Final Project Brief for MIME Capstone Design 2019-20

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Team # 122

Carbon Fiber Body for the Shell Eco-Marathon Urban Concept Vehicle

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Abstract

The objective of this project is to design and manufacture a finished mold, to be used in future layups of a carbon fiber body, for the student lead chapter of American Society of Mechanical Engineers (ASME) at Oregon State University (OSU). Before our project was commissioned, the car's body was made of acrylonitrile butadiene styrene (ABS) plastic panels that were riveted to a steel tube frame by a group of ASME members, who were under a time crunch. This resulted in a body that was not to the quality standards of the club; hence the commission of our team's project. Over the course of the project lifespan, deviations from the original timeline instigated a change in deliverables. The new list of deliverables are centered around providing a quality mold as well as materials and a procedure to be used in future layups of the carbon fiber body. Even with these redefined deliverables, our team ran into facility restrictions that ended up resulting in the halting and eventual termination of our project. While we were not able to deliver a completed carbon-fiber body, or mold, we were able to provide a quality mold plug and the necessary plans and materials for continuation, and successful completion, of the project.

1. Project Scope

1.1 Background and Introduction

As stated in the abstract, the objective of this project is to design and manufacture a finished fiber-glass mold, to be used in future layup of carbon fiber bodies, for the student lead chapter of American Society of Mechanical Engineers (ASME) at Oregon State University (OSU). ASME requires a completed mold representing the vehicle body for post processing of carbon fiber layup. This carbon fiber body is to be secured with a pre-existing chassis and drivetrain, of which they plan to use at the Shell Eco-Marathon Competition in April 2020. The Shell Eco-Marathon is a continent-wide event where student designed and manufactured, highly efficient, automotive concepts are raced and evaluated. In order to satisfy the ASME student leadership and fulfill our capstone design course, the mold of the vehicle body must be constructed and a thorough engineering process from design to manufacture must be composed and well-documented. Along with material, geometric, and quality standards, the vehicle body must be compliant with rules and regulations set forth by the Shell Eco-Marathon management.

1.2 Research and Previous Approach

Before our team's project was sponsored, the body consisted of acrylonitrile butadiene styrene (ABS) plastic panels that were riveted to a steel tube frame. This body was made by a group of ASME members, who were under a time crunch, over a span of two weeks. Because of the member's lack of time, in-depth design and craftsmanship were not priority. This resulted in a body that was not to the quality standards of the club; hence the commission of our team's project. Not all the body needs to be scratched, though. ASME told our team that they would not be opposed to the idea of keeping the steel tube frame for the safety that it provides the driver, as well as the convenience of using it as a point of attachment for various accessory components.

In order to produce this mold for improved vehicle body, our team of six mechanical engineering capstone students have created roles and responsibilities in both the design and manufacturing spaces of this project. Work is divided by each team member's unique skills and affinities, serving to increase morale while leveraging talents for task optimization. Research areas include aerodynamic design, structural properties, material considerations, mold construction, and manufacturing process dynamics. Our team believes that these research categories will provide us with the background necessary to construct a quality, carbon fiber, vehicle body for ASME.

These research areas were constructed with the intention of avoiding the mistakes of preceding capstone teams. After meetings with ASME student leadership and faculty advisors, our group determined that the focal points for our team will be manufacturing processes and material considerations. We were led to this decision after understanding that previous teams fell short of lofty design goals due to discounting their manufacturing requirements, leaving ASME without a quality body for competition. In the end, missing the hard deadline of the competition, or delivery of a low- quality product, would mean failure of the task. Therefore, devoting time to nominal improvements in aerodynamics or structural integrity through novel design will be under the guide of our understood manufacturing capabilities.

We did not intend to wholly rule out calculated and insightful design from the focal points of our team charter. Rather, we understood that a successful competition outcome, and thus a satisfied customer, would not be resultant of novel design, but rather shrewd and calculated manufacturing strategy. Focusing on development of original concepts would have hindered the time allotted to quality assurance and rapid manufacturing. Therefore, the design is such that manufacturability, rather than manufacturing for design, is a precedent. In the end, we believe that our outlined research paths put us in a position to deliver a quality product to ASME that is compliant with all rules and regulations of the Shell Eco-Marathon competition.

1.3 Stakeholders

Parties with vested interests in the success of the success of our team's capstone project are:

- ASME Student Leadership
  - Our team's greatest stakeholder, the ASME student leadership, has employed our capstone team with the construction of an integral piece of their competition vehicle. Our team's success is directly correlated with their chances of being successful in the competition. Success in the competition for ASME means enhanced public relations, marketing capacities, and ultimately more funding.
- Shell Eco-Marathon Management
  - The Shell Eco-Marathon management may not have their jobs on the line, but success of our group's project means greater competition and thus event publicity.
- Capstone Team Members
  - A successful capstone project means that our team has delivered a quality product to ASME. This will fulfill our capstone design requirements for graduation while enhancing our overall capacities as engineers. Real experience in product realization is invaluable on our journey into the engineering workforce.
  - Team members:

Member name	**Roles**
Brian Blasquez	Aerodynamic design & material considerations
Ryan Doyle	Mechanical & Manufacturing Engineering

Cody Bloomfield	Manufacturing of carbon fiber molds
Yin Sing Lee	Structural properties and material considerations
Jake Rocker	Aerodynamic design and structural properties
Mitchell Brown	Aerodynamic design and structural properties

Table 1: Team members and associated roles

- Dr. Chris Hoyle (ASME Faculty Advisor / Capstone Project Advisor)
    - As the ASME faculty advisor, Dr. Hoyle has a vested interest in the competition success of ASME. Therefore, his interest in the project is like that of the ASME student leadership.
- Dr. Jeff Hoffman (Capstone Instructor)
    - As the capstone instructor and general project manager of all capstone team assignments, our team's success is reflective of his guidance and prestige as an instructor.

1.4 Project Constraints

The project constraints our team were initially faced with included: budget, 2020 Shell Eco Marathon Rules, and scheduling. Colton Morgan informed the team that ASME will be able to provide a budget of $3,500 to cover all costs of the project. Costs of the project included materials required for mold plug construction, materials for mold construction, carbon fiber, resin infusion system, and miscellaneous fasteners and accessories. The 2020 Shell Eco-Marathon has a set of strict rules and guidelines that needed to be met in order for ASME's urban concept vehicle to qualify for competition. The team worked with Colton Morgan to ensure the vehicle's specifications meet the requirements of the rules for competition. Initially, scheduling seemed to be the largest constraint of the project, as it was seemingly difficult to coordinate six different schedules in order to find available meeting times outside of scheduled class. To mitigate this, the team made use of Google Drive and Slack to share files and ideas easily to ensure the team stays on track with deliverables and requirements. As the project continued, our team was capable of working around the busy schedules of our combined workforce, however a slew of other, unforeseen and unmitigatable, setbacks to the project led to the eventual cessation of our project. These unforeseen setbacks are further explored in section 4 of this report.

2. Design Solution

2.1. Geometric and Structural Design

Seen below are the group's final decisions on the geometric and structural design of the carbon fiber body. The group made the collective decision to select a body style that resembled the previous concept (Figure 1), with slight modifications to geometry to improve aerodynamics (Figure 2). The group also made the decision to keep the steel tube frame (Figure 3) on which the previous model was built. This is to maintain the structural integrity of the steel members as well as access points for attachment of accessories for competition.

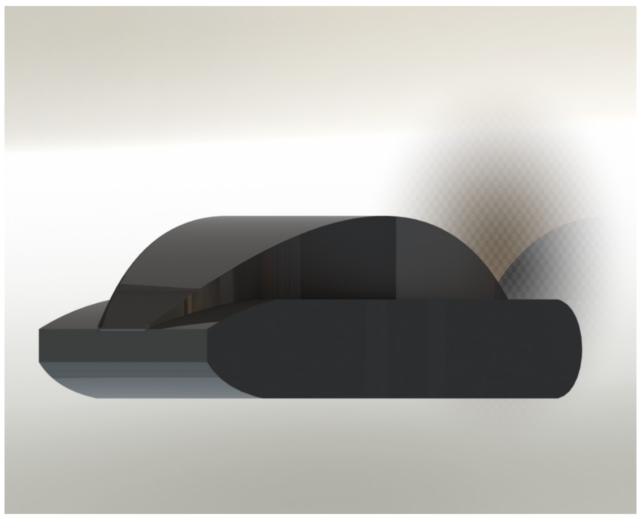

Figure 1. Previous Generation Body

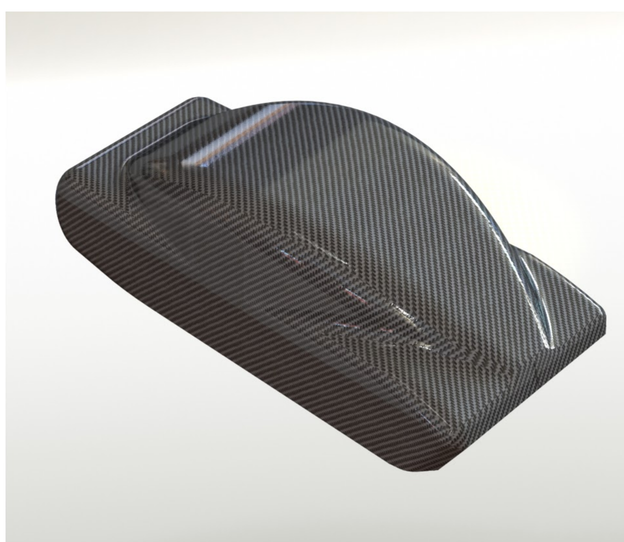

Figure 2. Proposed Design

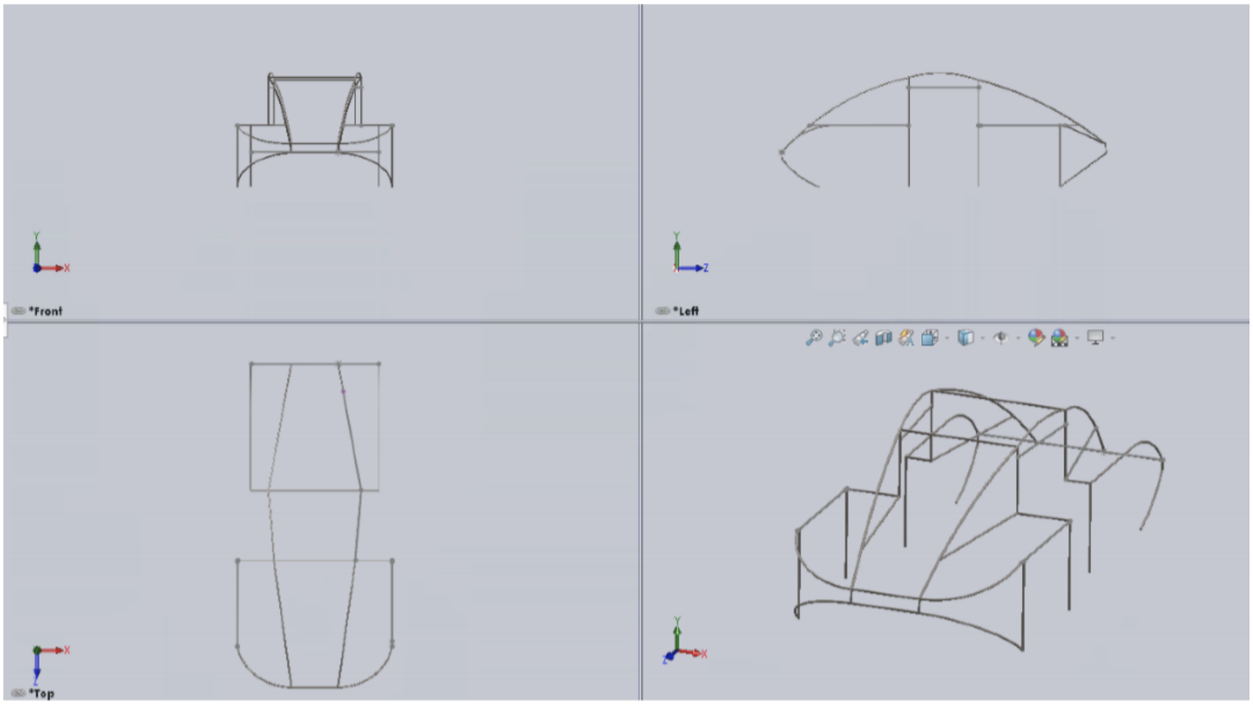

Figure 3. Steel Tube Frame from Previous Generation

2.2. Mold & Mold Plug Design

In order to manufacture the molds used to lay the carbon fiber, the group needed to design a mold plug to make the negative molds as seen below in Figure 5. The group will need to ensure a smooth surface on the mold plug, free of any defects. To do this the group decided on a multi layer system applied to the bulk shape of the mold plug made of wood panels and modeling foam as seen in Figure 4. First the mold plug would be covered in spackle to smooth out any rough changes in elevation along the curves and surface. Next, expanding foam will be utilized to fill any large voids or pores between the modeling foam and wood panels. Then, the group will cover the mold plug's surface in plaster and will sand it down to a sufficiently smooth surface. Once the group has deemed the surface to be acceptable a coat of RedGard will be applied before finally wrapping the mold plug in a layer of fiberglass. After the fiberglass has cured and hardened, the mold plug will be ready for mold construction as seen in figure 6.

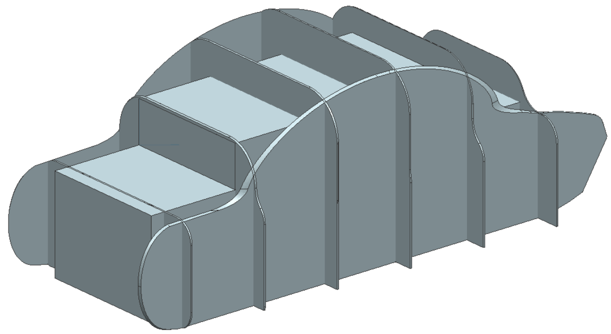

Figure 4. Wood Paneling Mold Plug before Modeling Foam

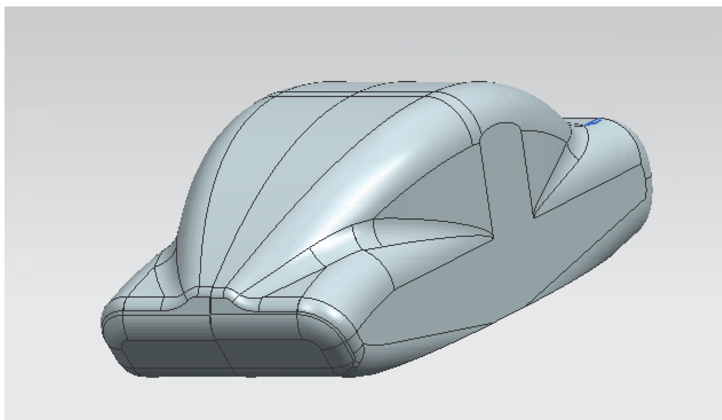

Figure 5. Completed Mold Plug

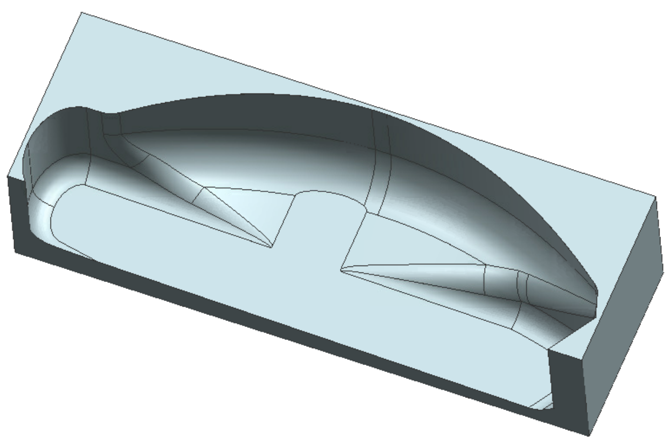

Figure 6. Fiberglass Mold

2.3. Carbon Fiber Laying

The group decided to go with a 6k 2x2 twill (Figure 7) [2] carbon fiber material that was not pre-impregnated with resin. This decision was made with insight that the structure of the vehicle body will come from attachment to the steel tube frame, removing the burden from the carbon fiber structure. A vacuum resin infusion system will be utilized to saturate the carbon fiber with resin. This will allow the group to take as much time as needed to lay up the carbon fiber in the desired orientation.

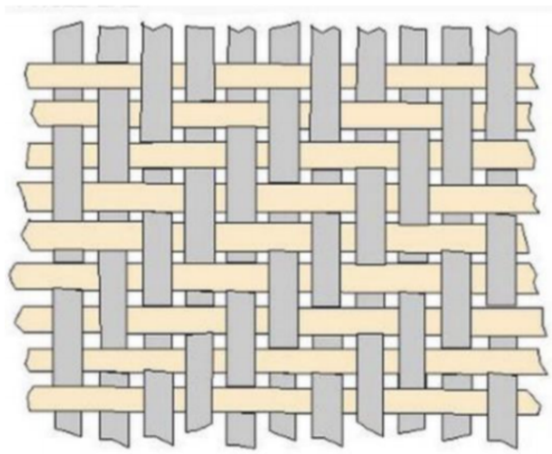

Figure7. 2x2 Twill Pattern

3. Results

3.1 Mold Plug Construction

One of the most vital steps in mold construction is an accurate, detailed, and high quality mold plug. There are three key components to a high-quality mold plug: high detail, smooth shape, and proper preparations for the mold layup. To achieve the primary shape of the mold plug, the wood frame was built, followed by cutting the foam to shape. Next, expanding foam, spackle, and plaster were used to finalize the shape, fill in cracks between foam, eliminate surface height differences, and smooth the surface finish of the foam. The state of the mold plug at this point can be seen below, in figure 8.

Figure 8: State of the Carbon Fiber Mold Plug after Initial Construction Phase

The next steps in completing the mold plug involve preparations for the fiberglass mold layup. First, the mold plug was sealed using Redgard, which prevents any liquid from being absorbed into the foam. Next, the fiberglass was laid onto the mold plug, with epoxy to harden it to its final finish. At this point, the surface of the fiberglass needed sanding prior to continuing to the next steps. However, due to the delay of the project, this was as far as the mold plug could be completed. The final state of the mold plug can be seen in Figure 9.

Figure 9: Final State of the Carbon Fiber Mold Plug

3.2 Mold Layup Testing

Throughout production, verification of manufacturing processes was key to ensuring the mold plug would not be jeopardized by a process that would not work, or materials reacting poorly with each other. The test piece went through initial foam cutting practices, laying spackle and plaster, spreading sealant, laying up fiberglass, and finally applying gelcoat. All processes were verified on this test piece before either applying them to the actual mold plug, or providing questions to ask if there was a problem.

All processes worked up to applying gelcoat, at which point it was discovered that it gives off Volatile Organic Compounds, and it was decided that it could not be applied in the current workspace. As well as this, it was discovered that gelcoat requires a hardening agent, which was not used on the test piece.

The sealant layer was another source of important testing on the test piece. While testing the sealant layer was successful on the test piece, it did not completely reflect what happened on the mold plug. When it was spread on the test piece, it worked with no problems. However, when applied to the mold plug, due to the larger surface area, many portions of the sealant cracked, which meant multiple layers had to be applied, and the surface had to be sanded to maintain a good surface finish.

4. Setbacks

Over the course of the project, our team ran into and overcame a significant number of facility, time, and tool constraints. Some of these constraints were greater than others, setting our project's timeline further and further into the future, and eventually leading to the termination of our team's segment of the project.

During construction, it was necessary to sand the surface of the mold plug after each step in its manufacturing process. This sanding step was critical because each layer of material on the mold plug must remain at a high precision surface finish; else, we risk affecting the surface of each continuing step. Initially, this sanding step was not a problem. However, upon sanding the plaster layer, it became obvious that our work space was insufficiently ventilated to remove the finer plaster dust from the air. Insufficient ventilation of such hazardous materials could put others in the shared workspace at risk for health complications. This meant that the team would need to move the mold plug to a "dirty room", a room designed with adequate ventilation for tasks that emit hazardous materials, before any further sanding could be completed. However, due to the size of the mold plug it is difficult to move between locations. After careful measurement, it was determined that the dirty room wasn't a large enough work space. Our only other option was to work outdoors, but due to unpredictable weather in the winter and spring, this option would likely produce more problems than it solved.

Due to these issues, further construction on the project was halted until appropriate accommodations could be made. In light of this problem, a step-by-step continuation plan has been included in this report to relay pertinent information to the ASME student group so they can finish the project when necessary facilities become available or weather permits.

5. Continuation Plan

5.1 Current State

The mold plug is very near completion. The first layer of fiberglass was applied before ventilation issues halted progress, but fiberglass defect removal could not be completed. Therefore, the mold plug is currently in a workable condition.

5.2 Mold Plug Completion

To finish the mold plug the first step that remains to be completed is defect removal. During fiberglass laying, bubbles and fabric bunches created surface imperfections that need to be repaired to create the desired surface finish. The suggested route to complete this step is the use of a rotary tool (such as Dremel) to cut out imperfections. It is important that this step and all following steps are completed in a well ventilated area and with the use of necessary safety equipment (ventilator and safety glasses). After the imperfections are removed, putty and/or spackle can be used to fill any voids introduced by the process and left to dry overnight. The whole mold plug should then be wiped down with warm water using a soft cloth. Fiberglass patches should cover these areas.

To patch the fiberglass the fabric should be cut to the size of the area being patched with about 1 inch of extra material on all sides. The fiberglass resin should then be mixed with hardener in a ratio of 3 to 1. Next, the resin needs to be applied using either disposable foam brushes or plastic spreaders and then left to cure for a minimum of 24 hours, although 72 hours is ideal. After the resin is fully cured, the patched areas should be wiped down with warm water to remove amine blush produced in the curing process. Light sanding will help to remove minor blemishes.

The next step necessary to complete the mold plug is attaching flanges in strategic locations so the mold is sectioned into manageable pieces. The suggested flange locations are along door edges and along the enter line of the car both lengthwise and widthwise. These flanges can be created out of sheet metal, plastic sheets, or wood. They should be attached using construction adhesive.

After flanges are attached, gelcoat needs to be applied over the mold plug and flanges to provide the final surface finish desired. The gelcoat should be mixed with hardener according to the product label and then applied in the same manner as the resin. The gelcoat needs to cure overnight in a very well ventilated area because volatile organic compounds (VOCs) are released during curing. Another light sanding can be completed to help smooth surface imperfections.

The last step required to produce a finished mold plug is the application of a generous coat of mold release wax to allow for the release of the molds from the mold plug after mold layup.

5.3 Mold Construction

Once the mold plug is completed with all necessary components (a smooth layer of fiberglass, flanges, gelcoat, and wax) the mold construction process can begin. Initially, the surface should be prepared by making sure there is no debris present on the mold plug. Next, an additional layer of gelcoat should be applied to the entire mold plug except the edges of flanges. This gel coat layer will be the final surface finish of the molds. After the gelcoat is applied ample time should be allowed to allow the gelcoat to fully cure. The amount of time should be based on the original equipment manufacturer's criteria.

Once the gelcoat has cured the chopped strand mat fiberglass can be applied to construct the mold. The chopped strand fiberglass comes packaged in a roll and the fiberglass can be pulled off from the roll in any size increment. The benefit of pulling chunks of fiberglass from the roll is to allow time to place the fiberglass on the mold, and have enough time to saturate the fiberglass with resin. The chopped strand mat should not overlap onto the edges of the flanges so that separate molds are made for each section.

The fiberglass resin should be mixed with hardener in a ratio of 3 to 1, and be prepared to saturate the fiberglass once it is applied to the mold plug. When the chopped strand fiberglass is applied on top of the mold plug the resin should be applied with rollers, scrapers, or foam brushes until the fiberglass has reached its fully saturated level. Each additional application of chopped strand fiberglass should overlap the previous application by at least 1 inch. If resin has cured for more than 1 hour, additional layers should not be applied for at least 24 hours. Cured fiberglass should be wiped down with warm water to remove amine blush before another layer is applied. Fiberglass layers should be applied until a material thickness of at least ¼ inch, but not more than ½ inch, is achieved.

After the final layer of fiberglass has fully cured, the molds can be released from the mold plug. Once the molds are removed from the mold plug, they are ready to be used to create the carbon fiber panels for the body of the vehicle.

5.3 Carbon Fiber Layup

Once the fiberglass molds are fully cured and complete the carbon fiber layup process can begin. First the surfaces of the molds should be cleaned and wiped well with isopropyl alcohol to clean any defects or dirt that can be passed on to the surface of the carbon fiber. A generous amount of wax release will need to be applied to the surface and especially curves and sharp points to ensure release of the carbon fiber from the mold after curing. If this step is done improperly it can result in the loss of both the carbon fiber and the fiberglass molds.

The carbon fiber resin and hardener should be mixed to a 3:1 ratio. Ensure sufficient individuals are available to assist in the laying process as once mixed the resin will begin to harden in 110 minutes. If the carbon fiber is not correctly laid and under a vacuum seal before the resin begins to harden there is risk of layer separation and ultimately failure. To lay the carbon fiber use a scraper to apply the resin and wipe off any excess before positioning the sheet in the mold. Once all sheets of carbon fiber have been saturated in resin and positioned within the mold, the mold needs to be placed under a 10 pound vacuum seal and allowed to cure for 2-3 days. After the carbon fiber has fully cured it can be removed from the molds and cut to remove any excess overhangs from the separating flanges of the mold.

6. Conclusion

Our capstone design team was centered around designing, manufacturing, and testing a carbon fiber vehicle body for OSU ASME student leadership to attach to their existing vehicle components and compete with in the Shell Eco-Marathon competition April 1st, 2020. In order to successfully deliver the vehicle body, our team established research areas, a project timeline with work breakdown structure, and project focal points based on customer requirements. Our team made design, manufacturing, material, and tooling/machining resource assumptions in the project planning stage to create a general project timeline. We analyzed the risk associated with taking on this project, our responsibilities to stakeholders, and our capacities as a student engineering team.

During the duration of this project the team took measures to successfully complete the defined project at hand; however, due to deviations in the project timeline, the project deliverables had to be reevaluated to better suit the OSU ASME student club in the future. The reevaluated deliverables included a completed mold; which the ASME student club can use in future years of competition, to finish constructing a carbon fiber body, for the urban concept vehicle.

Even with these redefined deliverables, our team ran into facility restrictions that ended up resulting in the halting and eventual termination of our project. While we were not able to deliver a completed carbon-fiber body, or mold, we were able to provide a quality mold plug and the necessary plans and materials for continuation, and successful completion, of the project.