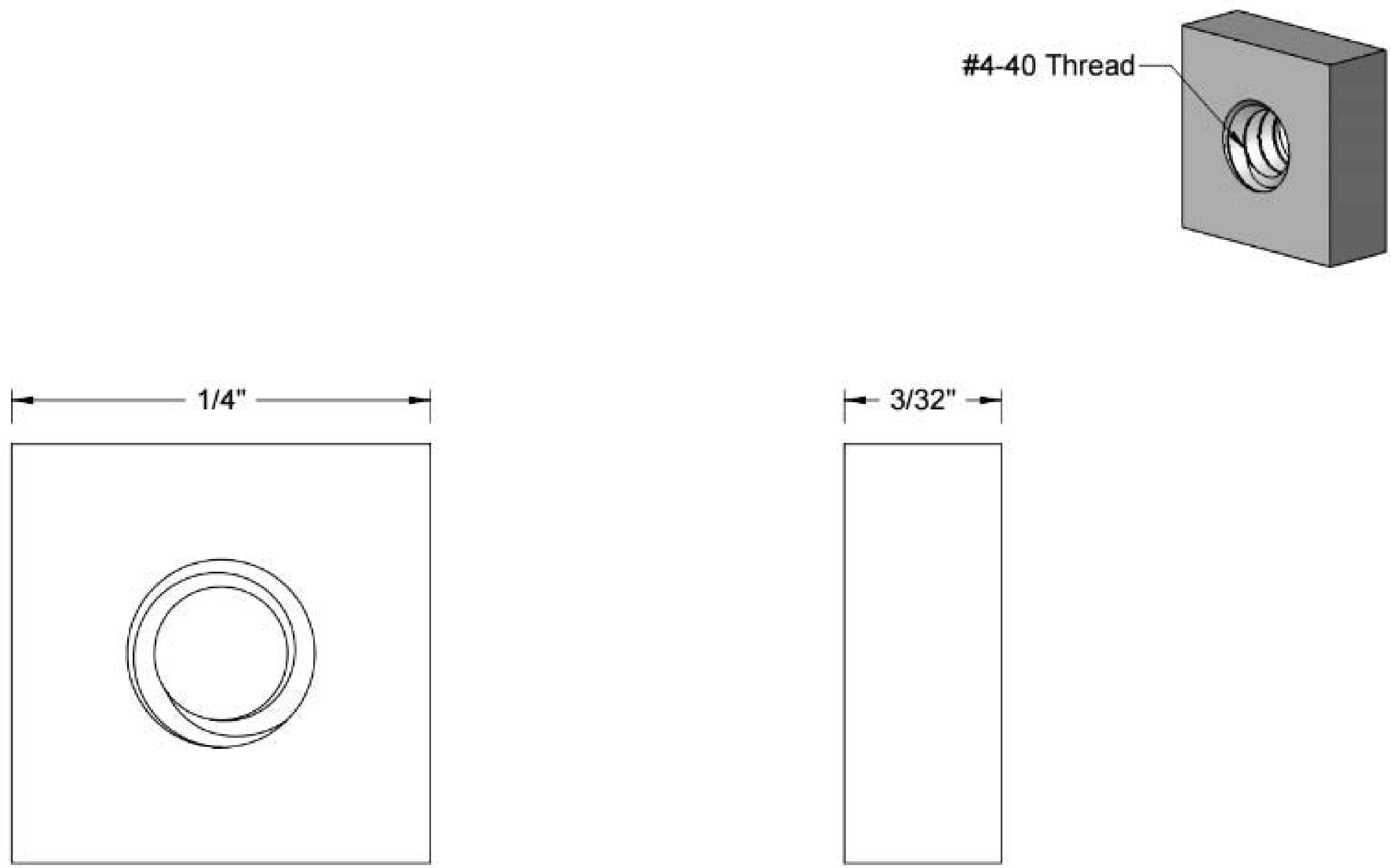




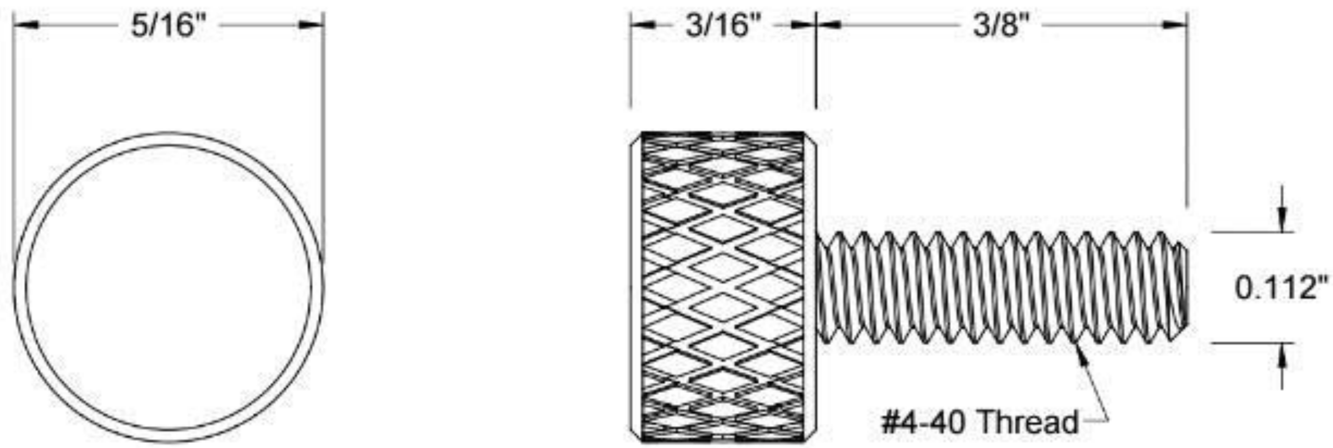


SECTION A-A
SCALE 1 : 3

Cal Poly Mechanical Engineering ME 428/429/430 - 2016/17	Part #: 1.2.1	Stiffening Ring	Drwn. By: Adam Eisenbarth
		02-05-2017 / Scale: 1:3	Chkd. By: Rama Adajian

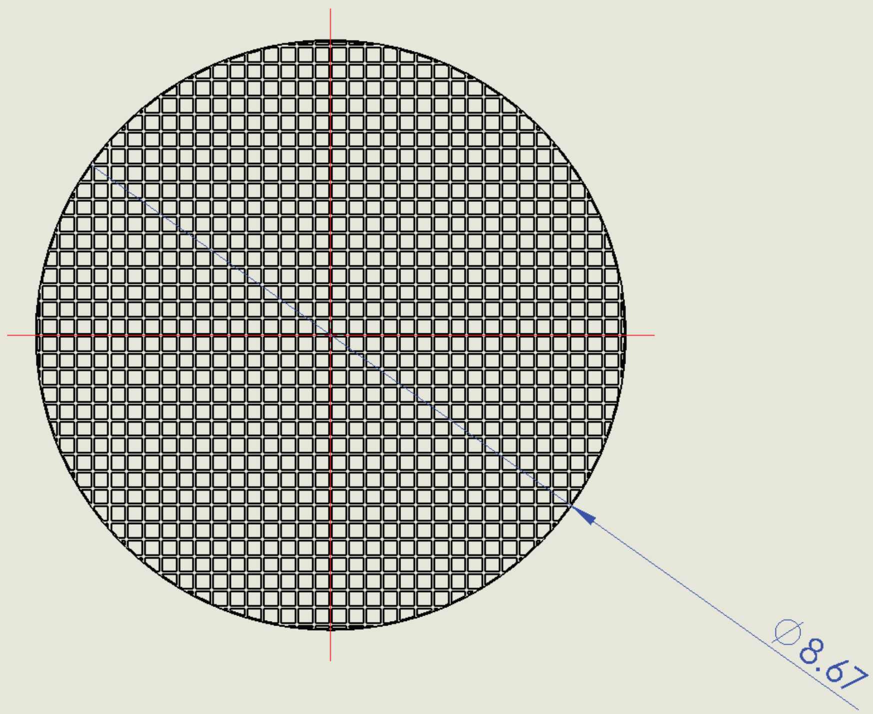


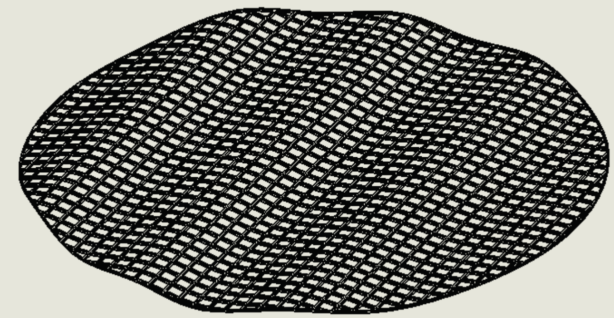
McMASTER-CARR® CAD	PART NUMBER	94855A281
http://www.mcmaster.com © 2016 McMaster-Carr Supply Company Information in this drawing is provided for reference only.	Square Nut	



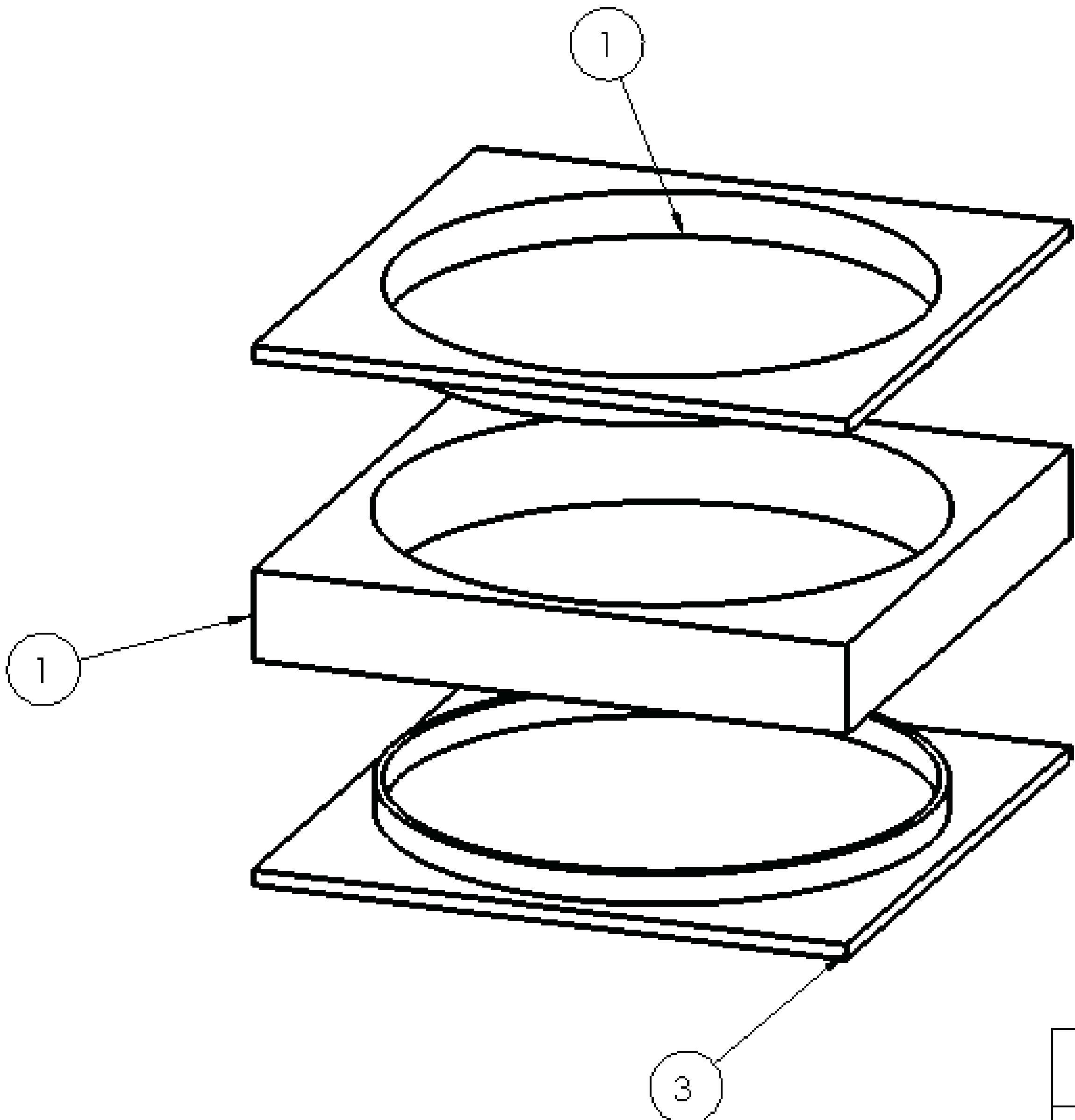
McMASTER-CARR® CAD	PART NUMBER 91746A114
http://www.mcmaster.com © 2014 McMaster-Carr Supply Company Information in this drawing is provided for reference only.	Knurled Head Thumb Screw

NOTES
UNLESS OTHERWISE SPECIFIED:
1. ALL DIMENSION ARE IN INCHES
2. A NYLON SQUARE ELASTIC NET WILL BE PROVIDED AND THEN CUT TO ∅8.67
3. MELT ALL FRAYED EDGES



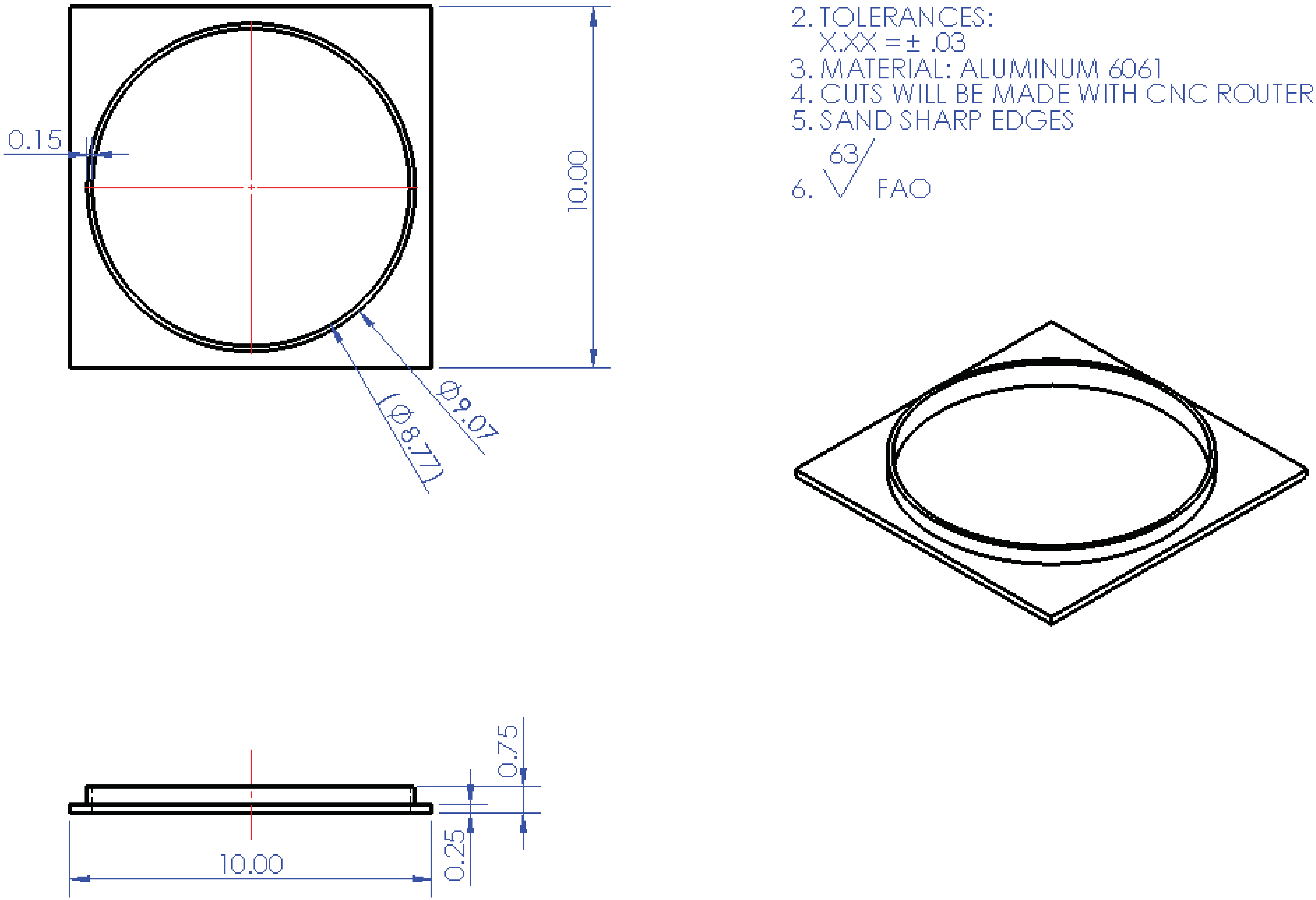


Cal Poly Mechanical Engineering ME 428/429/430 - 2016/17	Part #: 1.3.0	Title: Elastic Net	Drwn. By: Adam Eisenbarth
		Date: 02-06-2017 / Scale: 1:3	Chkd. By: Rama Adajian



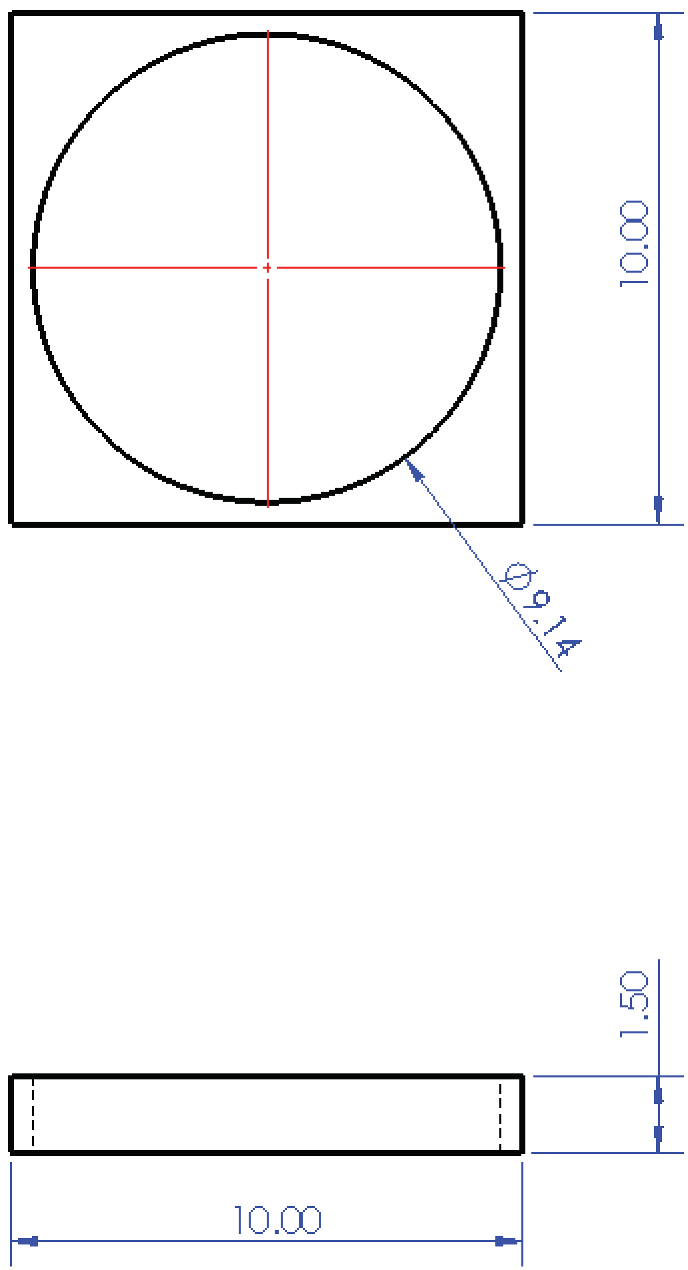
ITEM NO.	PART#	Part Name	QTY.
1	2.1.0	Top Piece of Mold	1
3	2.2.0	Centerpiece of Mold	1
1	2.3.0	Base Piece of Mold	1

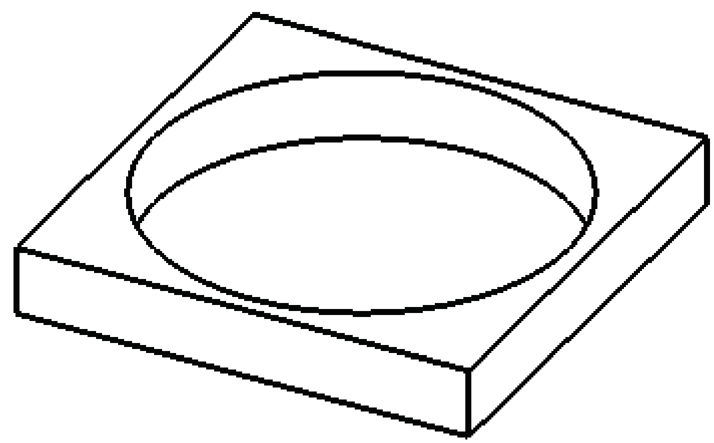
Cal Poly Mechanical Engineering ME 428/429/430 - 2016/17	Part #: 2.0.0	Title: Stiffening Ring Mold Assembly Date: 02/10/2017 Scale: 1:3	Drwn. By: Adam Eisenbarth Chkd. By: Rama Adajian



NOTES
UNLESS OTHERWISE SPECIFIED:
1. ALL DIMS. IN INCHES
2. TOLERANCES:
X.XX = ± .03
3. MATERIAL: ALUMINUM 6061
4. CUTS WILL BE MADE WITH CNC ROUTER
5. SAND SHARP EDGES
6. 63 √ FAO

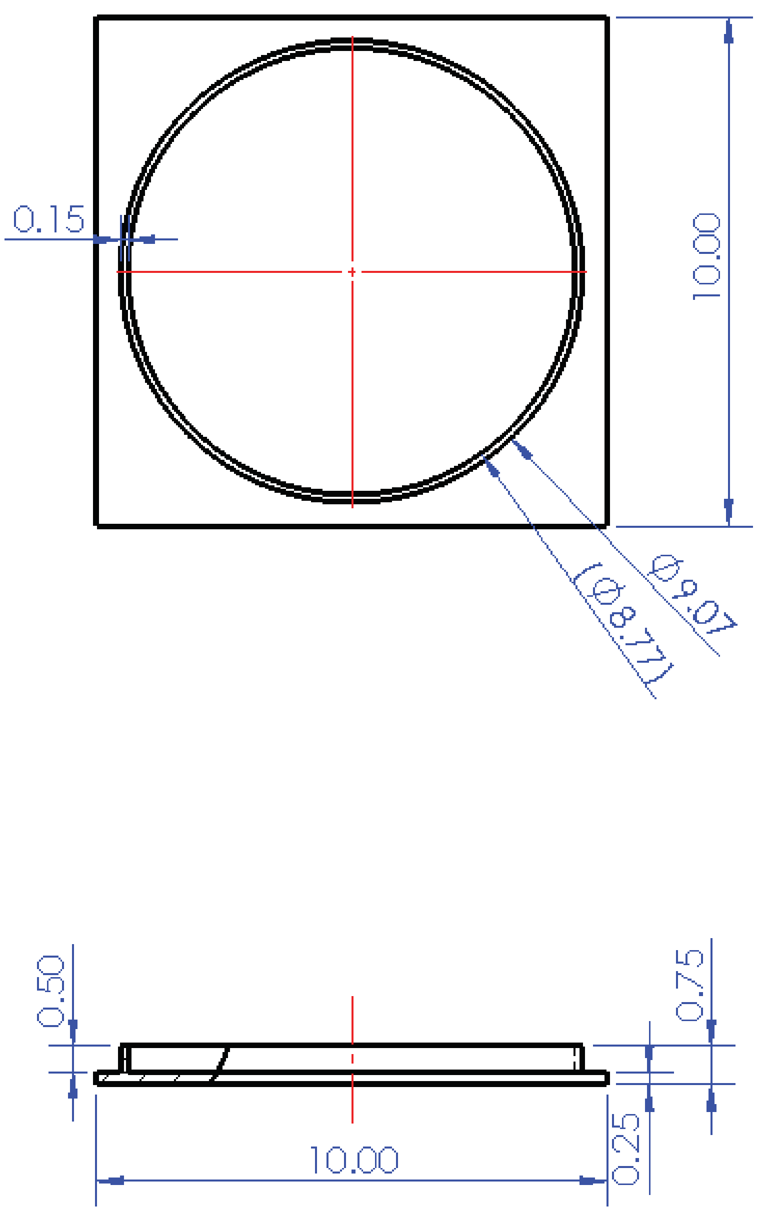
Cal Poly Mechanical Engineering ME 428/429/430 - 2016/17	Part #: 2.1.0	Title: Top Piece of Mold	Drwn. By: Adam Eisenbarth
		Date: 02/09/2017 · Scale: 1:4	Chkd. By: Rama Adajian

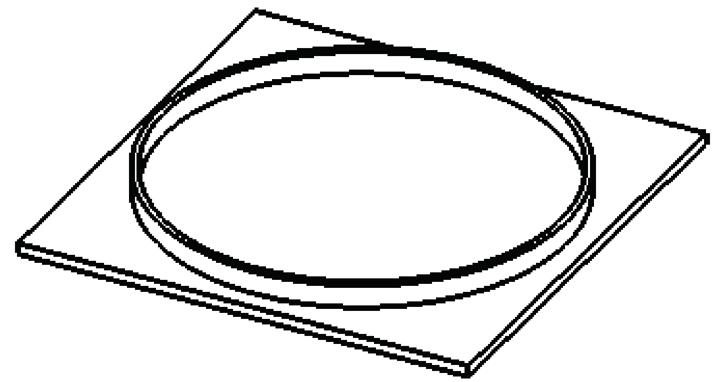




NOTES
UNLESS OTHERWISE SPECIFIED:
1. ALL DIMS. IN INCHES
2. TOLERANCES:
X.XX = ± .03
3. MATERIAL: ALUMINUM 6061
4. CUTS WILL BE MADE WITH CNC ROUTER
5. SAND SHARP EDGES
6. 63√ FAO

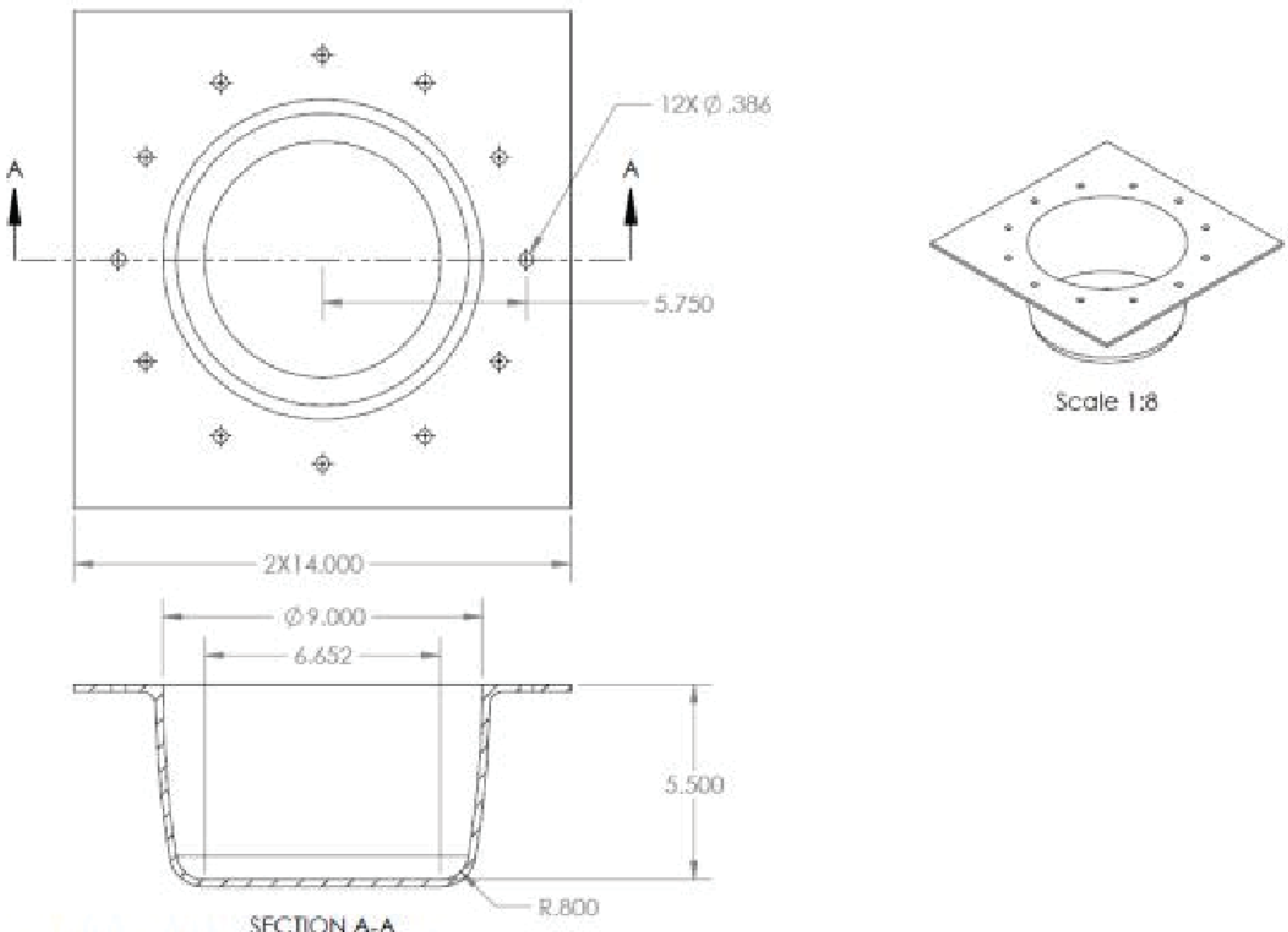
Cal Poly Mechanical Engineering ME 428/429/430 - 2016/17	Part #: 2.2.0	Title: Centerpiece for Mold Date: 02/09/2017 Scale: 1:4	Drwn. By: Adam Eisenbarth Chkd. By: Rama Adajian





NOTES
UNLESS OTHERWISE SPECIFIED:
1. ALL DIMS. IN INCHES
2. TOLERANCES:
X.XX = ± .03
3. MATERIAL: Aluminum 6061
4. Cuts will be made with cnc router
5. SAND SHARP EDGES
6. 63 √ FAO

Cal Poly Mechanical Engineering ME 428/429/430 - 2016/17	Part #: 2.3.0	Title: Base Piece of Mold Date: 02/09/2017 Scale: 1:4	Drwn. By: Adam Eisenbarth Chkd. By: Rama Adajian



Cal Poly Mechanical Engineering Lab Section:03	Tolerance: ±.030	Title: Carbon Fiber Bottom Mold		Drwn. By: Eli Rogers
ME 429 - Qtr Year	Dwg. #0-12-2		Date: 2/16/2015	Scale: 1:4	Chkd. By: Don Wood

TECHNICAL DATA SHEET
No. CFA-015

TORAYCA®

M46J DATA SHEET

MJ type high modulus fiber with enhanced tensile and compressive strength over *M* series fibers. Mainly used for premium sporting goods, aerospace, and industrial applications.

FIBER PROPERTIES

		English	Metric	Test Method
Tensile Strength		611 ksi	4,210 MPa	TY-030B-01
Tensile Modulus		63.3 Msi	436 GPa	TY-030B-01
Strain		1.0 %	1.0 %	TY-030B-01
Density		0.066 lbs/in^3	1.84 g/cm^3	TY-030B-02
Filament Diameter		2.0E-04 in.	5 µm	
Yield	6K	6,679 ft/lbs	223 g/1000m	TY-030B-03
	12K	3,347 ft/lbs	445 g/1000m	TY-030B-03
Sizing Type & Amount	50A, 50B	1.0 %		TY-030B-05
Twist	Twisted, Untwisted			

FUNCTIONAL PROPERTIES

CTE	-0.9 $\alpha \cdot 10^{-6}/^{\circ}C$
Specific Heat	0.17 Cal/g·°C
Thermal Conductivity	0.202 Cal/cm·s·°C
Electric Resistivity	0.9 x 10^{-3} Ω·cm
Chemical Composition: Carbon	>99 %
Na + K	<50 ppm

COMPOSITE PROPERTIES*

	English	Metric	Test Method
Tensile Strength	320 ksi	2,210 MPa	ASTM D-3039
Tensile Modulus	38.5 Msi	265 GPa	ASTM D-3039
Tensile Strain	0.8 %	0.8 %	ASTM D-3039
Compressive Strength	155 ksi	1,080 MPa	ASTM D-695
Flexural Strength	210 ksi	1,420 MPa	ASTM D-790
Flexural Modulus	32.0 Msi	220 GPa	ASTM D-790
ILSS	11.5 ksi	8 kgf/mm^2	ASTM D-2344
90° Tensile Strength	7.0 ksi	47 MPa	ASTM D-3039

* Toray 250°F Epoxy Resin. Normalized to 60% fiber volume.

M46J

C O M P O S I T E   P R O P E R T I E S * *

Tensile Strength	315 ksi	2,160 MPa	ASTM D-3039
Tensile Modulus	35.5 Msi	245 GPa	ASTM D-3039
Tensile Strain	0.8 %	0.8 %	ASTM D-3039
Compressive Strength	145 ksi	980 MPa	ASTM D-695
Compressive Modulus	33.0 Msi	225 GPa	ASTM D-695
In-Plane Shear Strength	8.5 ksi	59 MPa	ASTM D-3518
ILSS	12.0 ksi	8.5 kgf/mm^2	ASTM D-2344
90° Tensile Strength	6.5 ksi	45 MPa	ASTM D-3039

** Toray Semi-Toughened 350°F Epoxy Resin. Normalized to 60% fiber volume.

See Section 4 for Safety & Handling information. The above properties do not constitute any warranty or guarantee of values. These values are for material selection purposes only. For applications requiring guaranteed values, contact our sales and technical team to establish a material specification document.

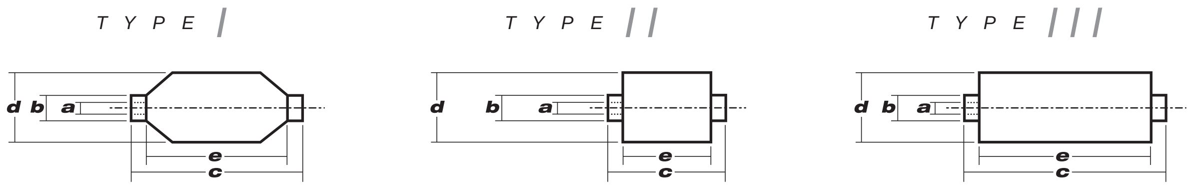
P A C K A G I N G

The table below summarizes the tow sizes, twists, sizing types, and packaging available for standard material. Other bobbin sizes may be available on a limited basis.

Tow Sizes	Twist[1]	Sizing	Bobbin Net Weight (kg)	Bobbin Type[2]	Bobbin Size (mm) a	b	c	d	e	Spools per Case	Case Net Weight (kg)
6K	A	50A	1.0	II	76	82	192	126	156	16	16
	B	50B	1.0	II	76	82	192	126	156	16	16
12K	B	50B	2.0	II	76	82	192	157	156	12	24

1 **Twist** A: Twisted yarn B: Untwisted yarn made from a twisted yarn through an untwisting process C: Never twisted yarn

2 **Bobbin Type** See Diagram below



T O R A Y   C A R B O N   F I B E R S   A M E R I C A ,   I N C .
6 Hutton Centre Drive, Suite #1270, Santa Ana, CA 92707 TEL: (714) 431-2320 FAX: (714) 424-0750
Sales@Toraycfa.com Technical@Toraycfa.com www.torayusa.com

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.

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.

McMASTER-CARR®

Low-Strength Steel Square Nut

Zinc-Plated, 4-40 Thread Size

In stock
$2.81 per pack of 100
94855A281

Material	Zinc-Plated Steel
Thread Size	4-40
Thread Type	UNC
Thread Spacing	Coarse
Thread Fit	Class 2B
Thread Direction	Right Hand
Width	1/4"
Height	3/32"
Drive Style	External Square
Nut Type	Square
System of Measurement	Inch
RoHS	Compliant

Large flat sides make these nuts easy to grip with a wrench and keep them from rotating in channels and square holes. About half the strength of medium-strength steel square nuts, use them in light duty fastening applications, such as securing access panels.

Zinc-plated steel square nuts resist corrosion in wet environments.

18-8 Stainless Steel Knurled Head Thumb Screw

5/16" Diameter Low Head, 4-40 Thread, 3/8" Long

In stock
$1.96 Each
91746A114

Thread Size	4-40
Length	3/8"
Head Style	Knurled
Head Profile	Low
Head	
Diameter	5/16"
Height	3/16"
Material	18-8 Stainless Steel
Drive Style	Unslotted
RoHS	Compliant

Roll the finely knurled, slip-resistant screw head between your fingers for controlled adjustment. Screws are fully threaded. Length is measured from under the head.

Inch sizes have a Class 2A thread fit.

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/yd² (min.)	87 g/m²	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

ACP Composites
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 | Livermore, CA 94551
1-800-811-2009 | P. 925-443-5900 | F. 925-443-5901

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

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/mm^2	 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/cm^3	1.11	D792
Yield $in^2/lb/mil$ $m^2/kg/25\mu m$	 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.

Finite Element Analysis of an Ultra-Light Composite Bear Canister

FEA Project Report

Rama Adajian

radajian@calpoly.edu

December 9, 2016

ME/BMED 404 – 71

Tuesday & Thursday 8-11am Lab

Fall 2016

Mechanical Engineering Department

California Polytechnic State University

San Luis Obispo, California

1. Abstract

The Bear Minimum is a senior project that is attempting to design the lightest bear canister on the market by utilizing composite materials. The ultimate goal is to create a carbon fiber and composite bear canister for lightweight backpackers. Our project is a continuation of a senior project from 2015 which designed the body for the canister, but did not design a lid or locking mechanism. The canister must sport an internal volume of 600in^3 and withstand the force of a 100lbm mass dropped from 1ft on the side or top of it simulating the force of a grizzly bear rolling or pouncing on the canister as seen in figure 1.

Top Load Case Side Load Case

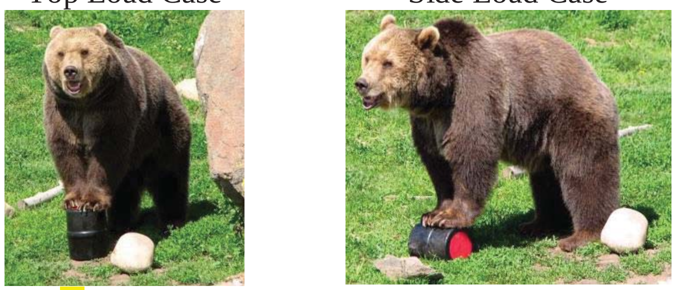


Figure 1. Live bear showing top and side loading cases

Last year the a senior project team made the canister body but no lid. During the drop test the canister broke on the end where there was no lid, but stayed intact on the bottom where the hoop stress was allowed to propagate to the other side of the canister and be distributed. To pass the loading case tests there must be no visible cracks and the deflection must be under 0.25in for both cases. The team last year passed the vertical loading test, but the side deflection failed at a deflection of almost 0.5 inches.

The lightweight backpacking community is eagerly awaiting a lighter and stronger canister on the market. It is not uncommon for backpackers to go to great lengths to save weight, even if that means using their trekking poles as tent poles. While money is usually a concern for consumer products, the lightweight backpacking community will spend large amounts of money for lightweight products and canisters. This allows us to use expensive, but superior, materials such as carbon fiber.

2. Introduction & Background

Our task is to create a lid that integrates easily into the existing canister body and acts like a structural element. The canister locking assembly (body and lid) must pass the drop test and deflection requirements. The drop test represents a grizzly or black bear pouncing or rolling the canister as seen in the previous section loading cases. This is important as the canister must withstand the bear to not allow the food to be exposed. If the bear penetrates the canister the

backpackers food is lost, and more critically, the bear will learn that humans carry food around and actively seek backpackers for food. This is a contact situation bears and backpackers would both negatively benefit from.

Additionally, we also want to ensure the canister can withstand an internal pressure of 26psi if the internal hot air was to expand. We do not want the canister to fail and explode on the user under any circumstance. While manufacturing the canister, the composite was exposed to an internal pressure of 30 psi and did not yield. This is excellent news for the design as it passes the pressure requirements, but we would like to prove that the theoretical case also withstands the pressure. In summary, our main two questions in this investigation are as follows:

1. Will the canister withstand the equivalent force of a 100lbf weight being dropped on the male and female latching rings without deflecting more than 0.25 inches?
2. Will the canister not yield or excessively deflect (<0.25 inches which allows ring to keep adhered to canister wall) and not harm the user if the canister is pressurized up to 26 psia?

3. Model Development

The model is based off our selected design from our Bear Minimum senior project. The geometry was created in SolidWorks to allow for easy dimension manipulation. Once the team had created our desired geometry then it was exported to an. IGES file and then imported into Abaqus. The part was designed with simplicity and ease of manufacturing in mind. All of the part features are common shapes such as circles and squares. This allows for easy manufacturing as stock parts and simple tooling geometry can be used. Due to this simplistic design approach I did not have to modify the part geometry before importing into Abaqus.

One common technique utilized in FEA is to run analyses on a quarter or half model based on planes of symmetry. Unfortunately, although it appears are model is symmetric on one plane, it is not. Our selected locking design utilizes a twist-to-lock mechanism which requires two sliding channels. These channels extend in the clockwise direction, seen in figure 2 , which means there is no plane of symmetry. However, if four channel locks are used (spaced 90 degrees apart) then analysis could be done on a quarter model.

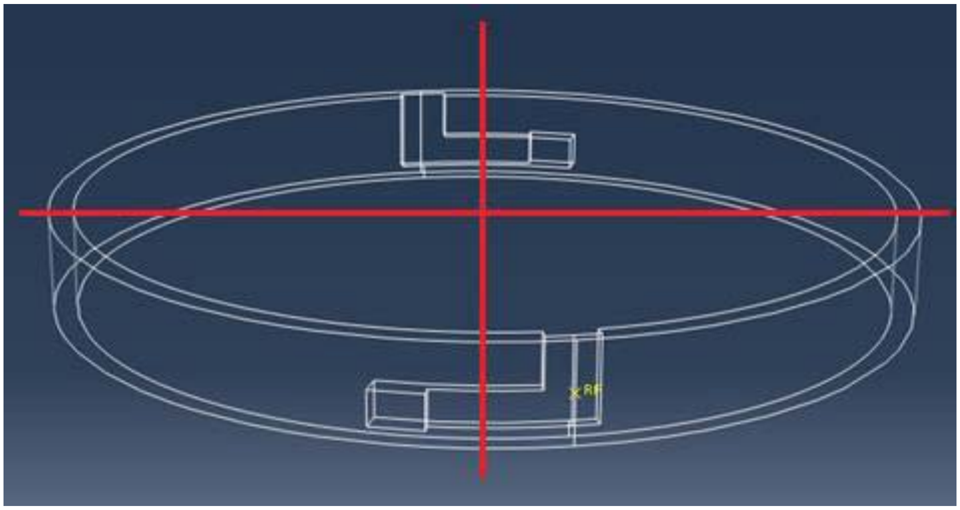


Figure 2. Wire mesh reveals there are no valid planes of symmetry.

Materials

The knowns about the system are the material used, properties, and dimensions. We know that the material is a prepreg carbon fiber epoxy matrix. More specifically the epoxy and carbon composite is Cytec 5320-1t650 which information on can be found at: https://www.cytec.com/sites/default/files/datasheets/CYCOM%205320-1%20Rev%20CR5.pdf). It weighs 1.31 grams per cubic centimeter density has a poisons ratio of 0.3 and the laminate layers (4 layers) combined to a modulus of 1015241 Psi, which was derived from the previous year's senior project report.

The ring material was modeled as short fiber isotropic composite which was compression molded. This was one ideal material the senior project team believes the rings can be manufactured from at Cal poly. The ring materials for each of the parts are as follows:

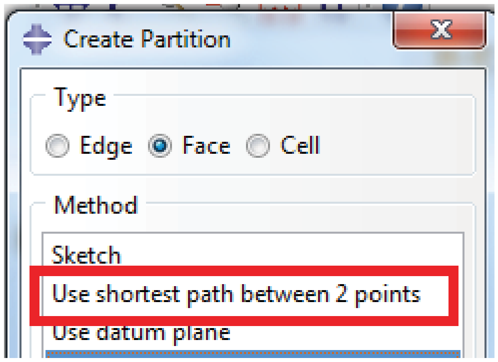
Materials:

- Short fiber Material for Rings:
  - E = 34.1 Msi = 34.1E6 Psi
  - Poisson's Ratio v = 0.33

- Laminate Material for Body:
  - E1 = 1,015,241 psi for both E1 and E2 v = 0.30
  - E2 = 1,015,241 psi
  - Poisson's Ratio v = 0.30

Geometry Preparation

To prepare the ring portions for loads and boundary conditions the rings had to have partition made for the pressure and fixing boundary conditions to be applied. The partitions were made using the *create partition* command window and the *Used shortest path between two points* option on the face of the ring. The partition is used as the surface for the boundary conditions in the section below to be applied on.



Boundary Conditions

Using the curved edge partition normal to 2 points, pinned boundary conditions were applied to one side of the rings for both the male and female rings as seen in figure 3 This pinned condition allowed the canister to not move in the three directions, but allowed free rotation. This simulates the canister being pinned to the ground from a bear pouncing on it. The canister would be pressed and fixed to the ground, but allowed to rotate, thus, U1 = U2 = U3 = 0. Earlier attempts to use encastre boundary condition resulted in model failure as Abaqus was unable to find a solution.

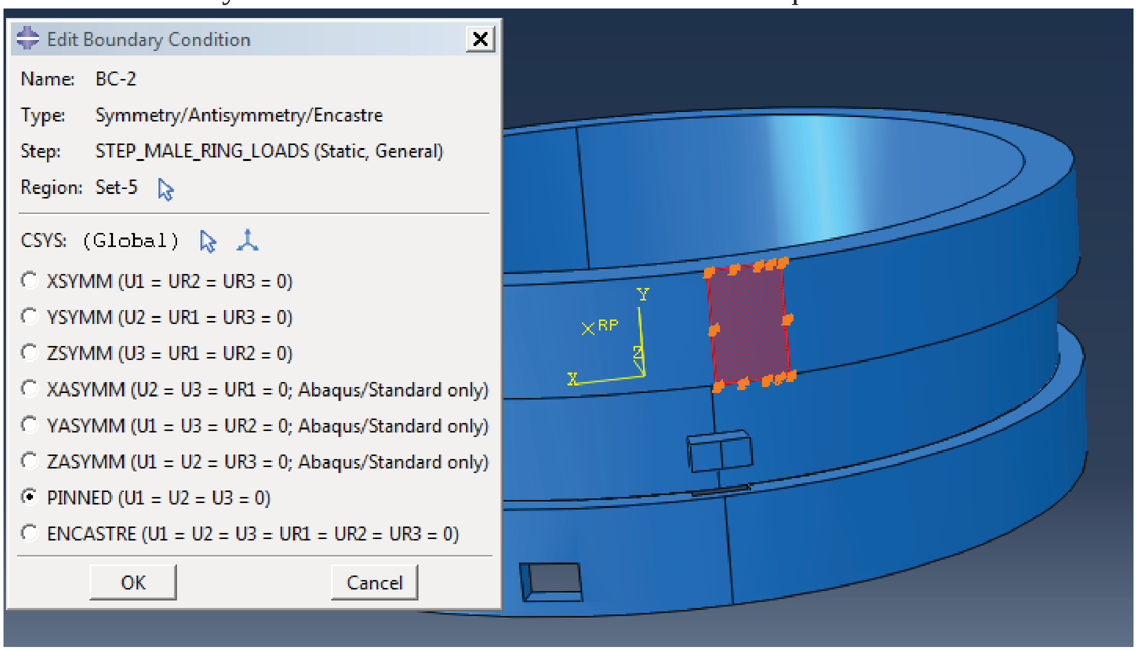


Figure 3. Boundary condition of pinned surface for both male and female rings

The rings are uniquely pinned to the ground for their loading cases, however, for the entire canister under pressure, the fixed portion would be the base of the canister seen in figure 4 below. Instead of selecting the entire base surface, only a few points were selected which restricts the model less and allows expansion of that face in the vertical direction if needed. This meant that only U1 = 0, and U3 = 0 for this boundary condition.

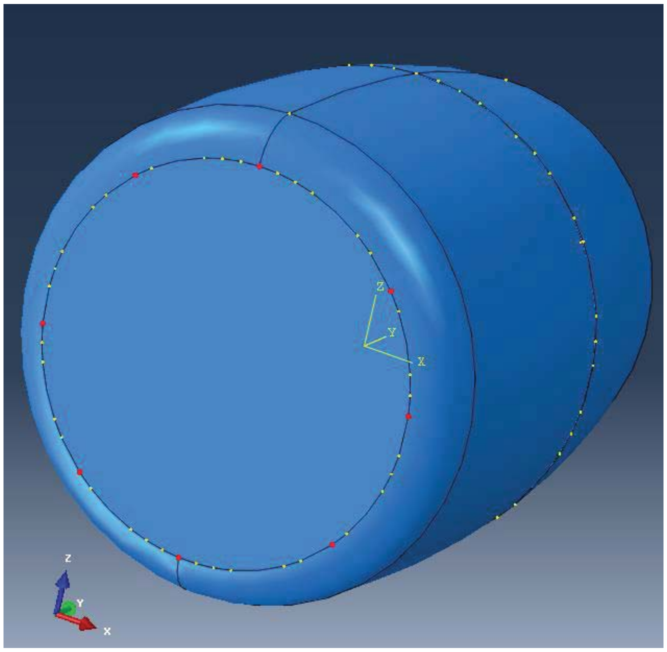
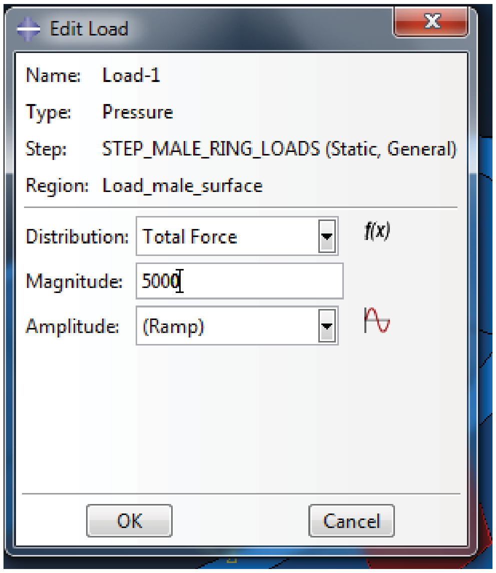


Figure 4. Boundary condition of pinned surface entire pressurized canister

Loads:



Loading for the models were created based on numbers form our senior project. For the rings, a load of 5000lbf was calculated. This was based off an impact of a 100lbf weight dropped from 1 foot high and impacting for a maximum distance of 0.25 inches. This force was applied to the created partition exactly half way across the canister from where the boundary condition was applied. The force was applied as a pressure, where the total pressure applied to the area summed to 5000lbf.

Loading for the entire canister was also a pressurized load, but this time represented as a hydrostatic pressure of 26 psi. This represents heating of the canister expanding the air inside causing the internal pressure to increase. The load was applied to the outer surface of the canister, but with the direction normal and outwards to the surface.

4. Mesh Development

The meshing for the canister rings was created with quadratic tetrahedral mesh, this corresponded to a C3D10 element type mesh. I believe this is a suitable element type for the 3D object because the tetrahedral element is flexible with the geometry, and quadratic shape functions improve the accuracy between nodes relative to linear shape functions. After choosing the element type, I

started out the elements at 0.250 inches to allow the elements to fit inside some of the tighter geometry such as the ring tabs. This small mesh size allowed the two ring models to have 0 distorted elements. For the canister body, I started out the mesh size at 0.5 inches. The element size was lowered with each model run to show convergence of the model when the number of nodes (1/3 of the model degrees of freedom) was high.

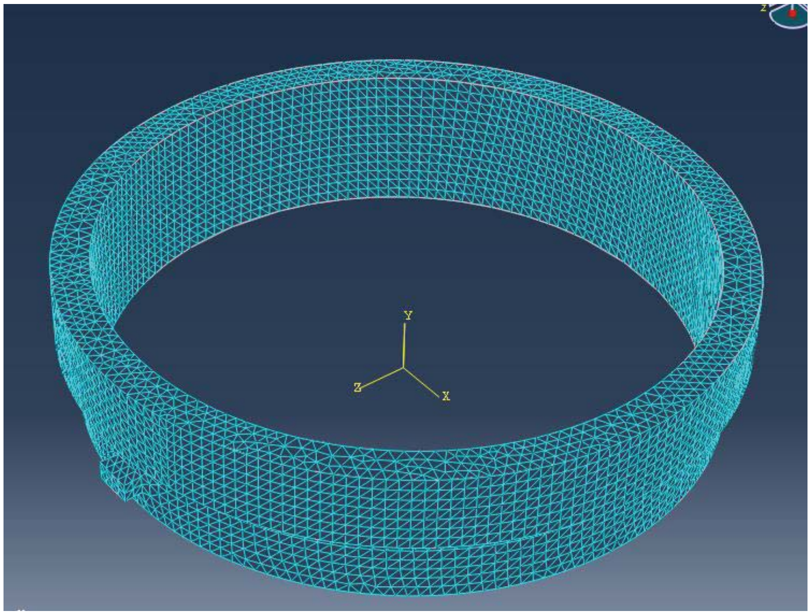


Figure 5. Wire mesh if male and female ring assembly

During the female and male ring models there were no distorted elements for all mesh sizes. However, for the entire canister there were 365 distorted elements on the largest mesh size. This is due to geometry and element type. As the mesh size was refined, the number of distorted elements went down to 33. This is because the smaller element size allows it to fit inside tighter geometry and corners while not being distorted. From the Abaqus message file definition of distorted tetrahedral element is as follows.

> "FOR DISTORDED ELEMENTS FULL CANISTER:
> DISTORTED ISOPARAMETRIC ELEMENTS: ANGLE BETWEEN ISOPARAMETRIC LINES IS LESS THAN 45 DEGREES OR GREATER THAN 135 DEGREES. TETRAHEDRAL QUALITY MEASURE: VOLUME OF TETRAHEDRON DIVIDED BY THE VOLUME OF EQUILATERAL TETRAHEDRON WITH SAME CIRCUMSPHERE RADIUS; 0 FOR DEGENERATE TETRAHEDRON AND 1 FOR EQUILATERIAL TETRAHEDRON. IT IS RECOMMENDED THAT THE TETRAHEDRAL QUALITY MEASURE BE GREATER THAN 0.02, THE MIN INTERIOR (DIHEDRAL) ANGLE BE GREATER THAN 10 DEGREES, AND THE MAX INTERIOR (DIHEDRAL) ANGLE BE LESS THAN 160 DEGREES."

From this definition, the distorted elements were contorted past the allowed angles and were considered inaccurate although the model does still run. Thus, these elements did not meet the max/min angle and aspect ratio criterias. The validity of the results is in question with distorted elements, but 365 elements is very tiny relative to the number of overall elements used (>50,000).

5. Analysis

The main analysis performed was a static analysis. Due to the complex geometry of the two rings mating together and needing to be adhered to the canister walls, this meant that the dynamic model would have been too time intensive. The loads on the static model were calculated to reflect the maximum force and deflection from a dynamic impact, although we needed an estimate for the impact pulse time to calculate the load.

There were a few main errors and warnings observed in this analysis. The first of which was that due to the geometry being imported in through the. IGS file, some edges were not 100% accurately mapped in solidworks. This lead to possibly a few of the distorted elements as discussed above.

The second main error was due inactive meshes. During initial trials of both the male and female rings since there are no mapped mesh on one or the other part. Abaqus gave a warning stating seen in figure 6 that the other part had no mesh and would not be used on the analysis along with reference points I created.

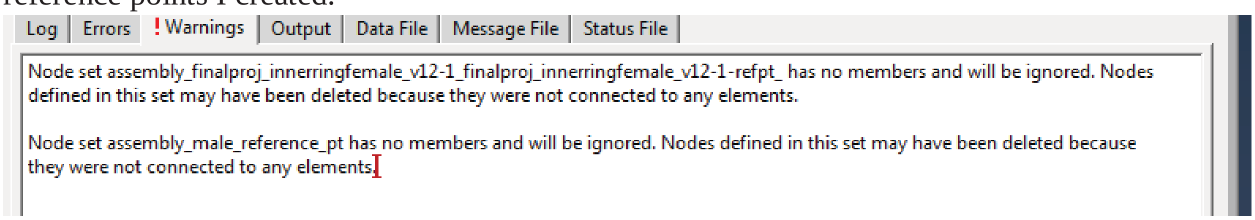


Figure 6. No mesh error

The third main error arose when modeling the overall canister with internal pressure. Since the model was imported in as a 3D element, laminate-type material layers could not be used with the 3D-stress type elements. It is only compatible with shell elements, however, the 3D shell element family does not support tetrahedral elements. The following error below in figure **7** was observed.

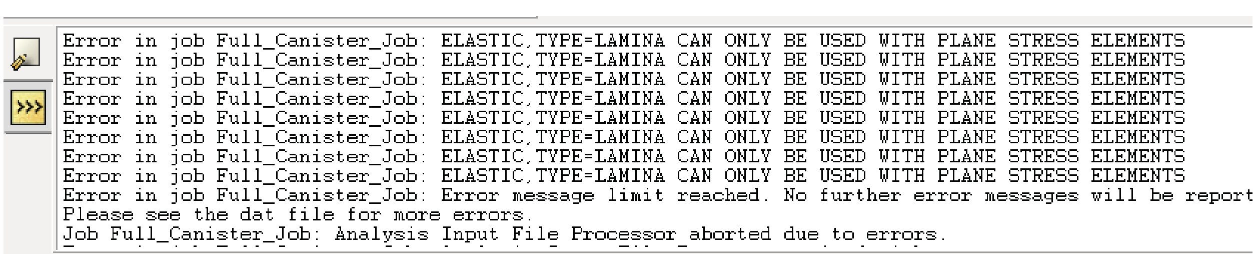


Figure 7. Laminate not modeling properly error

Eventually I had to change the material and section type from laminate to isotropic material. This is valid for the model because I was only concerned with the deflections in the U1 and U3 directions which is what the two inputted modulus's represented.

6. Mesh Convergence

It is important to in finite element analysis to show convergence of results as it proves that refining the mesh or element type will not significantly improve the accuracy of the results. Figures 8 9 and 10 below show the convergence plots for the left and right rings. This was checked by plotting the degrees of freedom, a good indicator of the number of nodes of the refined mesh, versus the von mises stress. In both the figures you can see the von mises stress graph asymptotes as the degrees of freedom increases. This signifies convergence for the two ring models.

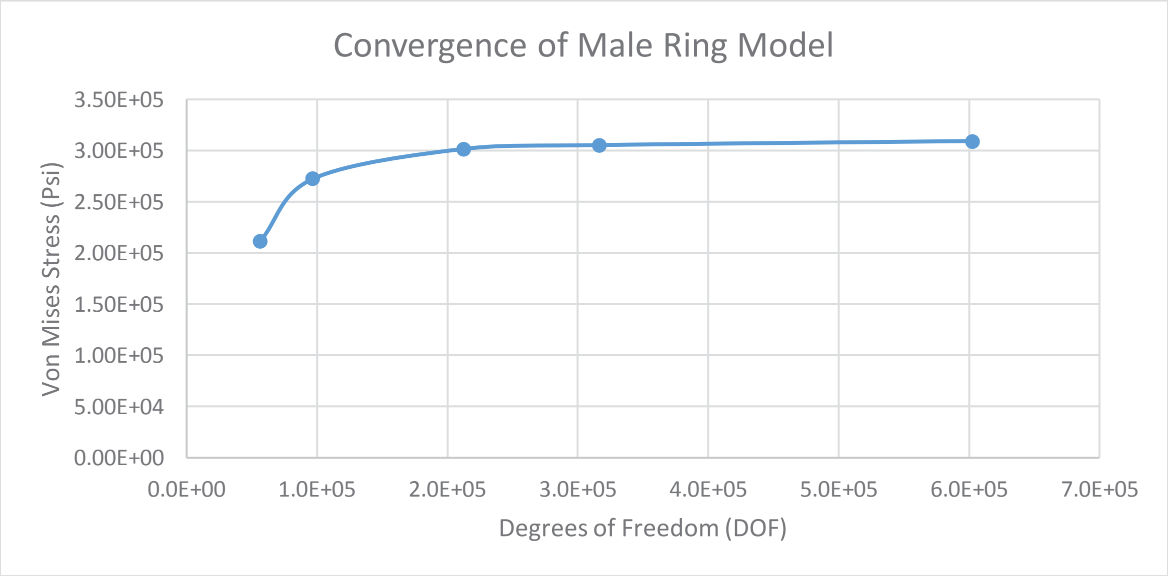


Figure 8. Male ring convergence

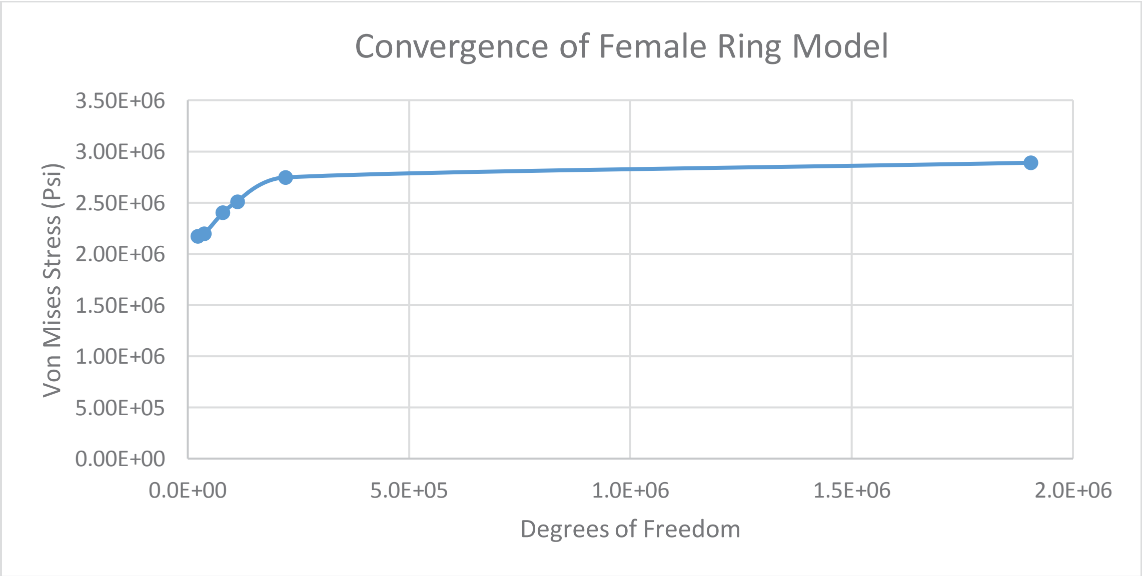
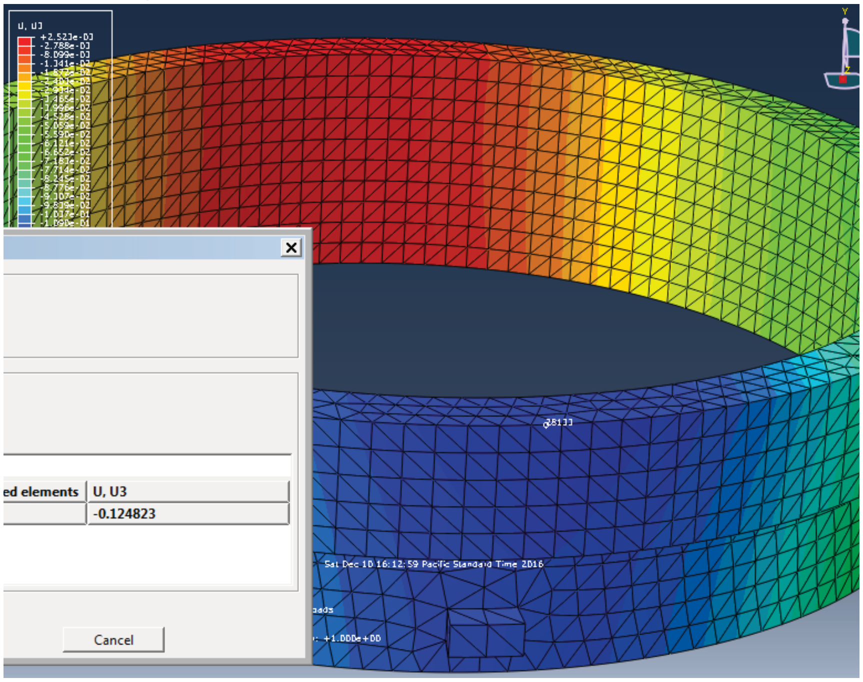


Figure 9. Female ring convergence

Values for the convergence graphs was taken at the points of maximum or most negative deflection (depending on axis orientation). For the two rings, the element of choice, seen in the figure X below, indicated a U3 deflection of -0.1248 inches representing the ring being pushed outwards for that location. This would reflect the canister latching ring bending and expanding outword during the loading case.



Unlike the two ring models, the overall canister model did not converge to a solution. Figure 11 seen below shows the Z direction deflection (U3) for the canister as the degrees of freedom increases. The graph is hard to inteperate and there is no clear value that the model asymptotes too. The lower value in the middle shows that the elements are inaccurate and the model is may have lots of error. The fact that the model had around 370 deformed elements indicates that the element quality may be poor, possibly the cause for no convergence.

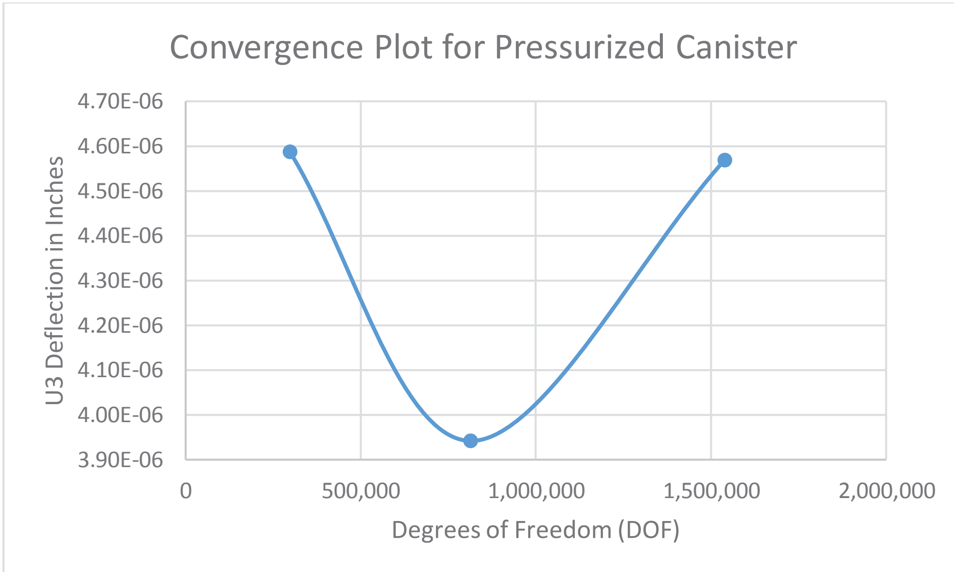
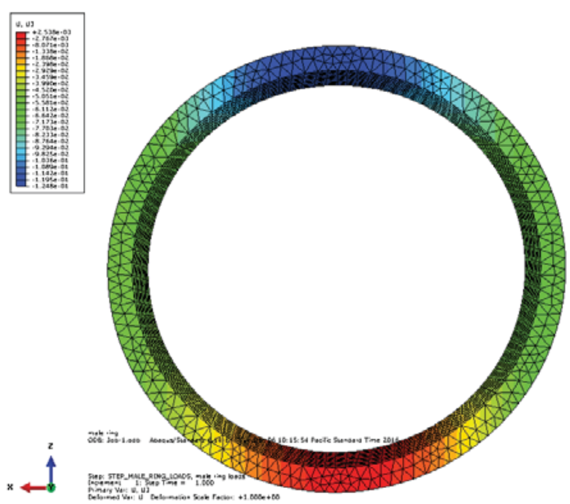


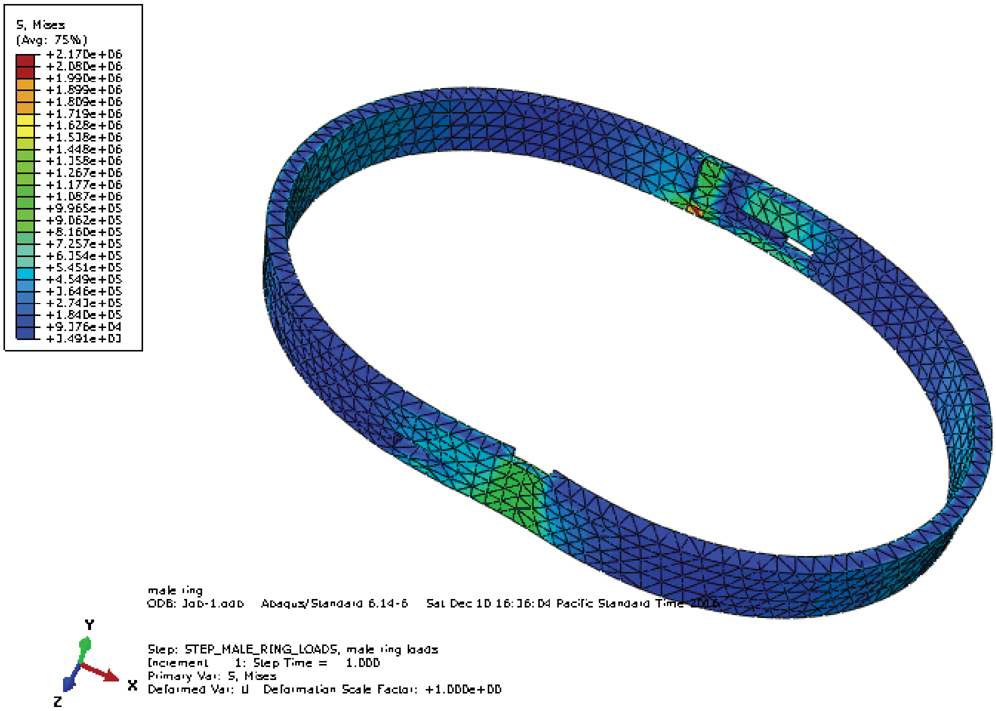
Figure 10. Canister convergence

7. Results

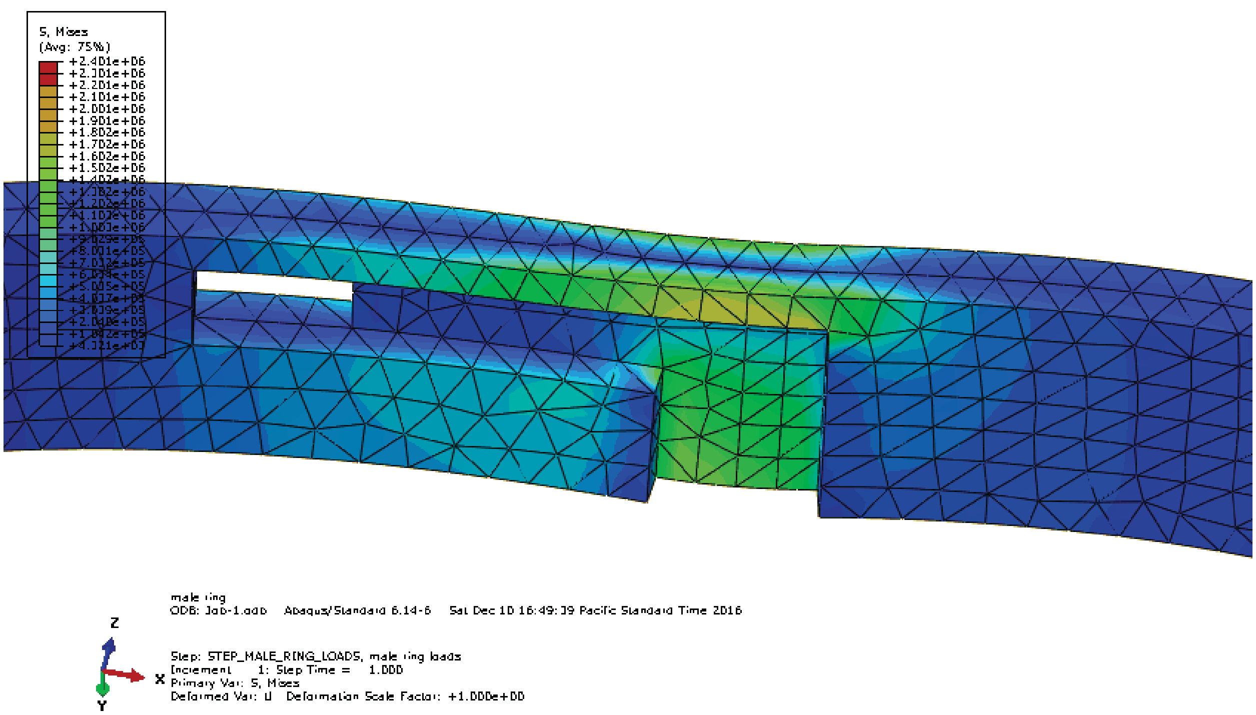
The analysis results can be seen in the following figures below. For the female and male rings, it was apparent that deflection was highest on the edge where the load was applied. This caused the edges to buckle outward while the base (pinned to ground) remains stationary for our boundary condition.



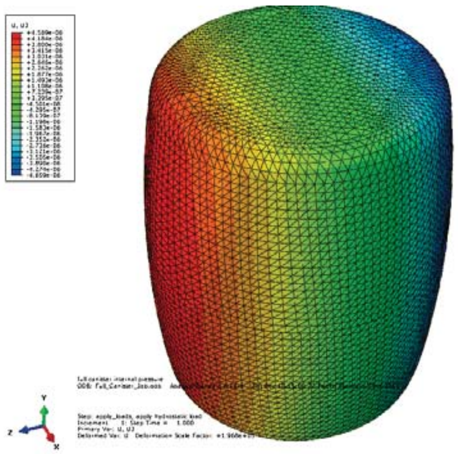
For the male ring, the loading test passed as the edges only deflected a maximum of 0.13 inches, half of the allowed deflection of 0.25 inches. Unfortunately, the female ring deflected almost 1.9 inches causing it to fail the deflection test on all run iterations.



The load causes stress to prorogate around the ring and be approximately constant throughout the ring, but the maximum pressure is observed around the latching slot. The latching slot has tight geometry and thinner material causing it to accumulate higher stress.



The pressurized canister exposed to 26 psi of internal pressure showed deflection on one side of the canister more than the other side due to the pinned boundary condition letting the edges rotate. The deflection was found to be around 6.11E-6 inches in the highest deflection case. This is due to the ridged carbon, and 26 psi of pressure is not much for such a large volume. The stress in the canister was very uniform due to the uniform 26 psi and saint Venant's principle. The one exception was the nodes where the pinned boundary condition was applied.



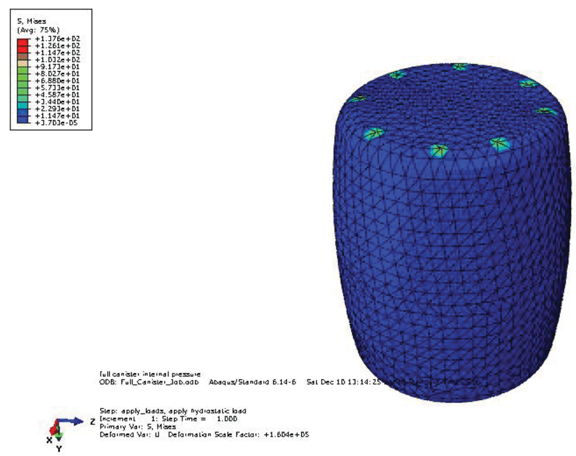


Figure x. Deflection of pressurized canister (Left) and Stress (right)

The raw data for both the locking rings and the pressurized canister can be seen in tables 1 and 2 below.

Table 1. Ring deflection and stresses raw data.

Element size	# of elements	MALE RING							FEMALE RING			
		DOF	Number of distorted elements	Deflection Max U1 (either side)	Deflection Max U3 (negative side)	Max Von Mises Stress	# of elements	DOF	Number of distorted elements	Deflection Max U1 (either side)	Deflection Max U3	Max Von Mises Stress
in	#	#	#	in	in	Psi	#	#	#	in	in	Psi
0.250 inch	10634	56610	0	0.08370	-0.1248	2.118E5	3388	21837	0	-0.9330	-1.926	2.170E6
0.200 inch	19237	97083	0	0.03910	-0.1249	2.726E5	6671	37341	0	-0.9473	-1.939	2.195E6
0.150 inch	43566	212493	0	0.08410	-0.1253	3.017E5	14632	79419	0	-0.9580	-1.956	2.401E-6
0.125 inch	66198	316947	0	0.08394	-0.1253	3.054E5	21049	111558	0	-0.9640	-1.963	2.506E6
0.100 inch	130590	602934	0	0.08419	-0.1254	3.094E5	44602	220323	0	-9.670	-1.968	2.746E6
0.050							392466	19038686	0	-9.843	-1.986	2.889E6

Table 2. Pressurized canister raw data.

Element size	Number of elements	Number of distorted elements	DOF	Deflection Max U1 Positive-X	Deflection Max U3 Positive-Z
in	#	#	#	in	in
0.500	68766	365	297,681	4.360E-6	4.587E-6
0.330	190745	272	812958	6.114E-6	3.942E-6
0.250	362892	33	1539225	4.619E-6	4.569E-6

8. Discussion

We discovered that the canister rings do not pass the deflection requirements. The female ring deflected almost 8 times the limit. The canister passes the pressure requirements and will be safe for use by the consumer

The deflection equation for the center of the lid is related to the stress. Based on the hand calculation of a 3/8 inch plate lid the maximum stress is 12.41 KSI which falls under the 360 KSI tensile strength while maintaining the 0.25 inch deflection limit. The FEA model shows closer to 3KSI which is much different than the hand calculations. The top of the canister is representative of what the lid stress should equal from our hand calculations.

We have not had time to test actual models of the parts, but in the near future we will actively load the parts for senior project and also submit the canisters for 60 minutes of live bear testing at the San Diego zoo or Yellowstone where the real life loading cases can be tested.

9. Conclusion

While I am happy with the results, the accuracy of the models can be challenged in the future due to the unsure nature of the boundary conditions, the laminate properties, and some of the elements being distorted. In the future I would model the canister as laminate with composite layers and better apply the 5000lbf pressure to the rings on the entire side, not just a small portioned area. In the extreme case I would model it as a point load on the side. The overall results conclude that the female ring is not nearly strong enough, while the canister body easily passes the pressure requirement.

To conclude this analysis, we will answer questions initially asked in the background section:

For the first question, if the rings would withstand the load applied without deflecting more than 0.25 inches, the rings only partially pass. The male ring passes the test at 0.13 inches due to its thicker geometry and increased moment of inertia. The thinner female ring failed the deflection test at 1.9 inches of deflection and experiences high stresses in some areas due to stress concentrations.

For the second question, the canister withstanding 26psi of pressure. The carbon laminate canister absolute passes this test as the average stress throughout the part is significantly lower than the yield of the composite at 200GPa. The canister also will stay adhered to the rings as it only expands outward less than 0.001 inch and will remain in contact with the rings.

Reference Page 1/3: Maximum Internal Pressure of Canister

Temperature	Internal Pressure	Internal Pressure
°F	PSIA	ATM
5	12.8	0.87
15	13.1	0.89
25	13.4	0.91
35	13.7	0.93
45	14.0	0.95
55	14.2	0.97
65	14.5	0.99
75	14.8	1.01
85	15.1	1.02
95	15.3	1.04
105	15.6	1.06
115	15.9	1.08
125	16.2	1.10
135	16.4	1.12
145	16.7	1.14
155	17.0	1.16
165	17.3	1.18
175	17.6	1.19
185 **DRY Epoxy Glass Transition Temp**	17.8	1.21
195	18.1	1.23
205	18.4	1.25
215	18.7	1.27
225	18.9	1.29
235	19.2	1.31
245	19.5	1.33
255	19.8	1.34
265	20.0	1.36
275	20.3	1.38
285	20.6	1.40
295	20.9	1.42
305	21.2	1.44
315	21.4	1.46
325 **WET Epoxy Glass Transition Temp**	**21.7**	**1.48**

Bear Minimum Senior Project - Team #28

```
%California Polytechnic State University, San Luis Obispo
%Rama Adajian
%11/11/16

clc
clear
close all
global Tmax
```

GLOBAL VARIABLES

```
%Tmax is the Glass Transition temperature of the epoxy.
Tmax = 325 %[Degrees F]
```

INITIAL CONDITIONS STP @ 70 Degrees F

```
n1 = 0.405 %[moles]
T1 = 72 %[Degrees F]
P1 = 14.7 %[Psi]
V1 = 600 %[Cubic Inches]
```

SECONDARY CONDITIONS @ INCREASED TEMPERATURE

```
n2 = 0.405 %[moles]
V2 = 600 %[Cubic Inches]
T2 = [5:10:Tmax]' %[Degrees F]
```

CALCULATING SECONDARY PRESSURE FROM IDEAL GAS LAW

```
for i = 1:length(T2)
    P2(i,1) = T2(i)
    P2(i,2) = ((T2(i)+459)/(T1+459))*P1
end
```

Reference Page 2/3: Pressure on Lid of weight dropped

Clamped Circle Stress 10/20/16 | Rama Adajian | 1

Impact Force: 100 lbm weight from 1ft onto surface of 6.5" Diameter circular clamped plate. Max deflection is 0.25"

$m = 45.35$ kgs (100lbm) $\quad V_{zz} = 0.997$

$h = 0.308$ m (1ft)

$V_{impact} = 2.44$ m/s

$KE = \frac{1}{2}mV^2 = (\frac{1}{2})(45.35\,kg)(2.44\,m/s^2)$

$\rightarrow KE = 135.49\,J$

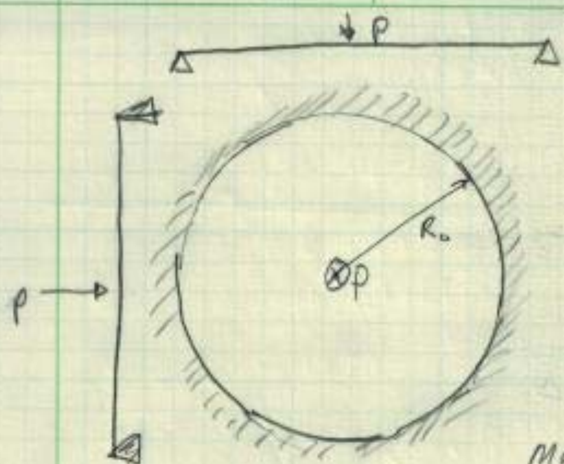
From Work Energy relationship with max impact deflection of 0.25 in or 0.00635 m

$\rightarrow$ Force, avg $= 21{,}337\,N \cdot \frac{1\,lbf}{4.44\,N} = 4797\,lbf$

$$Pressure = F/A = \frac{4797\,lbf}{\pi(\frac{1}{2}(6.5"))^2} = \boxed{225.9\,psi}$$

Reference Page 3/3: Simply supported all around max center deflection of lid

2



Displacement of center to not exceed 0.25 in under 226 psi pressure avg load. Fixed statically all around. Calculate Modulus needed if $\nu \approx -0.997$, 3/8" plate, $R_o = 3.25$". Calculate max stress and make sure not exceeded.

Displacement: Max @ center, $r = 0$

$$w(r) = \frac{p r_o^4}{64D}\left[1 - \left(\frac{r}{r_o}\right)^2\right]^2$$

@ $r = 0$ $\quad w(0) = \dfrac{p r_o^4}{64D}$

$$M_{max} = M_r(0) = M_\theta = \frac{p r_o^2}{16}(1+\nu)$$

Max Stress @ center of plate at t/2 depth

$$\sigma_{max} = \frac{6}{h^2} M_{max} = \frac{3(1+\nu) p r_o^2}{8h^2}$$

Bear Canister Facility Design

IME 443 Final Presentation

Agenda

- Project overview
- Space Requirements
- Layout Designs
- Location Option
- Economic Analysis

Project Overview

- Carbon Fiber Bear Canister
  - Two halves and middle ring
  - Lightweight but can still protect food from animals
- The Bear Necessities design team will define the manufacturing process for creating a bear canister, and design a facility that will be able to produce 5,000 units per year.
- Deliverables:
  - Facility Requirements
  - Cost Breakdown
  - Facility model (Sketchup)
  - Model Walk Through Video

Space Requirements

Department	Equipment	Workstations	Area/Workstation (sq ft)	Total Required (sq. ft.)
Carbon Fiber Prep	Die Cutter, Table, Chest Freezer	1	82	82
Mold Prep	Storage Cabinet, Spray Station Table	1	52	52
Carbon Laying	Female Stainless Steel Mold, Male Silicone Mold, Table	3	33	99
Heat Press	Hydraulic Heat Press	4	19	76

Space Requirements

Department	Equipment	Workstations	Area/Workstation (sq ft)	Total Required (sq. ft.)
Mold Separation	Table	1	33	33
QC & Hole Drilling	Drill Press, Table, Measuring Equipment	1	52	52
Locking Mech.	Dust Extraction System, Table	2	33	66
Ring Assembly	Ring Assembly Table	1	33	33
Final Assembly	Table	1	33	33
			Total Required Area	**522.6**

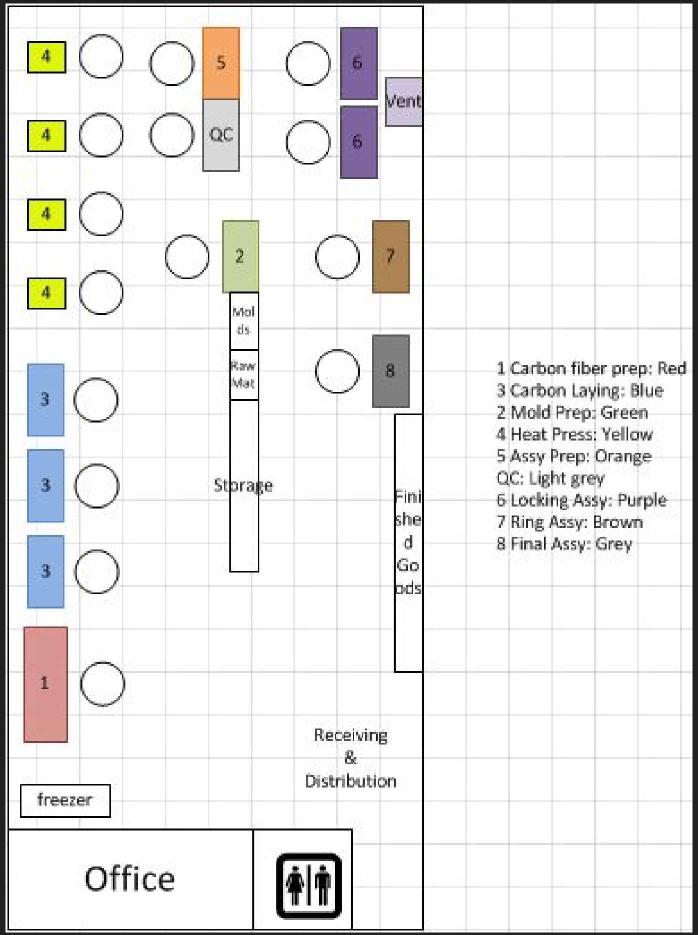
Design Layout Selection

- The weighted criteria used to choose the optimal design layout are as follows:
  - Distance Traveled
  - Maneuverability
  - Square Footage
  - Material Flow
- Range of ratings used to measure design layout spans from 1 being the worst, to 10 being the best.

	Distance Travelled	Maneuverability	Square footage	Material Flow	Total
Weight	10	8	5	9	
Layout 1	10	6	9	10	283
Layout 2	8	10	9	9	286
Layout 3	9	8	7	10	279
Layout 4	8	9	7	8	259

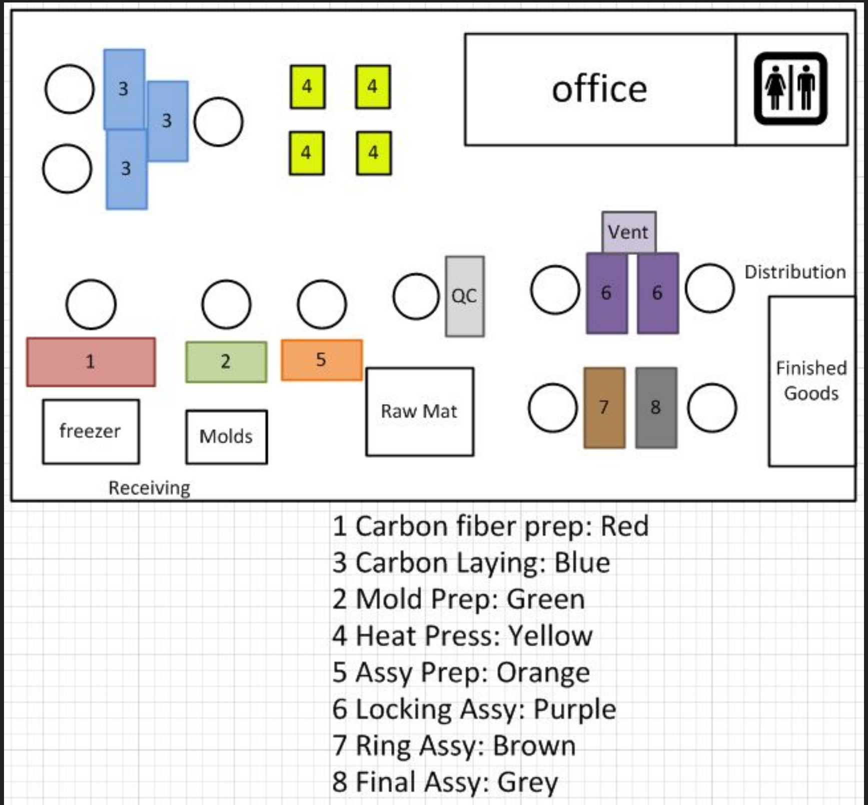
Design Layout Details

- Design Layout 4
  - More appropriate for 2:1 aspect ratio facility
  - Good maneuverability but distance travelled is 109 feet.
  - Larger square footage at 1850 square feet
  - Material flow not as efficient as other designs



Design Layout Details

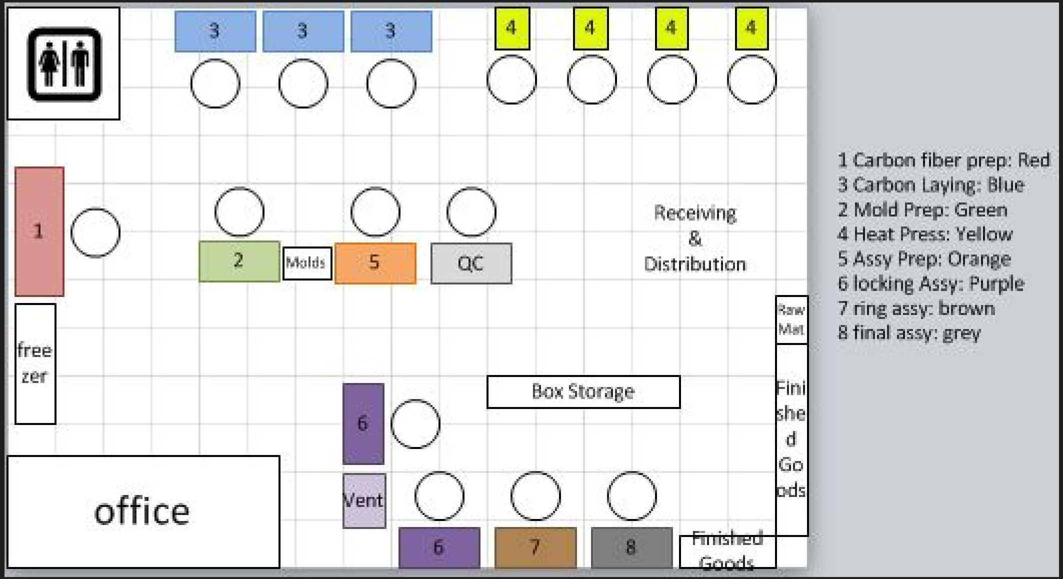
- Design Layout 1
  - Optimizes Distance Traveled at only 81 feet.
  - Allows for optimal Material Flow through manufacturing process
  - Smaller Square Footage requirement at 1,600 square feet.
  - Largest drawback is poor maneuverability



Design Layout Details

- Design Layout 2
  - Designed for optimal Maneuverability
  - A balance between Square Footage and Material Flow
  - Requires 1,650 square feet
  - Total travel distance of 106 feet

Recommended Facility Design



Location Option

- Grover Gardens Industrial Park
    - Minimum Divisible Space- 1,742 sq. ft
    - Space delivered with “Vanilla Shell” office space
    - Lease Rate: $1.00/sq. Ft
- http://www.loopnet.com/Listing/14101359/Huston-Grover-Beach-CA/

Annual Labor Costs

Employer Taxes	%
Social Security	6.2
Medicare	1.54
Mfg Workers Comp	9
CA Unemployment*	3.4
Federal Unemployment*	1.2
Employment Training*	.1

Labor	Qty	Hourly Wage	Annual Cost**
Skilled	4	$23	$215,952
Unskilled	8	$10.5	$198,604
Total labor cost per year			**$414,556**

* % taken off of first $7000 only

** Includes employer taxes and assumes a 250 work days per year

Capital Equipment Costs

Equipment	Qty	Vendor	Cost Per	Annual Cost	Link
6’ Chest Freezer	1	Sears	$550	$550	http://www.sears.com/kenmore-22-cu-ft-chest-freezer-white/p-04612822000P
Die Cutting Press	1	Tip Man Clicker	$3,000	$3,000	http://tippmannclicker.com/clicker-1500-die-cutting-press/
Die Cut Mold	4		$200	$800	
Hydraulic Heat Press	4	Ebay	$5,000	$20,000	http://www.ebay.com/itm/Tetrahedron-MTP-14-Compression-Lamination-Heated-Pneumatic-Platen-Press/371921606912?_trksid=p2047675.c100005.m1851&_trkparms=aid%3D222007%26algo%3DSIC.MBE%26ao%3D2%26asc%3D40130%26meid%3D7baf828b044e4bf3a2d50f2f214aef55%26pid%3D100005%26rk%3D1%26rkt%3D2%26sd%3D222491652015
Drill Press	1	Max Tool	$3,400	$3,400	https://www.maxtool.com/jet-j-2221vs-20-variable-speed-drill-press-115-230v-1ph-354221?google=1&CAWELAID=230005740000021097&CAGPSPN=pla&CAAGID=19685619371&CATCI=pla-144707421131&gclid=Cj0KEQjwgODIBRCEqfv60eq65ogBEiQA0ZC5-S83ERqydzp_JdnrqKp1NS3vlaezCKJjDTZ2ODYr8mEaAnCf8P8HAQ
Half Mold	8		$8,000	$64,000	
Ring Mold	4		$2,500	$10,000	

Capital Equipment Costs

Equipment	Qty	Vendor	Cost Per	Annual Cost	Link
Silicone	60 kg		$14.82	$889	https://wholesaler.alibaba.com/product-detail/good-price-raw-material-liquid-silicone_60494050611.html
Dust Extraction System	1	Baileigh	$567	$567	http://www.baileigh.com/dust-extraction-system-dc-1650b , http://www.baileigh.com/dc-accessory-kit-deluxe
Storage Cabinet	1	Ebay	$675	$675	http://www.ebay.com/itm/Parent-Metal-Heavy-Industrial-Premium-Storage-Cabinet-36x24x78-Putty-/112377290127?hash=item1a2a355d8f:g:l3EAAOSwgmJXyT7v
Workbench: 60”x30”	10	Global Industrial	$190	$1,900	http://www.globalindustrial.com/c/work-benches/open-leg?infoParam.campaignId=T9A&gclid=CKW3iqKS9dMCFdCXfgodC-8AhA
Workbench: 96”x36”	1	Global Industrial	$320	$320	
Storage Cabinet	2	your-industrial-supplies	$674.65	$1,349.30	http://www.ebay.com/itm/Parent-Metal-Heavy-Industrial-Premium-Storage-Cabinet-36x24x78-Putty-/112377290127?hash=item1a2a355d8f:g:l3EAAOSwgmJXyT7v
Storage Rack	5	Ebay	$187.24	$936.20	http://www.ebay.com/itm/Edsal-72-H-x-72-W-x-24-D-Steel-Welded-Storage-Rack-Industrial-Heavy-Duty-Black-/272572947588?hash=item3f769d1c84:g:7vkAAOSwCU1YthER
Total Initial Investment				**$107,711**	

Material Costs

Material	Qty	Vendor	Cost Per	Annual Cost	Link
Thumb Screw	3	McMaster	$2.84	$8.52	https://www.mcmaster.com/#thumb-screws/=17mphg7
Elastic net	1	Online Fabric Store	$5.70	$5.70	
velcro	0.027	Amazon	$21.49	$0.58	https://www.amazon.com/dp/B00006RSP1/ref=asc_df_B00006RSP14985821/?tag=hyprod-20&creative=394997&creativeASIN=B00006RSP1&linkCode=df0&hvadid=167126942869&hvpos=1o3&hvnetw=g&hvrand=532993939789216912&hvpone=&hvptwo=&hvqmt=&hvdev=c&hvdvcmdl=&hvlocint=&hvlocphy=9031723&hvtargid=pla-274443084439
cardboard boxes	1	ULINE	$0.64	$0.64	https://www.uline.com/Product/Detail/S-18344/Corrugated-Boxes-32-ECT/12-x-12-x-12-Lightweight-32-ECT-Corrugated-Boxes
6-32 screw nut	3	Fastenal	$0.03	$0.10	
Carbon Fiber 50 yard x 50 inches	0.0232	Prepreg	$1,900	$44.08	
Total Material Cost Per Canister				$59.62	

Other Annual Costs

Maintenance	Qty	Cost Per	Annual Cost
Die Sharpening	50	$50	$2,500
Mold Rework	12.5	$1,000	$12,500
Total maintenance per year			**$15,000**

Expendables	Qty	Cost Per	Annual Cost
Mold Release*	5,000	$1	$5,000
Respirators**	1,000	$14	$14,000
Total expendable per year			**$19,000**

* Assumes production of 5000 units, and a $1 cost per canister for mold release

** Assumes production of 5000 units, and a 5 year life

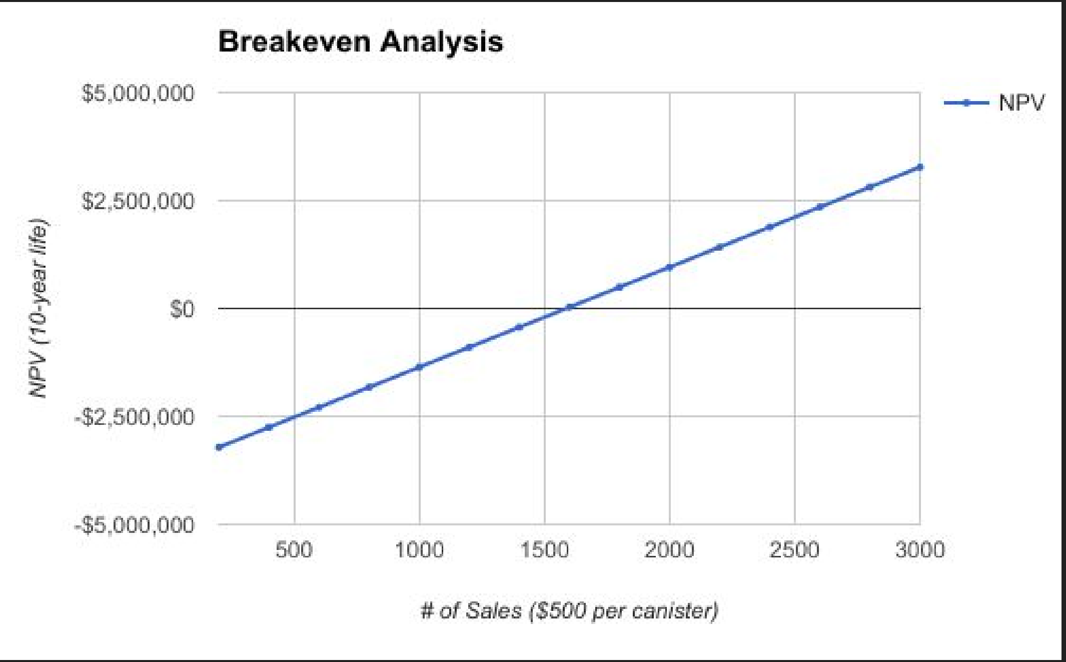
Cash Flow Calculation

Assumptions
10-year project life
5% interest rate
40% tax rate
Straight-line depreciation

Sales	$2,500,000
Initial Investment	($106,775)
Labor	($414,556)
Material	($298,083)
Other	($65,000)
Depreciation	($10,678)
Taxable Income	$1,733,039
Taxes	($693,216)
Net Income	$1,027,010
Depreciation	$10,678
CashFlow	$1,037,688

Economic Justification

- Need to sell 1587 canisters each year in order to breakeven
- Net Present Value assuming 5000 sales annually is $8 mil



Questions?

Appendix O.

User Operator's Manual

Your canister features the following parts

1. Canister Top with Attached Stiffening Ring
2. Canister Bottom Half
3. Net
4. Thumb screws (x3)

To close your canister:

1. Load your canister with food.
2. Stretch the net along the top of the inner surface of the canister top where velcro is and velcro net securing your food.
3. Turn your canister top upside down and attach to the canister bottom.
    a. Make sure the arrows are aligned so the holes on the canister top and canister bottom align.
4. Screw the thumb screws to lock the canister.

To open your canister:

1. Unscrew the thumb screws.
2. Pull apart canister ensuring the top half with the net is pulled from the top.
3. Take net off from its velcro supports.
4. Access food.

Maintaining your Canister:

1. Use attention and care when loading food into and out of container.
2. Do not overtighten screws when locking the canister.
3. Clearcoat or lacquer the outside of the canister to maintain its finish look, but do not sand.
4. Avoid impact forces on the canister or storing next to sharp objects.

Safety Guidelines.

1. Be aware of your lower back when lifting and setting down the canister.
2. Avoid contact with children, as the screws can be a choking hazard.
3. Do not continue to use the canister if the carbon fiber weave is compromised.
4. Use care and finesse when screwing in the bolts
5. Do not use either canister half to eat food off of.
6. Sit only on the canister if it is oriented in the vertical direction.