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Introduction:

The modern-day automobile is much more complex and sophisticated than it was when Henry Ford released the first model T in 1908. Vehicles are now not just a mode of transportation, but a vessel that can take people on incredible adventures to places many do not dare to go. In these incredible remote locations, five-star hotels are replaced by miles of lush forest, crystal blue lakes, and magnificent mountains. While standard camping might seem like the logical choice in these environments, it requires sleeping on the hard ground exposed to the elements and wildlife. However, there is another option that improves the luxury and security of sleeping under the stars.

A roof mounted tent is a device that is installed onto the roof rack of any standard SUV or vehicle. The tent is folded into a cloth covering, or hard top case, when traveling to incredible trip locations. The tent easily pops up when the adventure for the day is over. The main advantage of a roof mounted tent is that the tent is up off the hard ground. The elevation also keeps unwanted wildlife out of the tent at night. Most roof top tents fit a range of different vehicles and come in many different configurations to accommodate up to four people. The boxes themselves can be soft or hard shell. The hard-shell covers are made using fiberglass, ABS polymer, and a combination of fiberglass and ABS (1). The hard-shell covers allow the tent to be aerodynamic when traveling. Most models include an assisted opening mechanism to make opening and closing the tent easier when doing so while on the ground. The assisted opening also helps to keep the tent in the open position when in use. The size of the hard-shell tent cover depends on the vehicle type and the size of the tent. Figure 1 shows what a common hard-shell tent looks like when folded. Figure 2 and Figure 3 demonstrate what a typical hard-shell tent might look like.

The new design will focus on the hard-shell tents. The proposed idea for the new roof-top tent involves extrusion blow molding (EBM) an upper and lower hard-shell case. The case will be double walled for strength. Additionally, ribs will be molded into the cases for increased rigidity. The slots for the vehicle crossbars will also be incorporated into the design. This eliminates the need to insert these features after the molding process for the upper and lower shell. The shell will house a pop-up tent. The shell will open with hinges on the right side of the case. The upper half will fold 180° outwards to become
additional sleeping space. This design is unique and innovative for this product sector. Figure 4 shows a potential design concept for both the upper and lower shells. Figure 5 shows what the final product might look like. It retains the streamlined design of other models while incorporating new features not seen on products of similar caliber. The feature that will make this product quite unique is the addition of the second sleeping area created. This will be created by the opening of the top of the case. A preliminary drawing of this can be seen in Figure 6.

![Figure 4](image1)

**Figure 4:** The front, left, right side, and isometric views of the top and bottom half of the tent case.

![Figure 5](image2)

**Figure 5:** A sketch of the fully assembled tent case.

![Figure 6](image3)

**Figure 6:** A sketch of the product in use.

The current roof-top tents are made though compression molding with fiberglass and rotational molding with ABS, although some models utilize a combination of both materials. The fiberglass gives the case its strength and rigidity while the ABS outer layer increases impact resistance and aerodynamics (1). The current manufacturing methods ensure that the product is tough but also that the shape is as aerodynamic as possible. With the tent occupying up to a foot and a half of space above the car, a non-aerodynamic shape would produce lots of wind noise and reduce the gas mileage of the car. Rotational molding allows for a seamless design that can be very aerodynamic.
Application to the Process of Blow Molding:

Extrusion blow molding has many benefits to that of other production methods currently being used. Extrusion blow molding produces parts will reduce weight due to the thin part walls and the fact that the part is hollow. This reduction in weight would make putting the tent on the vehicle easier but would also reduce the strain it puts on the vehicle. The current models of the roof-top tents weigh between 120 and 140 pounds. Reducing the overall product weight would reduce the weight pushing down on the car and improve gas mileage as it will take less energy to power the car (5).

Extrusion blow molding would also reduce the manufacturing cost of the product because this manufacturing process uses less expensive molds than injection molding. Fiberglass uses expensive materials and molds to produce parts. Extrusion blow molding uses cheaper materials, thus saving on manufacturing costs. Additionally, there is no secondary operations required to remove flash on the parts since extrusion blow molding does not produce any flash. The reduced manufacturing cost directly translates to a lower product cost. The current models of this product cost between $900 to $5,500 dollars depending on the materials used, model type, and manufacturing process (4). A lighter and cheaper tent would appeal to the adventurer on a budget as well to the consumers that want to travel lighter.

Time of production is another factor when considering using extrusion blow molding in place of other manufacturing processes. The fiberglass process is very time consuming. Curing of the resin can take up to 24 hours depending on the materials used and size of the part being produced. Unlike the fiberglass process, extrusion blow molding only takes up to a minute to produce parts. With this process, more parts can be produced in a given amount of time. Additionally, the time it takes to finish a tent is greatly minimized. This reduces storage costs, material handling, and assembly time of the product while in the manufacturing plant. All of these attributes can reduce manufacturing costs and ultimately reduce the price of the final product.

This product cannot be produced through thermoforming because thermoforming cannot achieve the wall thickness that this product needs to remain structurally sound. Thermoforming only produces a single wall with thicknesses up to ½ inch. Producing walls this thin would not be rugged enough for the wind resistance needed when the vehicle is driving along the highway. The thin wall thickness would not be able to hold the weight of the campers inside, potentially resulting in a failure.

Injection molding is another process that would not be practical for this part. The thickness of the part needed would be over an inch thick. The molding cycle would be very long due to the amount of material needed to enter the part and the amount of time needed to cool it. Producing this part with injection molding would significantly increase part cost due to the increased amount of material used and the added press time needed to mold the part.

The first rooftop tent was invented in the 1930s (6). It was designed to fit on compact cars and was only a foot tall. The base of the tent and the ladder served as the support for the tent and the two campers that could fit in it.

In 1958 Italy started manufacturing rooftop tents (7). Two designed emerged during this time: the Maggiolina and the Air Camping. The Maggiolina was a shell model while the Air Camping was a folding fabric model. Originally the rooftop tents were made as an inexpensive alternative when travelling but over time they became an essential component of everyone’s adventures. These two designs are still prominent in the industry and are being made by companies around the world.
The roof-top camper is a rugged piece of equipment that is supposed to keep up with even the most daring adventurer. Common environments that the camper would be exposed to include extreme high and low temperatures, places with UV radiation, rain, hail, snow, dust, and areas with falling debris such as rocks and trees. The camper needs to be rugged enough to not be damaged during these conditions. The material needs to be we weather proof to ensure that the occupants inside the tent are protected from the elements.

**Design Details:**

Upon researching current roof-top tents on the market, the average tent can hold up to four people; or between 800 to 900 pounds (8). The design for the extrusion blow molded camper shell allows for both the top and bottom shells to be used as viable living space. Due to the large surface area, this tent will be designed to hold up to four people with a maximum weight capacity of 900 pounds. We will begin testing with ANSYS using a distributed load of 1,200 pounds. If the ANSYS analysis passes at 1,200 pounds, we can rate the tent for 900 pounds, giving the tent a factor of safety of 1.5. We want to start our loading relatively high to see where the design might need to be changed to achieve the specification of 900 pounds. We will continue to re-design the part until it can handle the weight limit specified. A distributed load will be used in the analysis to simulate the distribution of weight of the user laying down inside of the tent. Each half will be analyzed separately since they will be supported using two different mechanisms. The bottom half will be entirely supported on the roof racks of the car while the top half will be supported by sliding rails from the bottom half and by extendable legs touching the ground. These extendable legs will be stored in the top part of the top shell.

Additionally, the cost of the product will be specified to be under $800 dollars. This price is on the lower end of the price spectrum for similar products currently on the market. Developing a product with the weight requirements, spacious living area, and lower cost will make this roof-top tent a competitive product within the roof-top tent market.

The maximum deflection that will be allowed is calculated following the standards for maximum deflection of floors. The allowable deflection for floors is calculated using the equation L/360 = allowable deflection where L represents the span between floor joists. We can relate this to the roof top tent by having L represent the length between the roof and the supports that hold up the other end of the top half (9).

ANSYS analysis will be conducted.

a. The model holds the required weight of 800 to 900 pounds with a factor of safety of 1.5
b. The model deflects less than L/360 inches
c. The product meets the price specification of $800 dollars or less

If the ANSYS model meets these requirements, then the roof-top tent will be deemed passable and successful.

**Material Selection:**

After looking at the most common extrusion blow molding materials (10), a material matrix was put together as shown in Figure 7. 10 different factors were examined including:

1. Cost
2. Low temperature
3. High heat deflection temperature
4. Flexural modulus
5. Shore D hardness
6. Tg
7. Notched Izod
8. Density
9. Flammability rating
10. Water absorbency

A weight was assigned to each of these factors which can be seen in Figure 6 below. A higher weight was assigned to the factors that were deemed more important to the product and a lower weight was assigned to the less impactful factors.

![Figure 6: The factors for the material matrix and their weights.](image-url)
After looking that the weighted score for each of the materials, it was narrowed down to HDPE, PET, and PPO. The weighted score for these three materials can be seen in Figure 8 below. PPO scored the highest because of its excellent hardness, flexural modulus, high heat deflection temperature, and water absorbency properties. Although, PPO has exceptional properties in most categories, the price per pound is too high to justify selecting this material over HDPE or PET.

PET had the second highest score because of its outstanding flexural modulus and notched izod scores. The price per pound is much lower than PPO; which will help keep the cost down. PET has the highest density out of any of the materials which will produce a higher weight product, but that will not affect the specifications too much so it would be a good choice still.

HDPE also had a high weighted score because of its low cost, high notched izod, good water absorbency, and low temp properties. HDPE has the lowest cost out of all of the materials, which is a key factor because the overall cost needs to be below $800. The flexural modulus and hardness are not very high, which could cause this material to fail during the ANSYS analysis when the 1,200-pound load is applied. If HDPE can pass the ANSYS analysis, then it would be the best choice because of its extremely low cost but it could still be a risk to select this material.
Figure 8: The material matrix for the three best materials.

The best material for this application is HDPE. The specific type of HDPE that will be used is SABIC’S B4660AB medium molecular weight HDPE homopolymer for blow molding applications (11). This material has a high modulus of over 1000 MPa, flexural modulus of 1100 MPa, and an Izod of 150 J/m. Additionally, the brittle temperature is –75°C and the Vicat softening temperature is 127°C. These temperatures are well outside of the temperatures our part will be seeing under typical usage. This grade of HDPE should work well for the application of a roof-top tent shell. HDPE is currently used for pallets that support loads similar to what the tent will see. This helps prove that HDPE will be the right material for this application.

**Manufacturing Details:**

Extrusion blow molding parts can be produced by many different molding techniques. A few of the common techniques are Continuous, Intermittent, and 3-D. Continuous extrusion blow molding is the most common type. The extruder constantly extrudes material, even when the mold is over at the blowing station. This method requires that the material has a high melt strength so that is can support the weight of the increasing parison until the mold moves back into the filing area. This type of molding is ideal for thin walled, short parts, that do not require a lot of cooling time. The roof-top tent shells would not be a good product design for this blow molding method because of the large length of the shells. The cooling time will be lengthy to properly cool the part. This would make the parison hang and wait for the mold to return to the fill area. This would produce lots of variation in the wall thickness with multiple thin spots.

Intermittent extrusion blow molding is where the melt is contained in the barrel until it is pushed out in one shot (12). This method is ideal because the parison is not stretching while the other part is cooling. Additionally, fast cycles can be achieved since the melt is waiting in the barrel ready to drop down into the mold. More uniform wall thickness can be achieved with this method than the continuous method. This process is the best for the roof-top tent shells.

3-D extrusion blow molding is where the parison is laid down inside of a 3-D channel. This 3-D channel is the shape of the part. Parts made with this method have minimal flash. However, a disadvantage is the premature freezing off of the parison surface due to the long-time half of the parison is in contact with the mold surface (13).
The type of machine needed to make this product is an accumulator head extrusion blow molding machine for PET material (14). Accumulator heads are used when long, heavy parts need to be made. The accumulator head will collect the material in the barrel until the mold is ready. The head will then drop the parison into the mold. This prevents parison sag. The exact type of head that will be used is a first-in/first-out tubular ram-melt accumulator (15).

The machine we will be using to make this product is a 67lb Milacron Accumulator Blow Molder, Model T2900-150G-S60 (16). It has an accumulator head limit of 67 pounds. Each half of the shell is expected to weigh 30 pounds, so this gives plenty of room for the melt. The limiting factor when finding a machine was the size of the shells. Each shell is six feet long and four feet wide. This machine had a platen size of nine feet by six feet. This is plenty of space for the molds to fit in. The max daylight of 90 inches will be plenty of space to take the large parts out of the mold. All of the product features can be found in Figure 9 below.

![PRODUCT FEATURES](image)

Figure 9: Product features for the blow molding machine that will be used.

Using this machine to make the upper and lower shells is ideal for this application. The accumulating head will prevent parison sag and help in keeping uniform wall thickness. The intermittent molding process will accommodate for long cycle times and prevent the parison from stretching. The large accumulator head will be adequate for the size requirements of the product. The machine’s platens are large enough to house both the upper and lower shell molds.
A disadvantage of using this machine is the large minimum shut height of 30 inches. One shell is seven inches in depth. With the mold plates, the overall width will be just under 30 inches. Mold spacers should be able to fill the rest of the minimum shut height area. Other than the minimum shut height, this machine will be perfect for making these parts.

Preliminary calcs:

The roof top tent will experience loads up to 900 pounds per half. The lower half will experience a double cantilever deflection due to the weight since the bottom shell is fixed to the top of the car. The upper half will be connected to the lower by rails. These rails make the upper experience a single cantilever deflection. The deflection is expected to be higher in the top shell due to it only being a single cantilever connection. The bottom shell is expected to only deflect 0.0668 inches as it is fixed to the top of the car. This is an unacceptable number. Vertical supports will be considered to help support the top side of the tent when it is extended past the support of the car.

The wall thickness of the part was calculated to be 0.033 inches. This is an acceptable way for a part like this. Ribbing combined with the use of a double wall and kiss offs will increase the strength of the shell. The preliminary hand calculations are shown below, Figure 10.0 and 10.1, and the equations used as included in that as well (17).

Figure 10.0: Preliminary hand calculations for tent shell.
Figure 10.1: Excel spreadsheet that was used to calculate the wall thickness and the deflection for both the top and bottom shell as well as the equations used in the spreadsheet.

**Part Design 1:**

The original design concept for the roof top tent can be seen in Figure 11 below. The original idea was to add ribs going in both directions. That idea was not pursued because the ribs would be uncomfortable to sleep on even with the mattress on top of them, so the ribs are only in one direction now. More ribs were added across the width of the shell because rails will slide under them. These rails will be used to connect the tent shell to the car as well as provide support for the shells.

Figure 11: Original design concept.
The parting line for the roof top tent will be located along the top edge of the part for both halves. Figure 12, below, shows a picture of the bottom shell with the parting line highlighted. This was chosen as the parting line because the part is going to have a double wall so a cavity and a core will be needed to form the part. This is also where the two halves of the shell will meet so it is critical for alignment. The top and bottom shells will be identical so only the bottom half is displayed. This view of the part also displays the ribs that will provide extra strength and stiffness for the shells.

![Figure 12: The highlighted parting line on the bottom shell of the roof top tent.](image)

Figure 13, below, shows the bottom view of the bottom shell. In this view, the tack-off regions and ribs can be seen. The tack-offs are highlighted and there is a rib between each one. A combination of ribs and tack-offs was used to provide as much strength and stability as possible because the tent shells will each need to hold two people in them.
Figure 13: Bottom view of the bottom shell with the tack-off sections highlighted.

Figure 14, below, shows the draft analysis of the bottom shell. A 3° draft was applied to all of the walls that are parallel to the parting line. 3° was used because the blow molding design guidelines specify that at least 2° draft is required. We used 3° because more draft will allow the part to be ejected from the mold the easiest.

Figure 14: Views of the draft on the bottom shell.

Figure 15, below, shows a close up of the sectioned view of the bottom shell. In this view, the tack-offs can be seen as well as the double walls. The design guidelines for tack-off can be seen in Figure 16. Rounds were also applied to all of the edges except for the parting edge. 50% of wall thickness was used on the inside edges and 150% of wall thickness was used on the outside edges. This will allow the walls to remain concentric and prevent uneven wall thickness.
Mold and Tool Design:

Since the rooftop tent shell is six feet long, the parison thickness will begin to thin at the bottom due to stress relaxation of the polymer. To combat this, a diverging die will be used. The diverging die helps to prevent “curtaining”, or curling of the parison on the bottom, in large diameter parts. An example of the die and mandrel that will be used is shown in Figure 17.
A parison program will be used to ensure that the part will have a uniform wall thickness even after forming the deep cavities of the part. Without the program, the walls and corners towards the bottom of the part could be thinner than the top regions. Since the tent shell will be sitting flat on top of the car, thin sections would make the wall thickness proper on the left side of the shell while the right side would be thinner. This could lead to warping of the part or even failure of the part from the inability of the weaker region to support the required loads.

A parison program manipulates the die and mandrel gap to allow for various thicknesses of the parison as it extrudes. This helps distribute thicker walls to larger cavities within the part and prevent uneven wall thickness in thinner regions. In addition to thin regions, the parison program prevents blow outs in these thinner regions.

By using a parison program for the tent shell, extra material will be added near the bottom of the part to ensure that the stress relaxation does not cause thinning of the material. Figure 18 shows what a potential program for the part will look like.
With the parison program in Figure 18, the tent shell should have uniform wall thickness throughout the part. The changes in thickness in the parison will help against the stress relaxation in the polymer. The diverging die will help prevent the parison shrinking as soon as it exits the extruding head. With this process, the tent shells should have uniform wall thickness with each part produced.

Figure 19, below, shows a picture of the overall mold. Pinch-off and water lines were added to the mold. The waterlines are located on the top and bottom half of the mold and will help cool down
the part before it is ejected. The pinch-off will be removed after molding is complete to give the part a secure weld and good appearance.

Figure 19: Mold assembly.

Figure 20 and Figure 21 show the waterlines in both halves of the mold. The waterlines are highlighted in green in both figures. The waterlines were dimensioned based on standard waterline dimensioning. This part will be very large, and it will have double walls so the waterlines will ensure that it is cool enough when the molding cycle is over.
Figure 20: Waterlines in the cavity half of the mold.

Figure 21: Waterlines in the core half of the mold.

Figure 22, below, shows the pinch-off on the mold assembly. The pinch-off will seal the sides of the part so it will not be able to come apart. Secondary operations are needed to remove the material that is outside of the pinch-off.
Aluminum will be used to manufacture this mold. Aluminum will be used because it has good thermal conductivity which help to get the heat out of this large part and mold. This mold can be made using casting because of the size of the mold. The part is four feet by six feet and this will be too large for machining.

The part will be blown using a combination of a blow pin and blow needles. The blow pin will be will allow a large volume of air to enter the part quickly. The blow needle will be located on the front panel of the part. An additional benefit of having the blow pin in this location is that the hole can allow water or other moisture to exit the tent shell. A rubber cap will be inserted to prevent insects or animals from crawling into the hole when it is not being drained.

Blow needles will be used on the back panel of the part to provide a pre-blow and allow the part to form uniformly. If the blow needles were not used, the part may not form uniformly due to the large size of the part. The blow needle holes will be very small and unnoticeable to the average consumer.
Detail Drawings:

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Overall View and Dimensions

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[Diagram with dimensions and labels]
References:
