40 Quart Cooler Design

By:
Dominic Albano, Danny Miller, Dirk Prather
Federico Martolini, Bander Almazroua

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Department of Mechanical Engineering
Northern Arizona University
Flagstaff, AZ 86011

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1. Abstract

This Senior Design project focuses on a product provided by a local business, Canyon Coolers, in Flagstaff, AZ. They provide premium ice chests for their customers. Unfortunately, some of their products suffer minor defects originating from their design. After client discussions, it was determined that their 40 qt. model was an ideal candidate for research and development. The new design needed to be compatible in a wider range of uses, weigh less than 7 kg, withstand higher impact stresses, integrate numerous usable features, and maintain the current cost of the existing design ($199.99).

The process of designing the cooler under the constraints required a wealth of knowledge of the existing premium cooler design and manufacturing process. This demanded an extensive iterative process in order to adhere to critical manufacturing standards and project objectives. CAD modeling, stress simulation, temperature testing, and rapid prototyping were all utilized simultaneously during the bulk of the design process. Between these developments and communicating with the client and industry professionals, the final design was engineered to completion. The finished cooler design was able to meet and exceed the project constraints. Overall ice retention of the new cooler was theoretically improved by approximately 29% by means of experimental and theoretical modeling. Common production and design issues have been addressed thoroughly which have greatly enhanced both functionality and performance as per client specifications.

2. Problem Statement

2.1 Introduction

Canyon Coolers is a small business located in Flagstaff, Arizona that provides premium ice chests for its customers. The coolers they sell feature a rotationally molded UV resistant high density polyurethane (HDPE) shell injected with low thermal conductivity polyethylene foam. The demand for these products is rapidly expanding in the American market, creating increased competition between the numerous distributors. Canyon Coolers is looking to improve upon its existing designs in order to expand their business and develop a prominent position in the market.

The challenge presented was to overhaul the existing 40 quart model that is offered by Canyon Coolers. A number of models in their current product line suffer from minor defects that result in an intolerable profit loss. The 40 quart model was selected for research and development because of its current design concerns and its high demand in the premium cooler market. The goal of the new design was to engineer features that accommodate a wide range of use, while maintaining long term durability and the competitive price point of the existing design.

2.2 Background Research

Research was crucial to grasping the scope of the task and was an ongoing process for the duration of the project. Many possible directions were provided initially creating open-endedness for design possibilities. With this high degree of freedom came a required wealth of knowledge on a wealth of topics pertaining to the cooler business. Manufacturing specifications for double wall rotational molds and high volume injection molds were first priority. Existing designed were then examined across the premium cooler market paying close attention to reoccurring problems as well as proven successes. Once the design phase was under way it became clear that more information was needed on the computer software available for designing and simulating CAD files. Each sector of preliminary research helped lay a strong knowledge foundation for the project.

Rotational molding and injection molding each have a unique set of guidelines. Rotational molding is the process used to create the shells for both body and lid. There are several advantages of this manufacturing process for premium coolers such as large volume capacity and extremely strong material properties. The draw backs include length processing times and a rigorous set of rules that tend to vary with geometry. This last fact was the main focus for research. The many pamphlets developed on the topic (cited in references) were also aided by the knowledge of engineers that design the same products the client produces. Injection molding has an entirely different set of rules associated with it. Thankfully, faculty at NAU provided sufficient knowledge needed to produce a simple, single body rubber part.

Once the basics of the engineering were understood, further examination of existing designs proved to be much more informative. The wonderful folks at Canyon Coolers were nice enough to allow adequate access to their facilities, their records, and to some of the configurations they were currently considering still in the CAD development stage. Competing coolers were also analyzed for their strengths and weaknesses. The familiarity gained on the product was invaluable for the design of each cooler component: body, lid, and latch.

Throughout the duration of the project, a high volume of computer programs were used for drafting and simulating purposes. Some of the programs include; SolidWorks, Matlab, Cosmos, Simulation Xpress, FlowWorks, and Catalyst. Literature provided for each of these systems was utilized for the design project as well as specialized expertise from faculty.

2.3 Needs Identification

The client currently experiences a number of design flaws on their existing 40 quart model. These flaws include inconsistent body geometry, insufficient gasket thickness and subsequent latching force, and a limited range of use. These flaws occasionally cause a failing review in the quality assurance process, ultimately creating intolerable losses in profit for the small business.

A major concern for Canyon Coolers is the inconsistency in product quality. The cause of this is derived from overall mold quality and the rotational molding manufacturing process. The cooler geometry dictates how well the mold performs as it is responsible for distributing molten plastic evenly throughout the shell during production. Heat transfer also has major adverse effects during rotational molding. Heating and cooling rates and durations dictate the quality of the finished product. The better the mold is designed, the more consistent the product will be.

Gasket arrangement and latching weaknesses create additional issues related to the performance of the cooler. If a seal is not fully created between the cooler body and lid, heat permeates the cooler at an accelerated rate, thereby decreasing overall ice retention. The design of the current latching system poses yet another concern for Canyon Coolers. Despite Canyon’s employment of various latching systems, the one that is in high demand, because of its ease of use and low cost, is also the system that contains the most flaws.

The last concern proposed by the client was related to functionality. The demand for premium coolers is expanding in American markets, creating increased competition between a growing numbers of distributors. Price and functionality dictate consumer habits. While Canyon has an advantage in the prices of their products, their 40-quart model lacks the features provided by other brands. This list of client needs was comprehensively considered in the redesign of the 40-quart model.

2.4 Goal And Scope Of Project

Through methodical examination of client needs, the goal of the project was identified and was stated as such: to develop a cooler with an internal volume of 40 quarts that offers reliability and performance and meets the highest standards in the industry while maintaining an MSRP of no more than $199.99. In order to accomplish this goal to its fullest extent requires a large amount of financial stability as well as time. Accomplishment of this goal to full completion entails the production of a physical and fully manufactured body, lid, and latches. These parts all require a master mold in order to produce copies of the CAD drafted designs which are extremely expensive. A mold for a rotationally molded body and lid of 40 qt. cooler costs about $20,000 and a mold for an injection molded latch costs about $6,000, both excluding mass production and oversea shipping costs.

This placed a challenging degree of assurance in the quality of the CAD files for these molds. There is no prototyping in the field of roto-molding or injection molding as it is far too expensive. The designs for these molds must be engineered to an almost perfect level of precision to ensure that the cost of the mold does not turn into a devastating financial loss because of a faulty design. These implications aligned the scope of the project for both the team and the client.

The goal of the project stated above was accomplished to its fullest possible extent within the financial constraints. This does not mean that a physical product was produced. The client made the decision not to follow through with production of the new design in the time frame of the project. It was clarified, however, that the reason behind this decision was not because of any faults in the proposed design but a lack of funds. However, Canyon Coolers was extremely excited and pleased with the proposed design and now has the finished CAD file in their hands for use in production when the appropriate time presents itself. The scope of the project was focused around these details and was accomplished to the fit original goal.

2.5 Objectives

Following the goal of the design, a cooler that satisfies specific objectives and guidelines was created. Part of these objectives (Table 1) are the cooler must have an ice retention of at least 72 hours, and the cooler body and lid have to be able to withstand impacts and falls due to normal usage. Failure to do so could cause delamination of the polyurethane foam. The fixed MSRP is $199.99. The final product must weight no more than 8.5 kilograms when empty to create ease of mobility. One of the main objectives surround cooler dimensions; these must be designed so the outer dimensions allow for nested shipping and the inside allows the cooler to fit common items as well as hold an internal volume of 40-quarts. The cooler must require little to no maintenance as well, reducing costs.

Table 1: Objectives and basis for measurements with associated units

Objective	Basis for Measurement	Units
Well Insulated	Significant ice retention	Watts & t
Sturdy	No major dents upon impact	m
Inexpensive	Low MSRP	$
Light Weight	Easily carried by one person	kg
Dimensions	Nests into other coolers (shipping), and compatible with common sources of use	m
Maintains Shape	No warp from temperature changes	Degrees
Low Maintenance	Costly for distributer to fix	$

Table 1 represents a collection of measureable, tangible ways to guage the quality of design. While it was difficult to measure some of these objectives due to the lack of a physical design, each one was considered in relation to the others when devloping CAD models. Simulations played a big role in evaluating each objective.

2.6 Constraints

The objectives were divided into five categories; cost, geometry, weight, durability, and function. From there, each category was broken up into its constituent pieces, providing clear, achievable target constraints for the project.

Cost was the most important constraint because of the nature of the client's interest. It was stated that the manufacturer's suggested retail price (MSRP) of the cooler had to be no more than the $199.99 price point. This price represents the cost of the current model to the customer.

The geometry related constraints were defined as well. First, the finished product receives an additional cost benefit if it is able to stack efficiently. Products manufactured in Thailand are sent in shipping containers by barge across the Pacific Ocean, therefore the tighter the coolers stack, the smaller the cost per item. It is also fundamental that the coolers are able to nest directly inside bigger coolers manufactured by the same company. If the nesting is accurate, the same container can haul up to 50% more merchandise with a sensible saving on shipping expenses, therefore improving profit margins. Yet another important constraint for dimensions is for the new cooler to accept common food and beverage formats such as 12 oz. bottle or jug of water. Lastly, the internal volume of the ice chest must be approximately 40 quarts.

The weight of the finished cooler was decided collaboratively to be no more than 20 pounds at its dead weight. By doing so, the new 40 qt. cooler would be comparable weight wise with other products available to the consumer today. Aware that weight can easily become an issue when the device is filled to capacity, a constraint was self-imposed to engineer a system that provides multiple options for combating this problem.

Durability is one of the defining differences between traditional and premium coolers. This particular constraint proved to be difficult to narrow since it plays a role in every aspect of cooler design. Durability stems primarily from cooler geometry and material selection. Since the available materials were not susceptible to change, contours became the main durability concern. The cooler had to be designed as to mitigate warping in areas of high concern, to streamline the profile reducing impact stresses, and under no circumstances should the hull be permeable to debris, water, or air.

Function provided key constraints on cooler design. Ice retention, arguably the most crucial function of an ice chest, was to be improved upon. The other constraints pertaining to function are related to useful features. The highest quality products in the premium cooler market offer useful features that appeal to consumers. The constraint derived from this was to implement a variety of features such as tie down slots, lock slots, or a quick access port that provide increased function to consumers.

2.7 CRITERIA TREE

Displayed below is the criteria tree for the production of the 40-quart cooler. Cost is one of the main factors needed to be considered. The other two extremely important factors are build quality and global performance of the product. The criteria tree displays these tasks into a visual format for easy conceptualization.

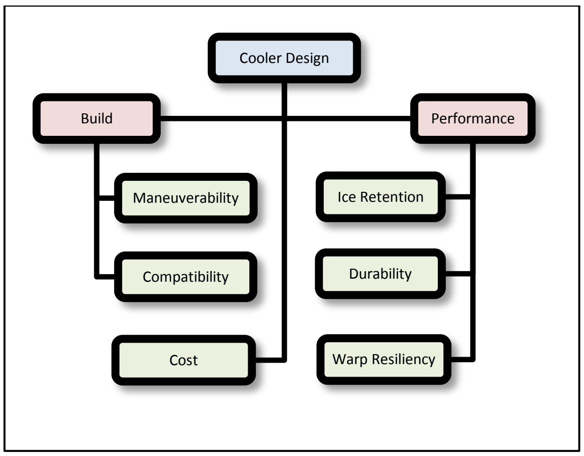

Figure 1: Analysis of criteria in relation to the cooler design

2.8 QUALITY FUNCTION DEPLOYMENT

A design tool that was used to determine how to relate engineering requirements to each other is the house of quality (Figure 2). The house of quality takes the engineering requirements and maps them against each other. Where the requirements intersect in the top region a "+" or "-" correlation is placed; i.e. modulus of elasticity and density are positively correlated therefore when one increases, the other increases. A "-" signifies an inverse relationship, where as one increases, the other decreases.

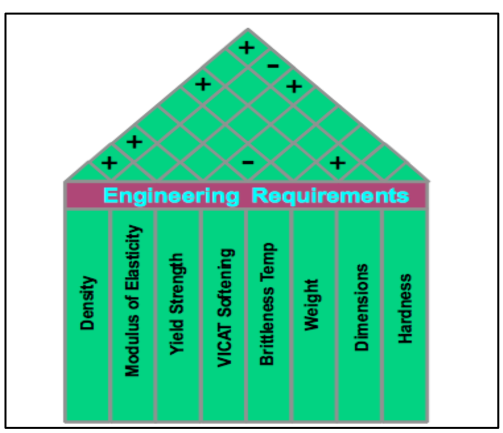

Figure 2: House of quality

3. Concept Selection

3.1 Hinge Development

The design of the hinge on the cooler was a very important feature during the design process. The client was concerned with a few changes that needed to be made to the existing design. The new design needed to have two opening positions and adequate ear spacing for warp resilience. The first feature is to ensure that the lid of the cooler can be opened wide enough while the cooler is flat up against a wall as well as all the way without falling back. The client was very concerned with this problem as the current design does not incorporate this feature. The design required that there be no extra parts on the cooler used to solve this problem and that all features were integrated into the mold itself. This task was completed by first designing a small cut-out version of the lid and cooler assembly in SolidWorks. This prototype incorporated the mechanism intended for the two opening positions. There is a small raised area on ear of the body that slides into a respective recess on the lid that is precisely positioned to facilitate the lid staying open against a wall. An angled portion near the back of the top of the lid ensures a maximum angle of opening flat against a wall. This initial design was then rapid prototyped using the fused deposition modeling machine which produced a functioning prototype of the cut-out design. This prototype was used to prove functionality and fit. The design was evaluated and iterated and then integrated into the CAD file for the entire cooler body and lid. The CAD file and physical prototype are pictured in Figure 3.

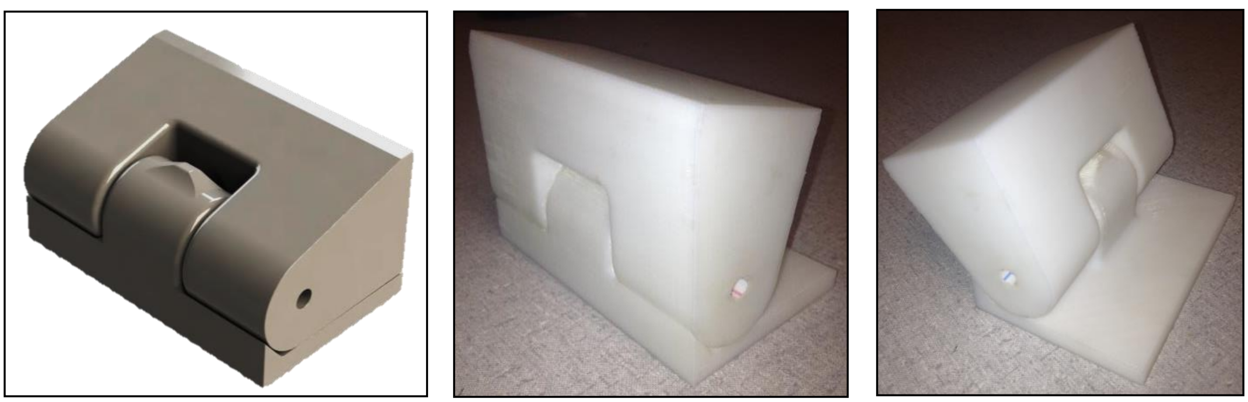

Figure 3: Hinge prototyping, CAD file (left), & prototyped (center & right)

The changes that were made from this first iteration were a smaller and rounder primary stopping design at the back of the hinge and an extension of the groove on the lid that holds the lid in the secondary opening position. After these changes were determined to be made the entire design was transferred onto the CAD file of the entire cooler. This process also included simultaneously integrating the lid and the body and their respective meshing components. These other components will be discussed in section 2.3 but are important to the design and scale of the hinge. The spacing of the ears was determined in the stage and was done via the process of incorporating the tie-slot locations while maintaining as much material on the lid as possible to support against warping. The final hinge design includes the primary and secondary stopping mechanisms, a fully concealed connecting rod, favorable ear spacing, and required tolerances for actuation and manufacturing. A cross section and full view of the final hinge design can be seen in Figure 4.

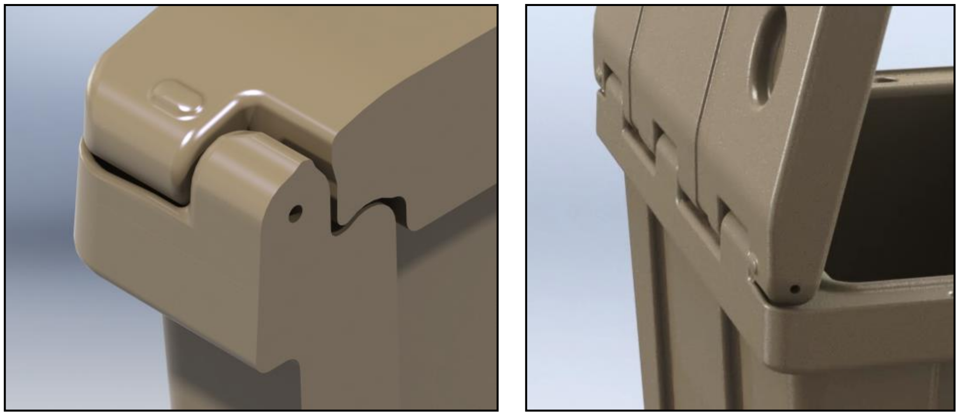

Figure 4: Final hinge design implementation, Cross section (left), actuation (right)

3.2 LATCH DEVELOPMENT

The latch design is in its finishing stages of development. The final design has been approved, materials have been analyzed, and manufacturers are in contact. The client now reserves the decision to move forward with manufacturing. The figure below depicts CAD photos of the latch as it progressed through the design phase.

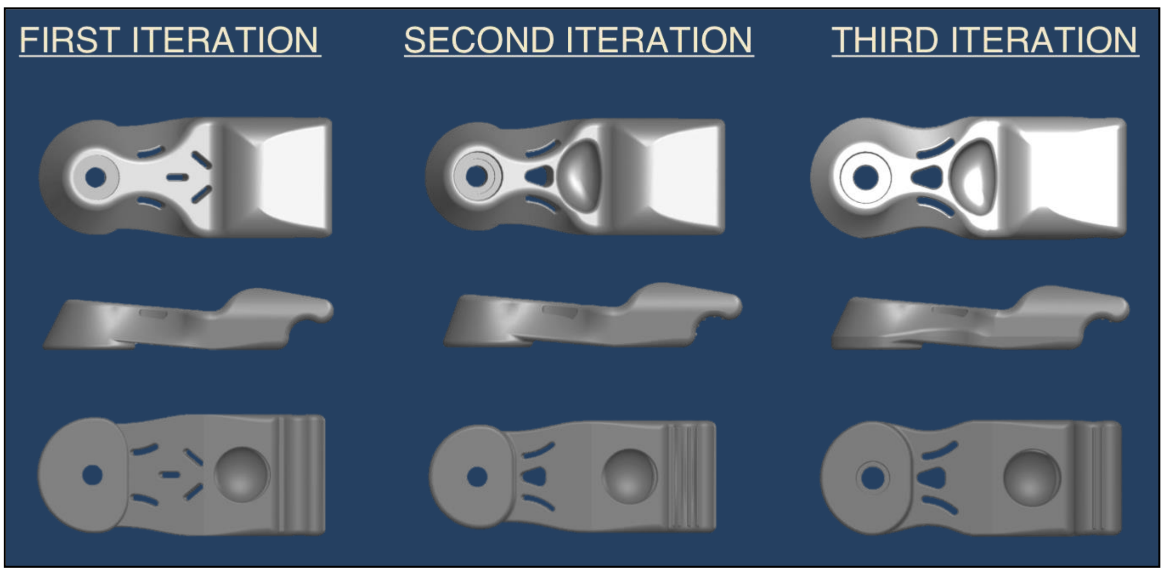

Figure 5: Top, side, and bottom views of the three latch iterations

The first iteration of the phantom latch was aimed at meeting the needs of the client. These were less overall bulk, and an improved fixture design. The first iteration addresses all of these with some additional improvements. A tapered cross section reduces stresses induced by foreign objects that come in contact with the latch. This in tandem with lower overall height and length reduce the volume of the latch while diminishing its chances to become an obstruction. The rubber at the fixture was increased in thickness to provide a stronger attachment between latch, rivet, and cooler lid. Features such as the ergonomic handle and through holes were also designed into the latch to increase functionality. Version 1 was RAPID prototyped and given to the client for evaluation.

From client feedback, and elementarily simulations the second iteration was produced. The aim of this iteration was to increase the range of applicable cooler models to which the latch could be implemented and to improve ergonomics. The width of the latch was reduced by 4 mm, and the nose length and finger lip were each reduced in length to accommodate the geometry of most coolers in Canyon's product line. A thumb insert was introduced to the top of the latch to increase the amount of force one can apply in a latching motion creating increased pressure on the cooler gasket. The through holes were altered to reduce stress concentrations and improve overall stretch. An insert for a shoulder washer was added to the fixture hole to stiffen the area of attachment thus providing the rivet a firm surface to engage upon. These improvements were again taken to the client for review and also to mold manufacturers to analyze its manufacturability.

The results that came back indicated a sound design, but a less than optimal parting line. Improvements centered on those manufacturing concerns. The geometry of the latch was first rearranged to fit the criteria for injection and compression molding and then second tweaked to reduce the overall cost of the mold. The fixture location was also improved by reversing the direction that the shoulder washer sits in the latch assembly. This third iteration was then taken back to the mold professionals and deemed ready for production. Pictured below in Figure 6 is an isometric view of the final latch design as well as stress testing, and a sectional view.

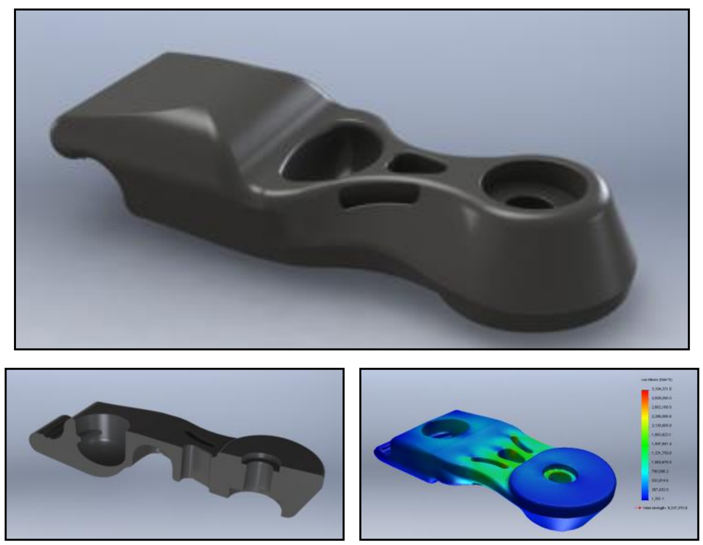

Figure 6: Final latch design (top), cross section of design (left), & VonMises stress map (right)

Manufacturer selection, material selection, and production specifications were the next decisions to be made. The capstone team was directed to consult a company based in Phoenix, ACME rubber, about cost estimates while the client discussed manufacturing and potential opportunities for the latch with their manufacturer in Thailand. The client is aiming for a unit quantity of 2000 per run at or less than $2.00 a unit. The one time mold cost needs to be at an affordable rate. ACME rubber provided good insight on design integrity and cost, but was overall unable to manufacture the mold because of process limitations. The manufacturer in Thailand has provided a quote of $6000 for the mold, but has another offer that is combined with current Canyon Coolers business.

The material that is being considered is an ethylene propylene diene monomer (EPDM) rubber with shore hardness between 40 and 50. The advantages of this material are numerous. One, it is highly weather resistant. It does not dry out when exposed to salt water, it does not photo-degrade in sunlight, and it maintains consistent pliability when either hot or cold. Two, it has a high ultimate tensile strength and overall stress resistance. Three, it has a non-slip surface finish. All of these properties make the rubber ideal for the reliability required for the latch.

3.3 Body Development

The design process of the cooler involved continuous brainstorming, prototyping, and heavy CAD drafting. The first step in the process was to develop ideas and features that satisfied the needs of the client. A multitude of sketches were drawn and three concepts were narrowed down that each incorporated different designs for each component. A pairwise comparison was used at this point in order to determine a scale of the importance of the design criteria in the concepts. This comparison is displayed in Table 2.

Table 2: Pairwise comparison of design criteria

	Cost	Ergonomics	Ice retention	Durability	Latches	Lock slot	Tie downs	Drain Plug	Aesthetics	Dynamic Handle	Total	Normalized Total
Cost	NA	1	0	0	1	1	1	1	1	1	7	**0.155**
Ergonomics	0	NA	0	0	1	1	1	1	1	1	6	**0.133**
Ice retention	1	1	NA	1	1	1	1	1	1	1	9	**0.2**
Durability	0	1	0	NA	1	1	1	1	1	1	7	**0.155**
Latches	0	0	0	0	NA	1	1	0	1	1	4	0.0888
Lock slot	0	0	0	0	0	NA	0	0	1	0	1	0.0222
Tie downs	0	0	0	0	0	1	NA	0	0	0	1	0.0222
Drain Plug	0	1	0	0	0	1	1	NA	1	1	5	0.111
Aesthetics	0	0	0	0	0	1	1	0	NA	0	2	0.0444
Dynamic Handle	0	0	0	0	0	1	1	0	1	NA	3	0.0666

After the scale was created for the features and applied to the concepts and their features a final concept was chosen because of its ranking score on this scale. The concept that was chosen is show in the sketch in Figure 7.

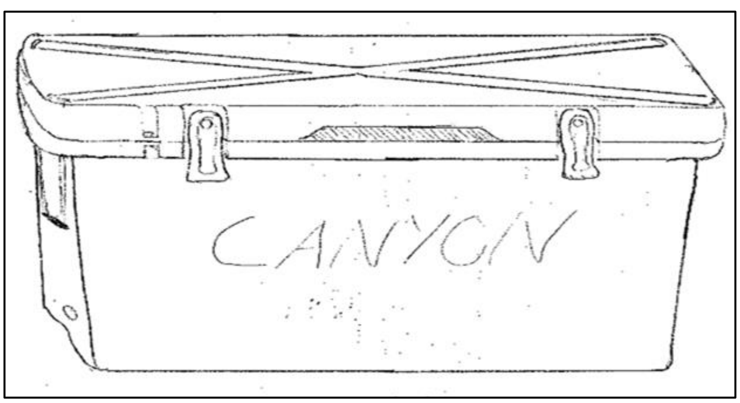

Figure 7: Sketch of selected concept

As for the features on the cooler, designs for the handle, seal between lid and body, latch and drain plug were sketched and can be seen in Figure 8.

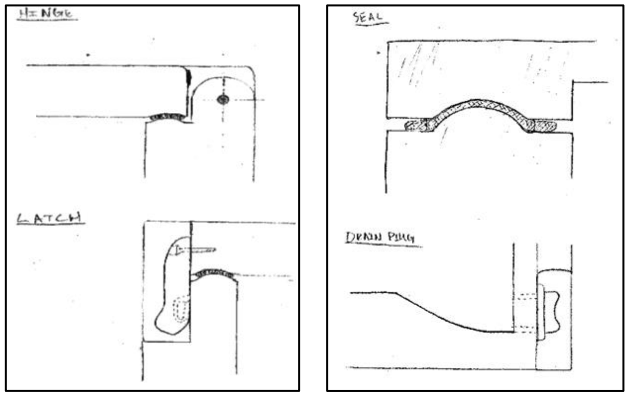

Figure 8: Latch & hinge design (left), seal & drain plug design (right)

The concept of the hinge was that of only one stopping mechanism for the fully open position. The latch concept followed the function of the existing latch under the assumption that heavy remodeling of the latch would occur. The seal concept featured a raised surface on the body that would fit flush with a respective recess on the lid and run around the perimeter of the interface of the lid and body with a foam seal glued to the lid. This design was intended to eliminate the sharp transition that occurs on the existing cooler while maintaining a firm and consistent seal. The concept for the drain plug was a dropped down cut out at the bottom of the inside of the body that led to a pre-manufactured drain plug that is screwed into the body. This original design was to eliminate the threads that are molded on to the existing coolers that experience significant seal and tolerance issues. The handle system remained constant from the existing cooler and was comprised of a length of rope with a plastic handle attached on either side of the cooler. Solid handles are also included in the geometry of the cooler. These concepts stayed consistent throughout the design process.

Of the features for this original design, a few underwent redesign and some features were eliminated after communication with the client and group deliberation. This body concept included an original idea for a tie-down system that did not include slots on the body. This concept underwent heavy redesign and deviated from the original concept. The original concept also featured a lock slot that was eventually eliminated due to tolerancing issues with the manufacturing process, which will be explained later in this section. The hinge design was redesigned to include the two opening positions, which were explained in Section 2.1. A design for the latch was also developed in detail at this time and was explained in Section 2.2.

After the concept of the cooler was determined and chosen, the process of CAD drafting the body and lid of the cooler was initiated. This was the most important step in the design of the cooler and required most of the time allotted and extreme detail. The first step in modeling the cooler in SolidWorks was to determine the dimensions required to house a 40 qt. volume on the inside of the cooler. This was done in conjunction with maintaining minimum dimension on the outside of the cooler to ensure nesting with at least one larger cooler in Canyon Coolers' product line in order to reduce shipping costs. A preliminary rough design with these dimensions was drafted and is pictured in Figure 9.

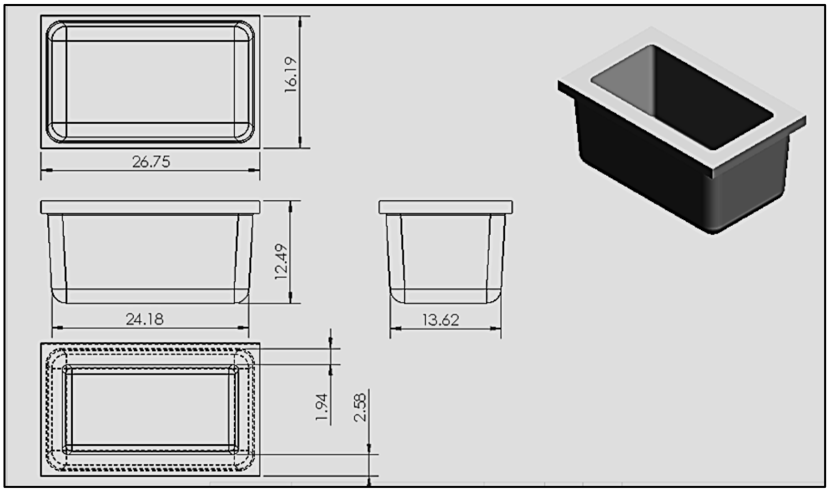

Figure 9: Initial CAD drawing using required dimensions

Once this setup was established, these dimensions were set as global variables in SolidWorks with all other dimensions defined by equations respective to these dimensions. Wall thickness at this point was left as a changeable variable as it was not yet determined what the desired thickness would be until after testing and theoretical calculations were completed. This initiated the designing process of the cooler and this original model experienced thorough modification and development.

Before the design was modified any further, however, a key feature in drafting the cooler was discovered. The CAD drawing was reoriented for the rotational molding, or roto-molding, process. A vital piece of information to consider is that this CAD file is intended to create a mold that houses the molten plastic that creates the cooler. The SolidWorks file is essentially the negative space that is machined into a solid block of billet aluminum. The implications of this process are crucial to the design process of the cooler. The design needed to have a minimum draft angle of 1º and a maximum of 2.5º to ensure that the finished molded product will pull out of the mold without any hang-up. The design also needed to incorporate a parting-line which is interface between the two halves of the mold. The roto-molding process is an extensive science within itself and much research was conducted in order to guarantee that the finished design of the cooler would be absolutely ready for this manufacturing process.

Once the roto-molding constraints were ascertained, modifying the CAD file began. The first feature to be modified on the body was the overall appearance of the cooler. This step included setting up locations for tie-down slots, handle spacing, and upper-lip width for seal and hinge placement. This first iteration is pictured in the CAD drawing in Figure 10.

Figure 10: First iteration of cooler body

This step was significant in solidifying the dimensions and locations of the features on the cooler. From this setup, the solid handles, rope holes for the dynamic handles and floor design were determined and applied. This step in the design is shown in Figure 11 which has a view of the full bottom of the body as well as a close up of the solid handle and dynamic handle rope holes and guide channels. The design of the floor has various strategic components one of the main features is the added angled and tapered material placed symmetrically across the base. This design is intended to increase the structural integrity of the base of the cooler; a main location of warping on the existing coolers which possess a flat base. Another key aspect of this layout is the reduction of floor contact points and area. After testing it was determined that the base of the cooler is a primary location of heat loss as the existing coolers have a large cross sectional area of contact with the ground. This design reduces the surface area that touches the ground, thus reducing the heat transfer. The last crucial trait of this layout is that the raised portions near the position of the inserted rubber feet are intended to allow for easy repositioning by one person. These raised surfaces allow for the cooler to be lifted on one side by one user and slid to a desired location. The sliding surface is transferred to the outer, more durable plastic edge instead of the soft rubber feet.

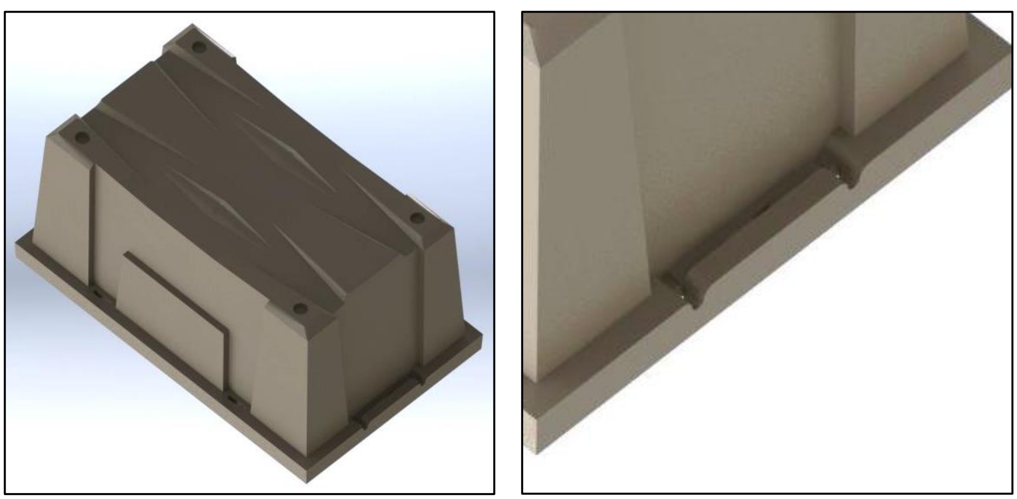

Figure 11: Initial Floor Design (left), Integrated Handle & Dynamic Handle Holes & Guides (right)

After these designs were approved, the spacing of the hinge ears, size and location of the critter-proofing, and the gasket seal were all placed onto the CAD file. This step in the process was crucial as most of the existing features that came within close tolerance of the gasket and critter proofing helped to remodel the dimensions of these features. The tie-down slots and rope holes were resized at this point. A depiction of this layout and a close-up of the hinge ear stopping features are shown below in Figure 12.

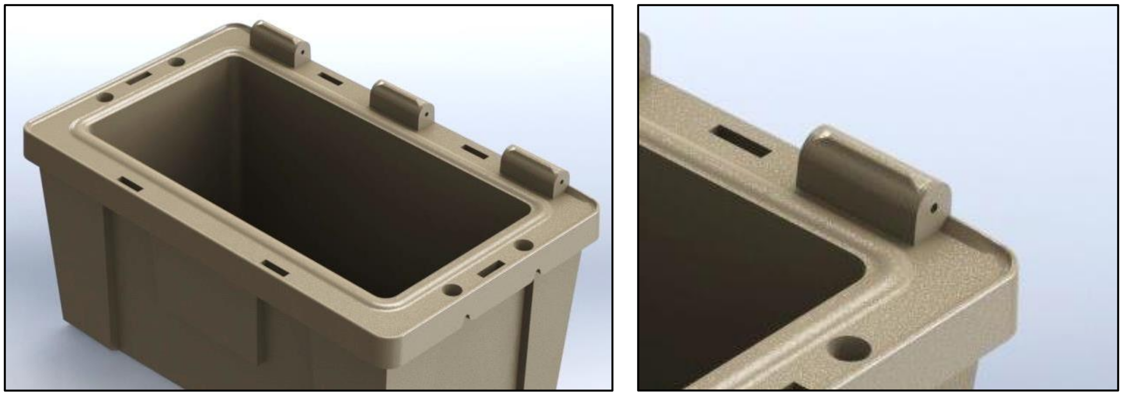

Figure 12: Critter-proofing, gasket seal, & ear placement (left), close up of components (right)

The placement of these features initiated the development of the lid and its meshing with the body. The dimensions for the lid were determined directly from the layout of the body features, hinge design, and desired wall thickness. The cooler lid was also drafted with the roto-molding specifications as guidelines. The lid of the cooler acted as a key component to the overall design of the cooler. Once the lid was drafted and met the dimensions of the body, tolerancing was completed for the interface between the two parts. The tie-slot locations, ear spacing, gasket dimensions were finalized at this point. The lid CAD file shown in Figure 13 in its initial stage.

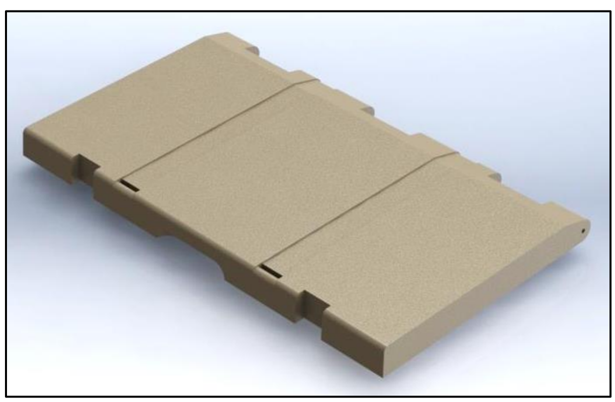

Figure 13: Cooler lid during initial drafting

Guide channels for tie-downs were implemented during this process as well as cut-outs for the two latches and solid handles for opening. Cut-outs for the latches were also placed on the body at this time, remaining consistent to dimensions and tolerance between the lid and body. An anti-warping section was added to the underside of the lid. This portion also assists in increasing the wall thickness in the lid, thus reducing prospective heat transfer out of the lid. Figure 14 contains a view of this layout.

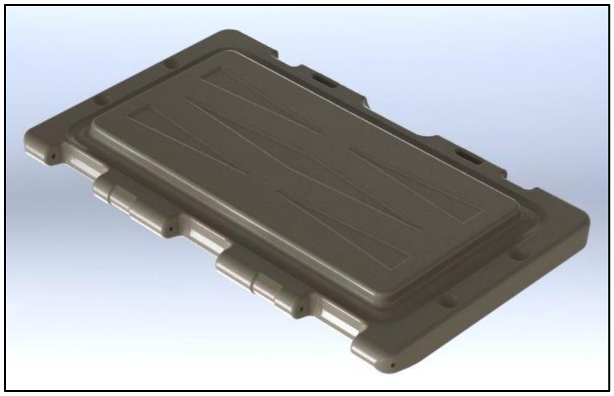

Figure 14: Underside of lid depicting anti-warping geometry

Finishing touches were enacted on the lid including heavy filleting, tolerancing fixes, and the inclusion of a cup-holder. The final product of the lid can be seen in Figure 15 which contains two views of the lid. The details of the selection of these design features are explained in further detail in Section 5.

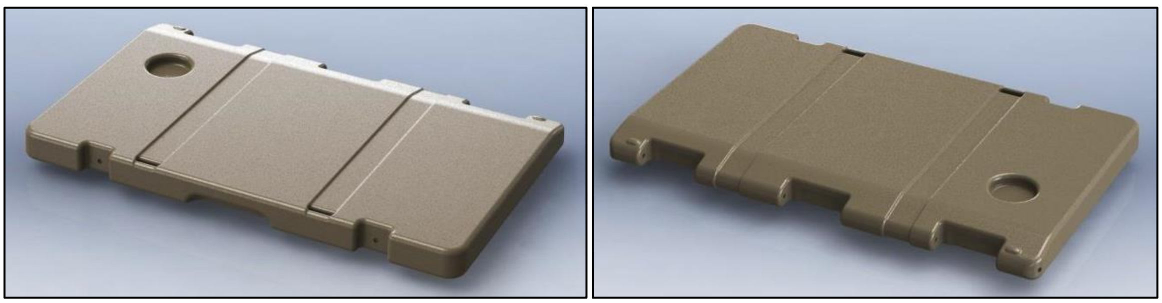

Figure 15: Front view (left) & rear view (right), of finished lid

After the completion of the lid, the final stages of the CAD drafting of the body were completed. Adjustments were made to ensure a proper fit between the two components was achieved and filleting of all severe changes in geometry on the base was executed. These fillets are to enable the plastic to flow into all surfaces of the cooler mold evenly and uniformly. Figure 16 shows the final design of the cooler body after all features were incorporated and finalized. All of the main features of the design on both the lid and body are explained in further detail in Section 5. An assembly of the two components, including the latches, is shown in Section 5.1, in Figure 21.

Figure 16: Finished cooler body CAD design

4. Testing

4.1 Experimental Setup

An experiment was conducted on Canyon Cooler's existing 40-quart cooler. The experiment's purpose was to gain valuable insight on the aspects of heat transfer into the cooler. The real data that this experiment provided helped with the theoretical testing on the new cooler design as well as fixing precise boundary conditions for heat transfer calculations.

Temperature testing was conducted on the existing 40-quart model. Eight T-type thermocouples, configured through an NI 9213 data acquisition center (DAQ), were affixed in strategic positions on the inside and outside of the cooler hull as seen in Figure 17. The DAQ was started as 24 pounds of ice were placed inside the cooler. Temperature readings were taken every 10 seconds until after all of the ice had reached a liquid state. A picture of the experimental setup can be observed in Figure 17. The experiment was conducted in the thermo-fluids lab at the Northern Arizona's College of Engineering building.

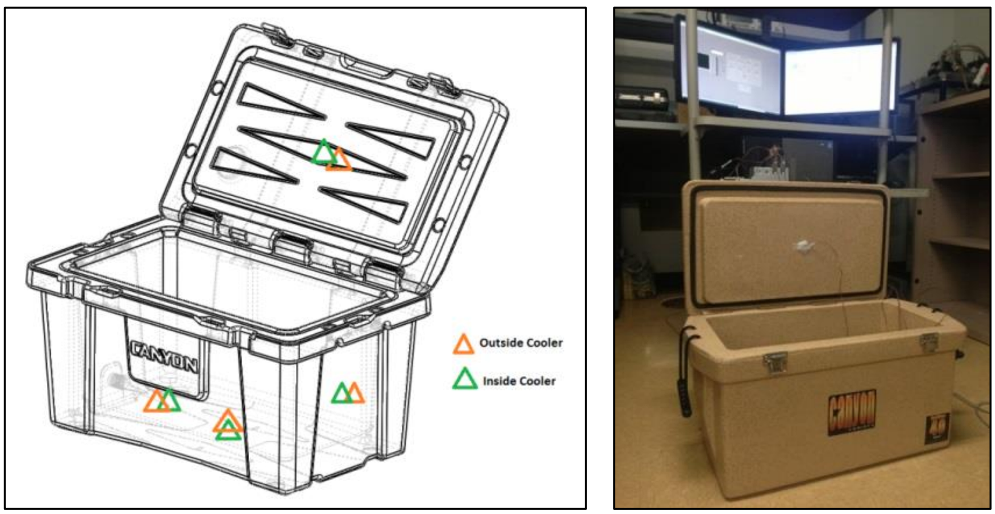

Figure 17: Thermocouple placement diagram (left), and experimental setup (right)

4.2 Results

The results of the thermocouple testing are depicted in Figure 18. Initially, all thermocouples started at the ambient air temperature until ice was added. At this point the readings from the sensors recorded a sharp decrease in temperatures. A steady state was reached after about six hours, at which point, all of the temperatures stabilize without changing for approximately 3 days. This behavior continued until all of the ice had melted, occurring around the fourth day of temperature readings. The temperatures inside of the cooler show a significant increase around the fourth day of testing, signaling the melting of the ice.

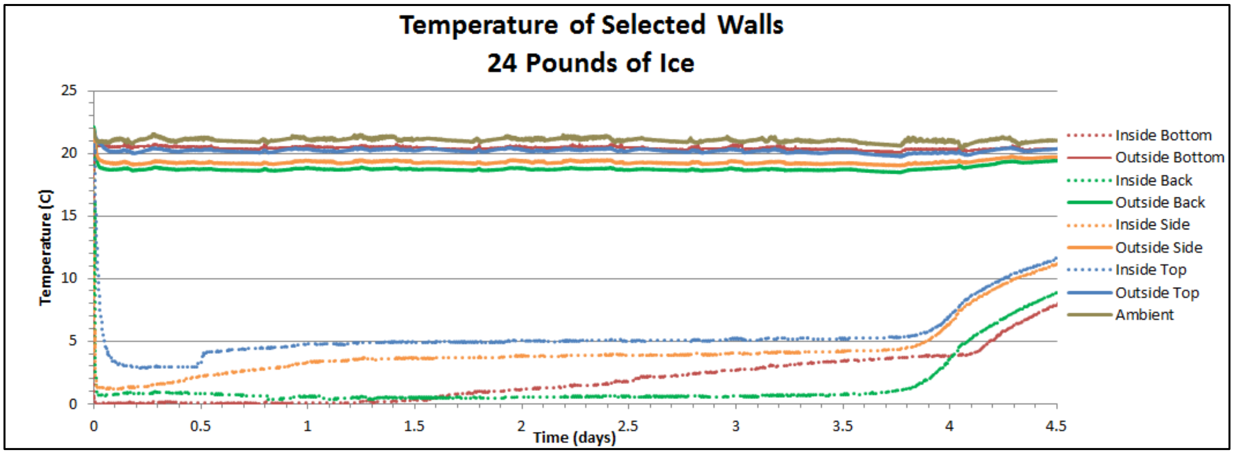

Figure 18: Temperatures of selected walls over 4.5 days

4.3 Testing Conclusions

The temperature testing of the cooler allowed for an in depth analysis of the heat transfer. The data collected allowed for calculations pertaining to the amount of heat flux the cooler experiences and a projection of the performance of the new cooler.

Preliminary analysis of the cooler was a 1-D heat transfer model. Assumptions for this model include, the heat flux through the corners of the cooler are negligable due to aspect ratio of the cooler wall panels, the entire cooler is isothermal, and discontinuities in the cooler walls are neglagible. The 1-D model carries a lot of assumptions and simplifications but does give a good indication of the amout of heat transfer going through the walls. Pictured in Figure 19 is a visual of the 1-D model developed.

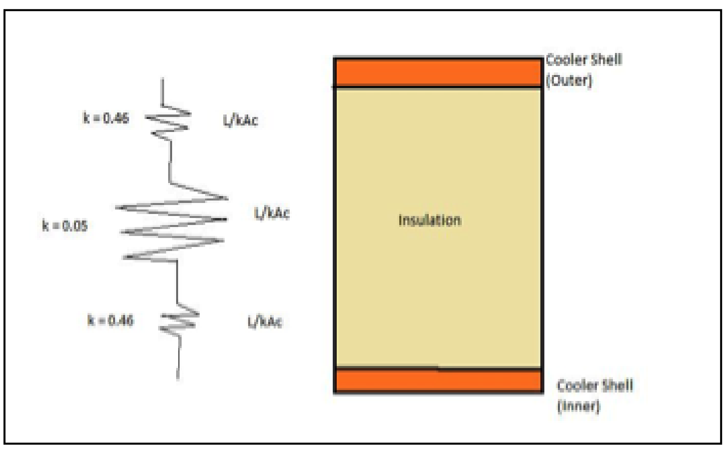

Figure 19: Diagram and thermal circuit for cooler wall

Heat transfer values were then calculated by using the temperature profiles collected in testing. It was determined that the new design would offer an approximate 29% gain in heat transfer performance. This enhancement is directly proportional to the increased wall thickness on the new design. The graph in Figure 20 shows the difference in heat transfer values between the current and new cooler designs as they were calculated from the time dependent temperature test.

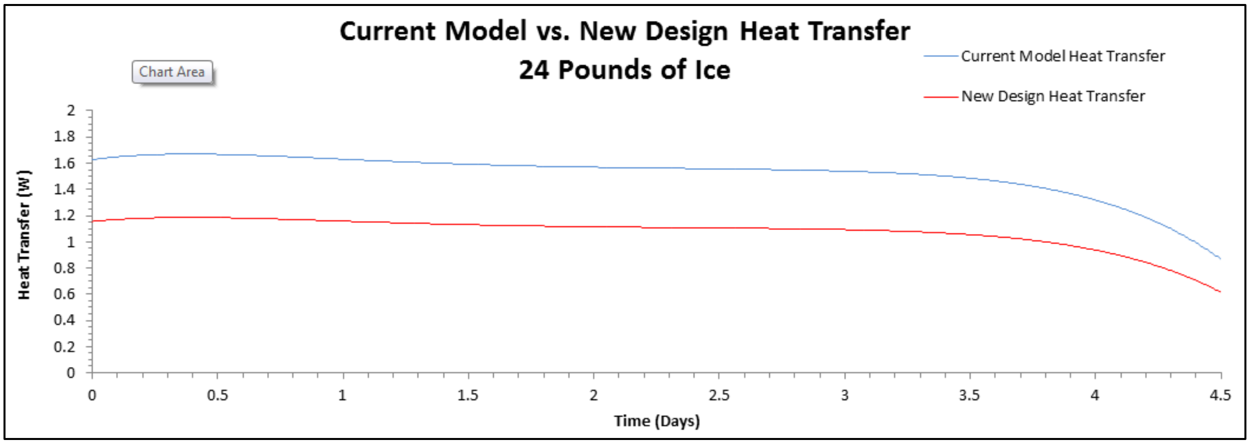

Figure 20: Current model heat transfer versus new design heat transfer

5. FINAL DESIGN AND DISCUSSION

5.1 DESIGN OVERVIEW

A detailed CAD rendering of the final design is shown in Figure 21.

Figure 21: Entire cooler assembly shown in the latched position

All major components of the cooler assembly were designed in SolidWorks software. The assembly consists of four part files: the lid, body and two identical rubber latches. The body and lid of the cooler were designed for rotational molding, whereas the latch was designed for injection molding. The CAD files were designed as blue prints for mold manufacturing. Each double wall mold functions as the hollow container that dictates geometry for the finished product. Outlined objectives, manufacturability, and aesthetic finish were all carefully considered in each component of the final design. All standard components of the cooler will be acquired from existing manufacturers. The list of materials is shown in Table 3 below. This chart also outlines the cost analysis which is explained in further detail in Section 6. Each material has a specified quantity and accompanying information as to the use and/or location of the part.

Table 3: All necessary materials required to produce one unit

Material	Unit Cost ($)	Quantity	Total Cost ($)	Notes
Plastic handle	0.98	2	1.96	Dynamic handle component
¼ in. diameter nylon rope	0.13 per ft.	4 ft.	0.52	Dynamic handle component
Drain plug	1.45	1	1.45	
3/16 in. Trifold aluminum rivet	0.14	2	0.28	Latch component
Nylon shoulder washers	0.02	2	0.04	Latch component (WS-0402-0201-0354)
Insulating PVC gasket	4.77 for 35 ft.	6 ft.	0.82	¼ in. x ¾ in. (PVC-PSA-1)
Plastic latch knob	0.25	2	0.5	Latch component
Flat head screws	0.09	2	0.18	Latch component
Rubber foot	0.85	4	3.38	
¼ in. Diameter steel hinge pin	3.45	26 in.	3.45	
HDPE plastic	TBA	17.9 lbs.	TBA	Cooler hull, lid & body
Polyurethane foam	TBA	2.26 lbs.	TBA	Insulation, lid & body
EPDM rubber	TBA	0.07 lbs.	TBA	Latch
	Component Cost		**12.58**	
	Target Cost		**66.70**	
	Manufacturing Budget		**54.12**	

5.2 Design Features

The cooler assembly contains numerous features, well integrated into the cooler hull, that combine to aid usability to the consumer as well as to offer increased functionality. Figure 22 depicts a few key design features.

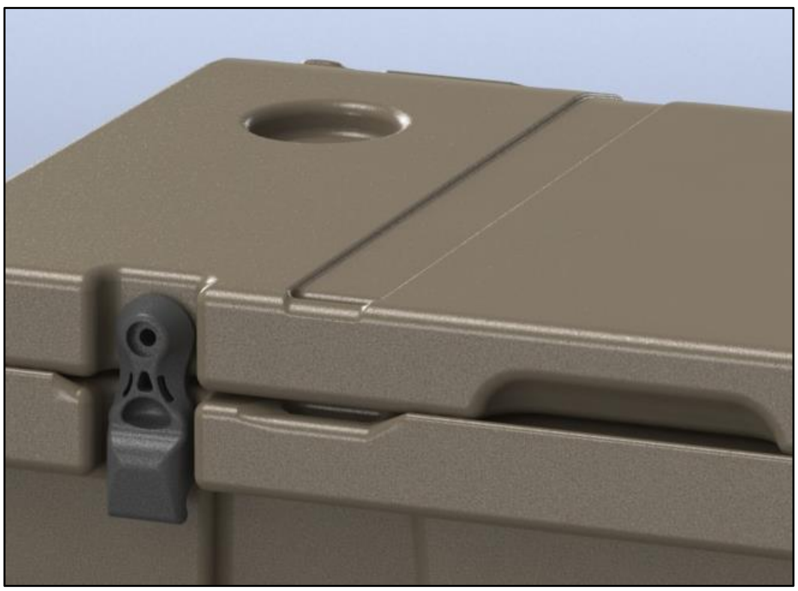

Figure 22: Recessed latch, top slot channels, front handle, and cup holder

All the assets of the cooler have been neatly recessed inward to help mitigate damage to components as well as help maintain the tightest possible dimensions in height, length, and width. The slot channel on top was designed to allow at least two thicknesses of webbing to fit flush with the cooler lid. The webbing is used to fix the cooler in place, objects to the cooler, or increase pressure on the gasket for improved performance. The handle placed in the front aids access to the cooler interior. A single cup holder, sized for standard 12 oz. bottles and cans, was introduced to the cooler lid. The cooler was designed to accommodate two open lid positions, flat against a wall and fully open. The first configuration is shown in Figure 23.

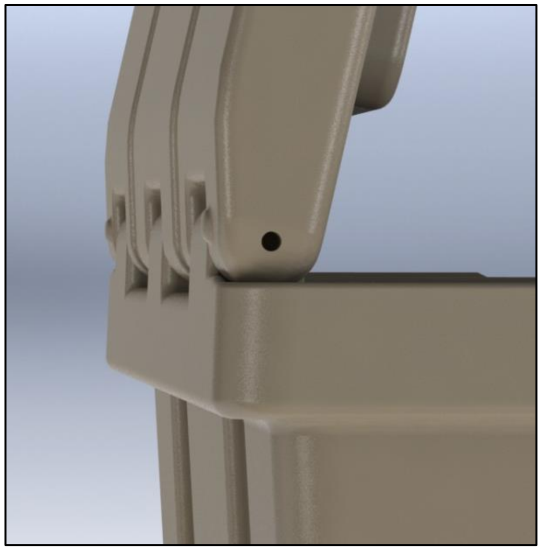

Figure 23: Secondary opening position

A unique notch on the body ears coupled with a female recess in the lid ears creates a rigid stop in the shown position accommodating use flat against a surface. The design utilizes the flexible yet sturdy properties of HDPE plastic to create sufficient friction to hold the lid in place while minimizing wear. The primary open position is depicted below in Figure 24.

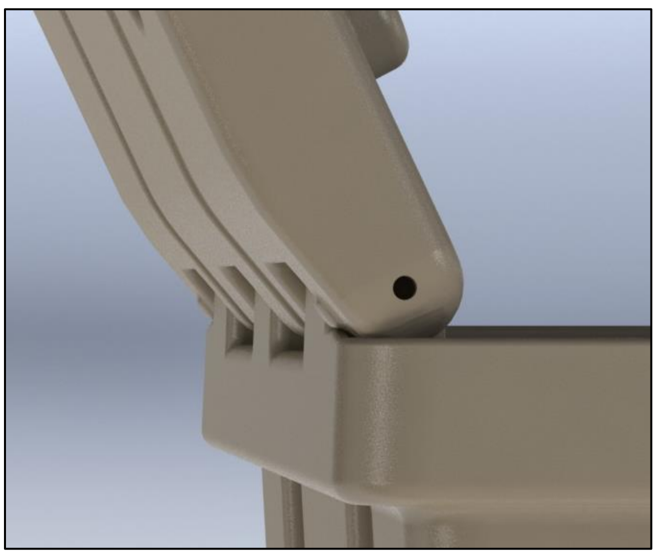

Figure 24: Primary opening position

This shows the cooler lid in the fully open position. This configuration allows complete access of the cooler contents while keeping the lid supported at an appreciable angle. The knob on the outside ears makes contact with the critter proofing which is seamlessly integrated into the outside body hinge ears. The hinge has been designed to utilize a single hinge pin. This encloses the pin inside the cooler hull minimizing its exposure to the elements. Another advantage of the single pin is the rigidity it adds to the system. This is key in reducing problematic lid warping which can occur from thermal expansion and contraction over time or from improper cooling in the manufacturing stage. An additional redundancy is in place in the ear spacing decreasing the chance of lid warp.

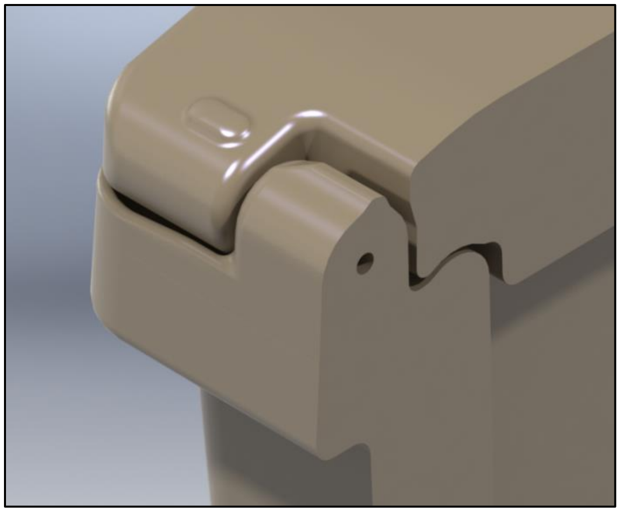

Figure 25: Hinge section view

The section view in Figure 25 gives critical insights on opening positions, fillet radii, hinge geometry, gasket mesh, and lid to body tolerance. This view is when the cooler is in the latched position. Large fillet radii were imposed on every curve of the design. This is one of the main constraints of rotational molding. It increases quality and consistency of the curves by aiding the flow of molten plastic through the mold.

The cooler has been designed for installation of the foam gasket to the lid. The tolerance between lid and body when closed is 0.1 in. A gasket with a thickness of 0.25 in. was chosen imposing a compression of 0.15 in. around the perimeter of the cooler. This compression distance leaves a water and air tight seal on the system. The dome geometry of the gasket should assist in contact between body and foam gasket. The overall tolerance between body and lid accommodates the natural shrinkage of the HDPE plastic as it cools.

Figure 26: Upside down cooler assembly

Figure 26 above depicts the floor design implemented on the cooler body. The simple design serves multiple advanced functions. The four holes in the corner are used for pressure injection of the polyurethane foam as well as inserts for the four rubber feet. The rubber feet give the cooler enhanced stability when needed but allow for easy slide maneuvering when desired. The slide plates initiate the slide when the cooler is tilted at the small angle of 2.2 degrees. The slide plates also serve to protect the rubber feet from impacts that can create stress in the plastic allowing water to penetrate the hull of the cooler. Since long flat sections of HDPE are prone to warp, the floor slide plates have been positioned to prevent this problematic phenomenon. The raised position of the floor also reduces heat transfer out the vulnerable bottom (coldest part of system) by adding insulation and utilizing the thermal properties of air.

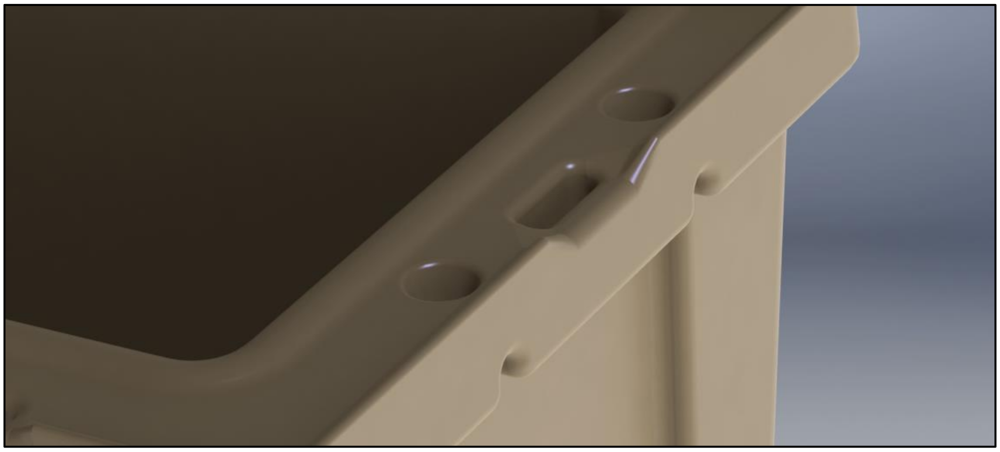

Figure 27: Top view of body lip features

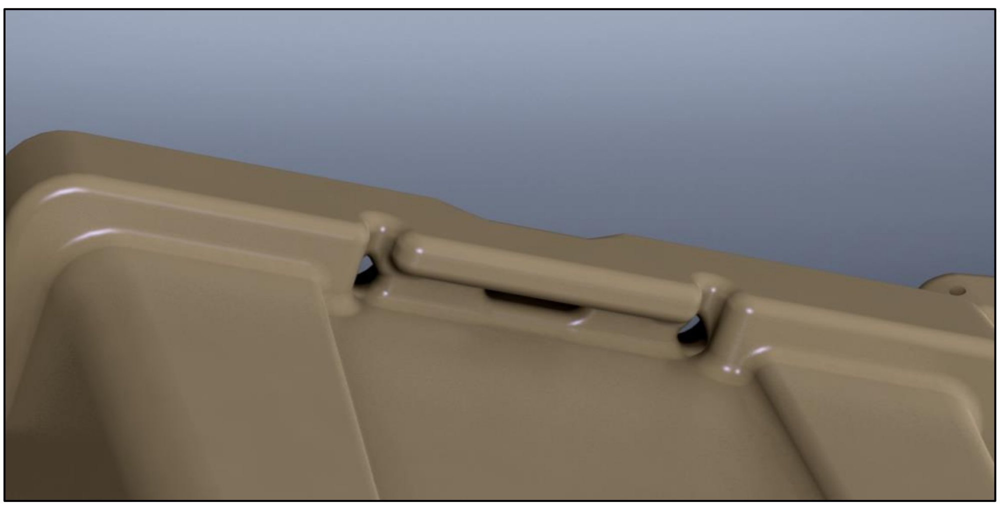

Figure 28: Bottom body lip features

Figure 27 shows the top view of the side and Figure 28 depicts the bottom view of the same edge. There are many features depicted in these images such as the critter proofing, tie down slot, fixed handle, and dynamic handle.

This cooler features a raised lip encircling the perimeter of the cooler designed to reduce the chance of infiltration from various notorious animals. The raised lip gently transitions into the cooler body at important locations such as tie slots and latch recesses.

The cooler features six tie down slots, one on each short side and two in the front and rear. These slots allow multiple fixture configurations for the user. One such configuration allows the cooler to be fixed to a surface while maintaining full functionality of the device. These slots can create problems at the manufacturing stage for a multitude of reasons and because of this concern, the slots were contoured to minimize the chance of quality issues.

Figures 27 and 28 give a great view of the handle systems, fixed and dynamic. This gives the end user a few options for transporting the cooler. The dynamic handle consists of section of nylon rope knotted at each end and strung through a plastic grip. The rope knots recess into the holes positioned to each side of the tie slot and the handle drapes down the side of the cooler recessed into the wall. The two channels positioned adjacent to the knot holes provide the rope a guide aiding stability while simultaneously reducing the amount of rope material needed. The density of features in this location provided a design challenge. However, careful examination of rotational molding specifications allowed each feature to compliment the other in a smooth manner.

6. CONCLUSIONS

The challenge presented was to overhaul the existing 40 quart model that is currently offered by Canyon Coolers. Evaluating project constraints was an excellent method for gauging project success. There are five categories the constraints are divided into. As stated in the constraint section of the report. Some constraints could be verified as complete using computation or CAD model analysis, while others could not due to the lack of the physical product. The cost analysis (Table 3) retuned a remaining budget for manufacturing of $54.12 to hit the target MSRP of $200.

Further product development will shed light on this constraint. All geometry constraints have been met aside from efficient stacking. The cooler nests into two existing models, it fits standard items, and has an internal volume of 40 quarts. Since the length of the cooler is not twice the distance of the width it does not meet the criteria for stacking efficiency.

The weight of raw materials came to 20.26 lbs. This did not include the added weight of components, or the true weight of the manufactured product. Therefore the success of this constraint was undetermined. Multiple weight assist features were introduced to the cooler such as a dynamic handle that features increased support, a fixed handle, and slide mechanism on the floor.

Durability constraints were also accurately addressed. The design has multiple rigidity components designed to stiffen areas that traditionally exhibit warping. The profiles of each cooler wall and latch body are smooth and free of unwanted protrusions. When drafting the cooler, overall mold quality was kept at highest concern. This resulted in smooth geometry transitions, appreciable draft angles, and minimized restriction to the flow of molten material. This, in theory, should produce a consistent mold that maintains equal wall thickness preventing weak points vulnerable to penetration.

The last group of constraints focused on the function of the design. Thicker walls and an improved latch and gasket design were designed to improve ice retention. Figure 20, heat transfer comparisons, verify the increased performance of the new design. Multiple features were implemented on the cooler body intended to provide users with enhanced functionality.

These constraints were accomplished through comprehensive testing, simulating, and designing. The end result was a fully equipped proposal for a new 40 qt. model that is completely ready for production. All existing components of the cooler were redesigned and enhanced as per client requests. New features were implemented into the design in an attempt to surpass the quality of the current model and launch Canyon Coolers into a more reputable and competitive position in the premium ice chest market.

7. References

"BATTALION T Handle Latch, Black, H 5 1/8 In." *Grainger*. N.p., n.d. Web. 6 Dec. 2012. <http://www.grainger.com/Grainger/BATTALION-T-Handle-Latch-1XPA8>.

"Buy Engel Coolers." *Engel Coolers*. N.p., n.d. Web. 6 Dec. 2012. <http://www.buyengelcoolers.com/>.

Castello, Jason. "The Last Cooler You Ever Need to Buy." *Canyon Coolers*. N.p., n.d. Web. 6 Dec. 2012. <http://canyoncoolers.com/index.php?main_page=index>.
"EL-USB-2." *Lascar Electronics*. N.p., n.d. Web. 6 Dec. 2012.

<http://www.lascarelectronics.com/temperaturedatalogger.php?datalogger=102>.
Figliola, R. Beasley, D. Theory and Design for Mechanical Measurment, 5th edition. November 2010.

Incorpera, F. DeWitt, D. Bergman, T. Lavine, A. Fundamentals of Heat and Mass Transfer, 7th edition. April 2011.

"MatWeb, Your Source for Materials Information." *MatWeb*. N.p., n.d. Web. 6 Dec. 2012. <http://www.matweb.com/>.

Mraz, Stephen J. "Putting The Right Spin On Rotational-Molding Designs." *Machine Design*. Fawcett Design Inc., 18 May 2000. Web. 6 Dec. 2012.

"SolidWorks Design." *SolidWorks Corp.* Dassault Systèmes, n.d. Web. 6 Dec. 2012. <http://www.solidworks.com/>.

"Welcome to Mityvac® Automotive & Vacuum-Related Tools & Equipment." *Mityvac*. N.p., n.d. Web. 06 Dec. 2012.

"Welcome to T-H Marine." *T-H Marine*. N.p., n.d. Web. 6 Dec. 2012. <http://www.thmarine.com/>

Foamtapes, . N.p.. Web. 23 Apr 2013. <http://www.foamtapes.net/Default.aspx?tabid=84&List=0&txtSearch=*&CategoryID=27&Level=1&SortField=Free3,Free1>.

Dr. Brent Nelson. "" Conversation about numerical simulations"." 20 2 2013. Speech.

Willie, Dr. David. "" Advice about numerical heat transfer simulation in 1-D." 3 2013. Speech.

8. APPENDIX

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