End of Semester Report

Composite Stand-Up Paddleboard

Submitted to

BoardSport Technologies Enterprise

By

Wake Team

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boardsport technologies enterprise

Senior Design

Executive Summary

Through BoardSport Technologies Enterprise, the wake team has chosen to design and manufacture a stand-up paddleboard. This project will take place over two semesters and is part of the Senior Capstone program through enterprise.

A stand-up paddleboard is similar to a surfboard. It allows the user to stay standing and move across larger bodies of water. It is normally used as a relaxing way to enjoy the lake. By designing a paddleboard that is stronger and lighter, the wake team can minimize the water displacement of the paddleboard design. By doing this, the user can have better maneuverability without sacrificing stability.

In order to accomplish this goal, all materials were considered for a composite paddleboard. IT was eventually reduced to three possible foams and three possible fibers. The foams are polystyrene foam, divinycell foam, and I-foam. The fibers are carbon fiber, fiberglass E grade, and fiberglass S grade.

The nine possible combinations were made into samples and tested. While the results of the testing have not been completed yet, the composites all seemed to perform as expected during testing and the data should be statistically significant.

In order to design a board that will maximize the material qualities of the improved paddleboard, a CAD model was made. The board is a displacement hull paddleboard. This means that the shape of the board will help to minimize the water displacement and help the user track across the water with better maneuverability.

The model was used to create FEA, or finite element analysis, simulations. These simulations are not yet completed due to material property errors, but the simulation is working and will soon help predict the forces under specific loading scenarios that each composite board can expect. This will help to ensure that the paddleboard is built with the proper confidence limits in place.

The final material selection is not yet completed, however, a primary composite will be chosen before the end of the semester. This will allow the wake team to manufacture the board with high care and precision to develop a high quality board that competes heavily with the current industry standards.

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INTRODUCTION

1.1 BoardSport Technologies Enterprise

BoardSport Technologies Enterprise was formed in 2006 to research, design, and manufacture new and improved boards in all areas. The enterprise is split into three teams; Snow, Skate, and Wake. These teams each focus on their respective board types for a majority of their project work. The Composite Stand-Up Paddleboard project is working as a Wake Team project. This is the first project that Wake Team has done that is not a high speed water sport, and it's goal is to help branch out the team and provide a sport that does not need a boat.

1.2 Team Members

The team is composed of three members: Cleyton Cavallaro, who is the Secretary of BST, Chris Grace, who is a dedicated team member, and David Swanson who is the Wake Team Leader.

1.2.1 Backgrounds

Cleyton Cavallaro is from Brighton, MI and is in his fourth year at MTU, studying Materials Science and Engineering. He has been interested in longboarding and snowboarding since a kid, and has recently found an interest in water sports as well. Cleyton is also a member of Sigma Tau Gamma fraternity where he has held several leadership positions. The Stand-Up Paddleboard project is part of Cleyton's senior design capstone for enterprise.

Chris Grace is from Muskegon, MI and is a fourth year student studying Materials Science and Engineering. He is active in most winter and summer boarding sports. Chris is also a member of Sigma Tau Gamma fraternity and has held multiple positions. The Stand-Up Paddleboard project is part of Chris's senior design capstone for the enterprise.

David Swanson is from Marinette, WI and is a fourth year studying Mechanical Engineering at MTU. David grew up next to Lake Michigan and water sports have always been a part of his life during the summer. He also is interested in snowboarding and new BoardSport ideas in industry. David is a part of the American Society of Mechanical Engineers chapter on campus and is helping Cleyton and Chris with their senior design project as a part of wake team.

1.2.2 Qualifications

Cleyton Cavallaro has had great experience through BST in past projects to help develop skills in preparation for this capstone project. Some of these include designing and manufacturing wakeboards and longboards. Cleyton has held several internships during the past few summers, which include a Research Assistant and the Pathology Laboratory in the University of Michigan and a Corporate Quality Intern at ArcelorMittal. Both of these internships provided valuable experience such as organization and documentation skills, as well as the refinement of processes.

Chris Grace has contributed to multiple projects with the enterprise including sensor board, composite ski and snowboard rack, and stand-up paddleboard. During the summer of 2015, he was in South Carolina with Nucor Steel as the rolling mill metallurgical intern where he acquired further useful experience. He focused on quality control of the final products, as well as, improved materials processes.

David Swanson has had much hands on and technical experience with helping reviving the wake team's presence in BST. He helped manufacture two wakeboards and learned in depth about the wakeboard construction process. David has had local internships in his town of Marinette such as a Piping Engineer Intern at Marinette Marine and a Plant Engineering Intern at Waupaca Foundry. These internships helped David with his computer skills and gave him valuable experience with working with numerous engineers in the workplace.

1.3 Background

Stand-Up paddleboards, or SUPs, are similar to surfboards and are used to allow surfers to paddle further into the ocean or ride around in rivers, or lakes, where the waves are not as big. SUPs are generally not a fast paced adrenaline sport, and are generally used for relaxing travel across lakes. They can even be used for yoga. SUPs are larger than typical surfboards to create a more balanced ride and ensure the user has no trouble staying balanced while standing. The materials used in SUPs are also similar to surfboards and are generally composed of a foam or hollow core, a composite shell, and a fin.

Most paddleboards are made out of fiberglass (E grade) and EPS foam. This combination provides the necessary properties while being easily available and manufacturable. Wake team will also be considering other foams and fibers for the manufacture of an improved paddleboard. The basic properties of these materials can be seen in table 1 below for a comparison to the industry standard.

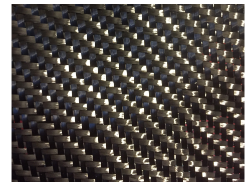
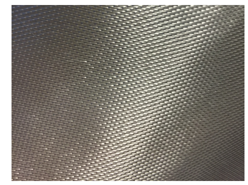
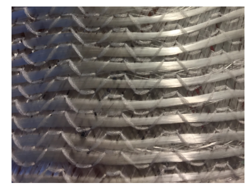
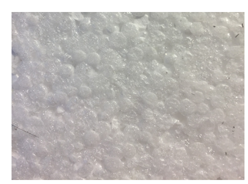
Material	Density	Yield or Compressive Strength	Images
Carbon Fiber	0.0004637 lbs./in^2	580 ksi yield	
E-Glass Light	0.0004409 lbs./in^2	268 ksi yield	
E-Glass Heavy	0.0007874 lbs./in^2	592 ksi yield	
EPS Foam	0.000795 lbs./in^3	0.0232 ksi compressive	
Divinycell Foam	0.00159 lbs./in^3	0.0624 ksi compressive	
I-Foam	0.000880 lbs./in^3	Undetermined	
PP Foam	0.00159 lbs./in^3	0.0305 ksi compressive	N/A

Table 1: Material Properties for various paddleboard components. Densities were measured; strengths were obtained from CES Edupack.

The foam or hollow core is designed to create a lightweight structure for the board. The composite shell provides the high strength and durability needed while also limiting the overall weight. The fin is typically made out of a moldable plastic or composite; it helps direct and steer the board while limiting swaying from side-to-side.

Multiple material properties are important when considering the proper materials for this application. For the foam core, density is necessary to reduce the weight of the board and increase buoyancy. The elastic modulus is also important to help maintain the structure while riding without being too stiff.

For the fiber selection, the tensile strength is important to withstand the stresses applied during use. The fiber is placed on the bottom of the board and provides most of the strength and stiffness of the board. The price is important when considering all materials to create a price efficient and manufacturable final product.

The overall weight is the biggest selling factor for stand-up paddleboards. By reducing the weight, the board is more buoyant and easier for the user to carry and maneuver. Paddleboards created with a hollow core are typically lighter than the foam core boards. The stiffness of the board is vital to be able to contain its shape during use. However, too stiff of a board is more susceptible to damage when hitting an obstacle and may be less stable. Hollow core SUPs have minimal stiffness, while foam core boards retain their structure better and can be cheaper and more affordable. Most foam or hollow core paddleboards range from $900 to $1500.

The shape of the board is crucial, but varies depending on the type of use. For beginners or best overall use, planing hulls are chosen. A planing hull closely resembles a surfboard with a flat and wide base. The wide base provides extra stability for new users and waves. Displacement hulls are for more experienced riders or someone who races or does long-distance trips. Displacement hulls have a pointed nose and narrow body similar to kayaks and canoes. The displacement hull's shape allows the SUP to push the water to the sides and displace a minimal amount of water. This allows the board to move faster and have easier tracking across the water, but as a consequence it is less stable as a consequence [1].

DESIGN PROBLEM ANALYSIS

2.1 Design Requirements

Stand-up paddleboarding is a relatively new sport and industry. As the sport becomes more popular, the technology is quickly advancing. To compete with industry quality paddleboards, the wake team has planned to meet or exceed all current paddleboard standards.

2.1.1 Objectives

Several main objectives must be reached for the Stand-Up Paddleboard project to be determined successful. First, optimal materials for a SUP through a process of material selection, testing, and analysis should be selected. The properties of the materials should have the goal of improving upon the current industry standard SUP in weight, strength, and quality of ride. Safety of the board and user should always be a priority as well. The final product should be designed and built using CAD software and machining technology. By manufacturing a high quality board with specific materials and processes, the wake team should develop a set of procedures for an improved SUP upon what is currently an industry standard. The SOPs developed can be further expanded on for future projects within BoardSport Technologies.

2.1.2 Constraints

When working towards these objectives, the team must also work with the constraints that a high quality board requires and the BoardSport Technologies sets for itself. These constraints can be both soft or hard constraints, the prior being a constraint that can be adjusted slightly as more research or experimentation is done, and the latter being a constraint that cannot change under any circumstances.

Current industry SUP sizes range from 9 to 12 feet long and 28 to 36 inches wide. The new design should lie within these size ranges. The new design should also aim to be an appropriate thickness that can provide at least industry strength without loss of durability.

The board's overall density must provide enough buoyancy to be able to support an average person with a significant safety factor. This will be predicted with calculations based on the densities of all materials. If the density constraint is met, the board will also meet the expected weight constraint, which is approximately 25 to 30 pounds.

The strength of the board must be able to withstand use in both normal and choppy waters with appropriate safety factors in play. This will be analyzed and predicted with FEA and material testing. The strength of the board must still allow some flexure when cresting waves in order to prevent fracture and help the rider maintain balance.

To stay within budget and create a mass-producible final product, the board must cost less than $500. The budget is the only soft constraint defined in this section. If more funds are needed, the team will contact potential sponsors, inquire with the MSE department, and compete in competitions in order to meet the monetary needs.

The project must be completed within two full semesters at Michigan Technological University. This began in the fall of 2015 and will finish in the spring of 2016.

2.1.3 Design Summary

The wake team has a defined project goal as described above. The paddleboard must be within industry standards for size and below standards for weight. The project must be completed within two school semesters and should be safe and able to support an average person with a significant safety factor. By striving to be as safe as possible, the board will be made out of mostly recyclable and "green" epoxies and materials. This will provide a prototype, quality board that would be a strong competitor on the open market. The paddleboard will cost no more than $500, ensuring that it can be competitively priced against current paddleboards on the market.

DESIGN DECISIONS

3.1 Materials Selection Process

The materials selection will compose of three parts. These are the fiber used on the bottom of the board, the foam used for the body of the boards, and the epoxy used over the surface and for adhesion of the board.

All fibers were first analyzed in with CES Edupack. This software enabled our team to make an adequate estimation of the three best fibers that should be selected. All fiber selection charts, figures A1 through A3, can be found in the appendix.

Examining price and density of the fibers, several fibers are seen to be low in both. Silica, fiberglass (E and S grade), and carbon fiber are all shown to be primary contenders. Kevlar, which was expected to be a contender originally, was ruled out because price is too high.

When looking at tensile strength and density, carbon fiber, fiberglass, and silica all still have a good strength. This is important because the fiber will be located on the bottom of the board, where it will have very high tensile stresses on it.
In order to ensure that all fibers would not deteriorate in the water, they were also compared in a chart. This last comparison, water versus price, shows that our main three fiber choices are all excellent in the water.

Silica was shown as a top contender in the CES charts, but after further research, it was not expected to both perform well during the layup process with epoxy and be easy to find for purchase. This made the team rule our silica as a fiber choice.

The final three fibers that were chosen are fiberglass (E grade), fiberglass (S grade), and carbon fiber. Fiberglass (S grade) is simply a thicker version of E grade, so to further reduce on costs, a thin and a thick fiberglass that are currently used in the BoardSport Technologies Shop were decided to the fibers of choice.

CES Edupack was again used to analyze the foam selection for the wake team. The foam will both be under compression and tension, as well as need to meet required density, water capability, and price constraints. These charts are located in Appendix A and are labeled figures A4 through A7.

Density and compressive strength were first compared in CES. These are the two most important properties because of the constraints upon the foam. Many types of foam seem to fit into the "acceptable" region of this chart. Polypropylene (PP), carbon foam, Polystyrene (PS), PVC cross-linked, polymethacrylamide, and Polyurethane were all considered.

After price was considered, polymethacrylamide was immediately ruled out. Carbon foam was also decided to be too expensive for the purposed of a prototype paddleboard.

When looking at the tensile strengths of foams, a property expected to be low, PVC foam, PS foam, and PP foam all appeared to be the ideal choices. After looking further into the acquisition of these three foam types, it was discovered PP foam is very difficult to obtain in blocks large enough for SUP manufacturing. Foam called “I-foam,” that exhibits properties from both PP and PS, was substituted. This decision was made because PS exhibits higher strengths while PP gives lower densities. The copolymer is expected to give desired properties greater than what PP alone would have provided.

A simple comparison of the foams to their ability to withstand water showed that all selected foams of interested are rated excellent in water.

The selected foams are I-foam, Polystyrene, and PVC cross-linked, which is also known as divinycell.

The epoxies selected were not chosen from CES but were based from the industry standards. Originally, one type of epoxy was chosen for the whole board. This epoxy is BoardSport’s standard from entropy resins. The stresses will be concentrated mostly on the epoxy right between the fiber and foam on this board, and they will be exaggerated because of the size of this board so additional research was done on different epoxies. It was discovered that there are different types of epoxies. Traditionally, a rigid epoxy is used on wakeboards, surfboards, and paddleboards. There is also a type of semi-rigid epoxy that provides better peel strength than traditional epoxy [2]. This semi-rigid epoxy was selected for the layer between fiber and foam, and a rigid epoxy was decided upon for the outer shell, as a user can stand on it safely and it is more water resistant.

Solarez epoxy was selected for between the fiber and the foam because it is a tackier, semi-rigid epoxy than a hardened epoxy. Solarez is a UV hardening epoxy, unlike most, and will continually get stronger and tackier as the board is put into use in the sun [3]. The lower yield strength of Solarez ensures the epoxy will not fail by fracture and will instead fail by yielding. This is not only safer for the board, but it should also provide a better flex of the paddleboard. Flex is desired because it helps the rider stay on the board through any unexpected waves and can be more forgiving.

Entropy Resin epoxy was chosen for the rigid epoxy outside of the foam and fiber [4]. The rigidity will help to secure everything from the elements and help provide a clean, polished look on the board.

3.2 Test Method Selection

The test methods were selected based on the expected points of failure in the composite, and the time required to test.

In order to stay on schedule with the Gantt chart, endurance tests were ruled out. It was decided that the final selection of foam and fiber might be tested for cyclic load failure if the data is needed at the end.

The expected points of failure are both the flexural strength of the composite, and the shear strength of the epoxy. These were determined because the loading scenario of a paddleboard may give significant flex in the board, as it is very long. This will in turn put the highest concentration of stress on the epoxy between the foam and fiber.

After deciding the points of failure, the ASTM database was searched for tests that are meant to determine these values for the composites. ASTM D2344M and D7264M were found and selected to help quantify the points of failure for each composite. ASTM D7264M measures the flexural strength of the samples that were cut to size based on the ASTM ratio which was 1.5" x .5" x .25" for the 3-point bend test. The samples that were used can be found in Appendix C displaying the samples before they were cut to the standards for testing. ASTM D2344M measures the laminate strength between the fibers and their laminates. This standard consisted of a 4-point bend test with requiring the samples to be 8" x .5" x .25" to meet the correct ratio for testing standards.

3.3 Design of Experiment

3.3.1 Hypotheses

A hypothesis was developed prior to testing the sample coupons. These are used to help prove or disprove the results of the test, as well as provide direction for design of the DOE. By knowing ahead of time what the test is supposed to find, how it related to a better paddleboard, and how the hypothesis can be tested, a better product and testing design can be developed. The hypothesis that was developed is listed below.

H_1: If a fiber with higher yield strength is used in the composite, then the composite will be less likely to fail, because a larger shear stress is required prior to plastically deforming.

3.3.2 Format of D.O.E.

In order to a full DOE, all 9 combinations of foam and fiber composite will be tested for both flexural strength and laminar strength. The analysis of the DOE will be done in MINITAB. The sample testing has been completed, but the data has not yet been analyzed. This will be finished up this week and the final material choices will be able to be made based off of which foam and which fiber perform best. Statistical significance of the data should be able to be reached as each set of samples had at least 5 samples tested in it. If significance is not reached, more samples can be tested easily because extra samples were made for this purpose. The D.O.E. should provide quantitative proof of which composite sample performed the best for a paddleboard.

3.4 Final Concept

3.4.1 Composite Model

The model of the paddleboard was designed using NX. Figure 1 below, as well as figures B1 through B4 in the appendices, shows the completed and final model of the foam core. Image B5 shows the mesh of both the foam core and the fiber layer, which will be located on the underside of the board, ready for FEA.

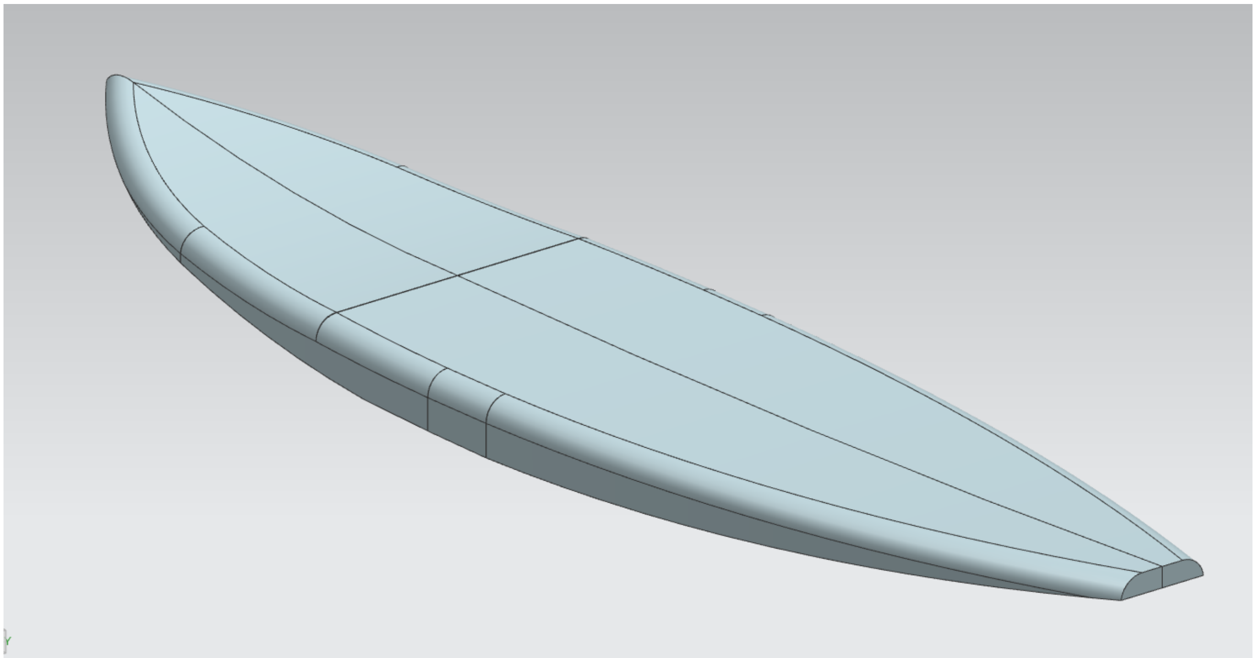


Figure 1: Completed model of SUP. More pictures are located in Appendix B.

The model was based off of several different industry standard boards. The length is 11 feet long and the thickness is approximately 4.75 inches thick in the center. The board tapers off towards the front and rear. This taper helps the keep the most buoyant part of the board underneath the user. The style of the board, a pointed, unidirectional board, is one that will help the user track across the water in a more straight and controlled manner than most paddleboards. The general shape of the board should help highlight the targeted qualities of a good board that the material choice will help to provide.

3.4.2 FEA Modeling

FEA, or finite element analysis, is being done on the finished model of the board. As seen in Figure 2 below, the board core is meshed and joined with a fiber sheet located on the bottom side of the board.

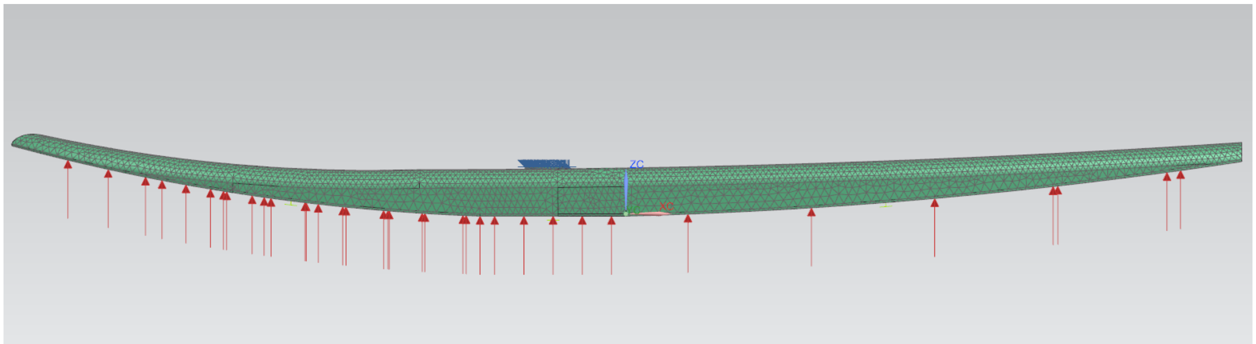


Figure 2: Loading scenario for the modeled SUP. Red arrows are forces and blue lines are fixed constraints.

The loading scenario of the paddleboard was slightly difficult to design. A user, when standing on the board, is letting gravity push them into the board at the point where their feet and the board meet. The board, by sinking slightly into the water, then pushed back towards the user in equilibrium. The image above helps to show the resultant forces on the board. By fixing the location of the feet in place on the board, and by applying an equal force to the underside of the board, FEA simulations could be run that closely resemble a real life scenario.

The wake team is currently still running FEA simulations on all of the different composite types. The first simulations were recently finished, however, there seems to be a significant deviation from the expected results, therefore, the team will be trying to redo these tests. It is assumed right now that the error stems from the material properties associated with the design. They will be researched more thoroughly in the coming weeks and the FEA will be completed as soon as all the input data is confirmed to be correct.

3.4.3 Primary Components and Rough Budget

The team estimated a rough budget that would be used for both semesters to help research and construct our composite stand-up paddleboard that can be found Appendix D2. The budget consisted of 9 items that were taken into account based on quantity and price. This semester, the spending is under the estimated total because of donations and discounts that were received. Next semester's budget will consist of many hardware and SUP accessories plus the foam blank that will possibly be pre-sanded from Marko foams. The team is considering a pre-made foam blank that will be based on the CAD model because of the health hazards of sanding foam in an open area and not having proper respiratory masks.

WORK-PLAN STATUS

4.1 Task Descriptions

There were many tasks that had to be completed on schedule to keep the SUP project on time. A Gantt chart was created to help assist with identifying tasks and the time needed to complete them. There were a total of 9 tasks for the composite SUP for the fall semester of the senior design project. The Gantt chart was approved through BoardSport Technologies Enterprise and

Dr. Dan Seguin and can be found in Appendix D of this report. The tasks are listed as assignments on the Gantt chart.

Before the start of the project, both the project proposal and the Gantt chart had to be developed and distributed for approval. The project proposal was approved before the start of the school year, and the Gantt chart was finished by week two.

Research is a vital portion of the project. The members of wake team continuously researched in order to solve problems and learn the industry standard as well as the new and experimental methods for constructing a paddleboard. Research started week one and should always be continued.

Research was required to be started before a budget could be completed. The BoardSport's treasurer approved this budget, found in Appendix D. The budget lists specific items that are to be purchased. The budget is final once it is submitted, so the components needed for the entire project must be fully researched and included.

The selection of possible materials is done through CES Edupack. The material selections, 3 foams and 3 fibers, are the materials that are to be physically tested as different composites. The selection of possible materials can be considered the design of possible composites.

The design of the samples goes hand in hand with the design of the testing parameters. First the standards were selected, based off of what the tests were trying to measure. Once the tests were selected, the ASTM standards were used to calculate a sample size for each test. This size was selected and the coupons were made and cut out. The last part of the testing parameter design was to get trained on the machines and ensure that the sample size and standards were possible.

A CAD model was needed to represent the paddleboard that will be manufactured next semester. The model is used in the milling and shaping of the board as well as performing FEA on the board to simulate how the foam and fiber selections would react to different stresses placed on the board.

The testing machines for the 3-point and 4-point bend tests are located in the Minerals and Materials building at Michigan Technological University. The testing provides data for a final analysis of the composites and helps select the proper composite for a high performance board.

The final material selection is the last objective to be done during the first semester. Using Minitab, the data from the testing is to be analyzed and a choice should be made on the best composite.

4.2 Timeline

An outline of tasks that were to be completed was developed last year during the project proposal. This outline was then refined and added to by week 2 of the semester. This Gantt chart was followed for the entire semester thus far.

There were several difficulties that were encountered when working along the developed timeline. The most significant of these was an issue with the Shop that BoardSport Technologies works out of. It was discovered halfway through the year, after OSHA visited the shop, that the shop did not have proper air handling equipment in place for the handling of epoxy fumes and fiberglass or epoxy dust. This caused all manufacturing operations to stop until proper air filters were put into place.

Wake team avoided major hold ups by working on the design portion of the project and moving to different areas of campus to mix epoxy and layup the samples. After the new filters were installed, the team was able to cut out the samples for testing and still stay on schedule. The complete Gantt chart can be found in Appendix D1.

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[6] *CES Edupack*. Cambridge, United Kingdom: Granta Design, 2015.

APPENDIX A

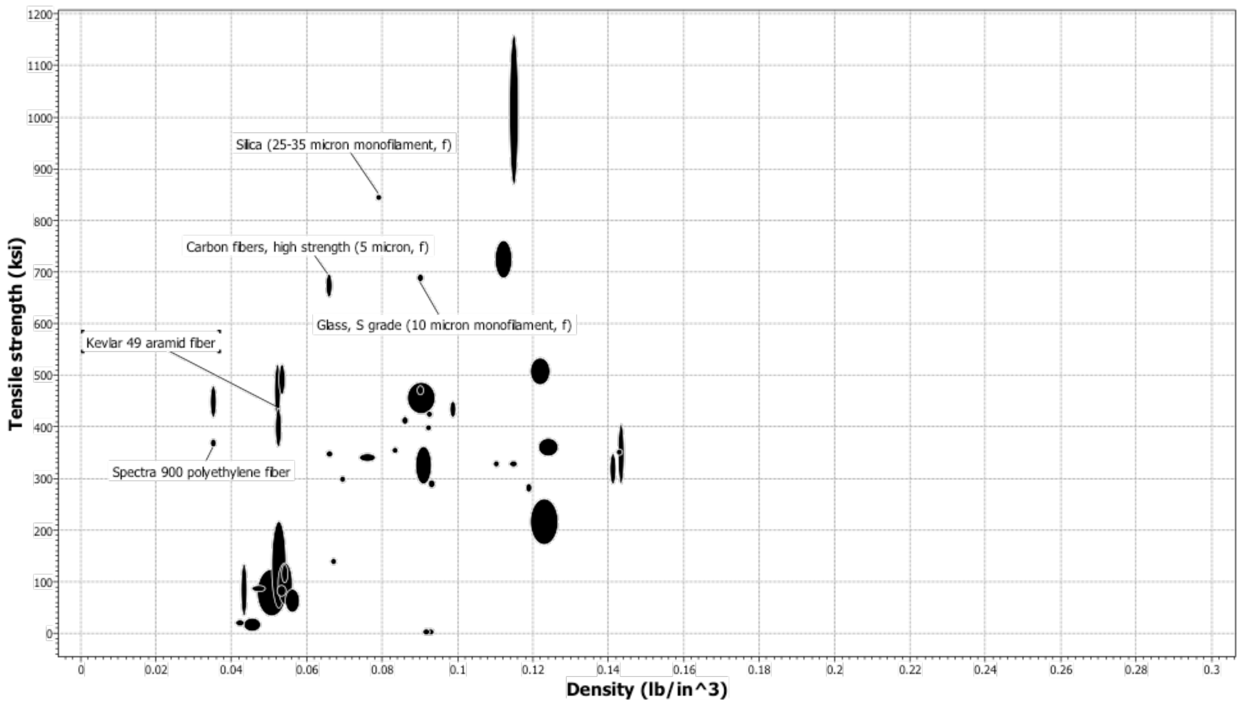

Figure A1: CES Fiber Graph of strength versus density. This shows the comparison of fibers that meet both standards. Fibers of interest are labeled.

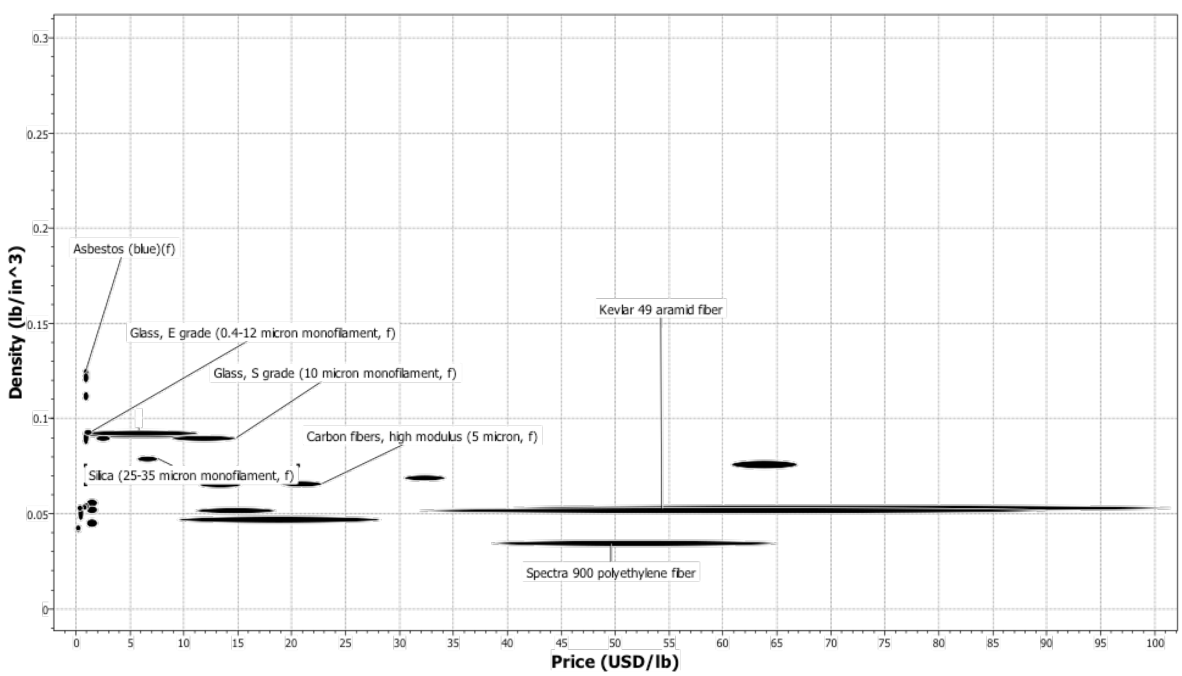

Figure A2: CES Fiber Graph of density versus price. This shows the comparison of fibers that meet both standards. Fibers of interest are labeled.

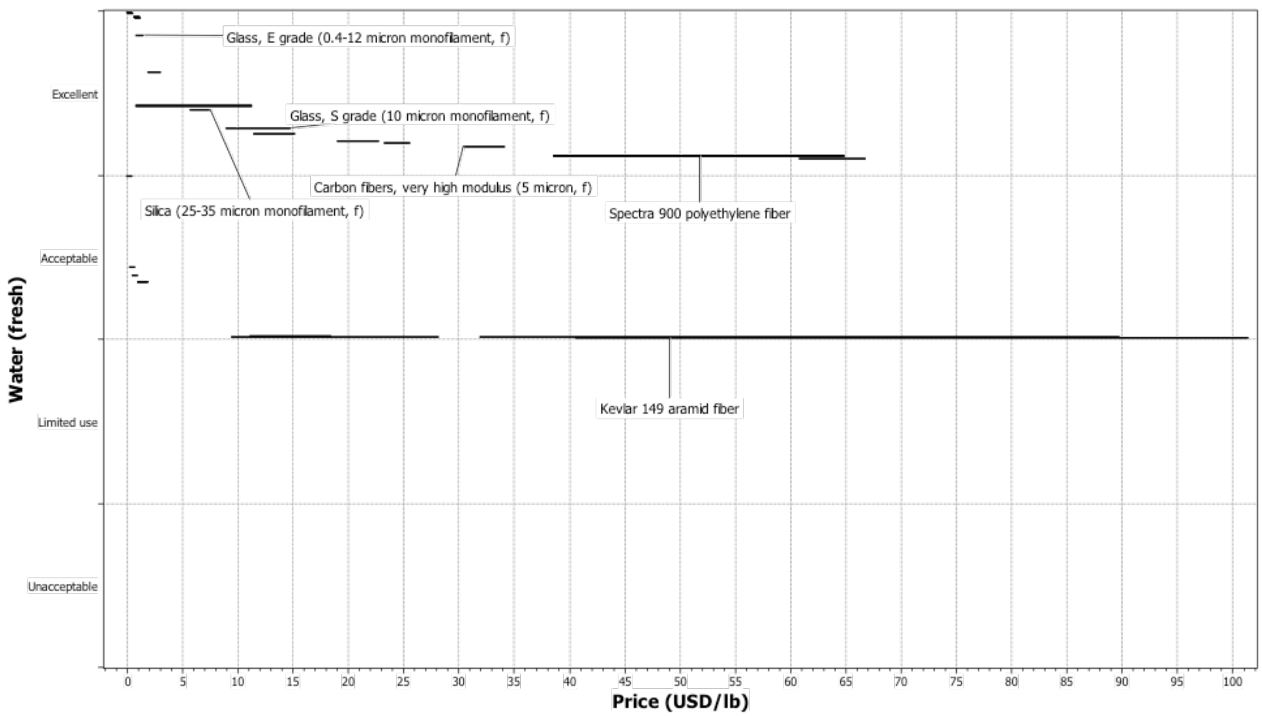

Figure A3: CES Fiber Graph of water acceptability versus price. This shows the comparison of fibers that meet both standards. Fibers of interest are labeled.

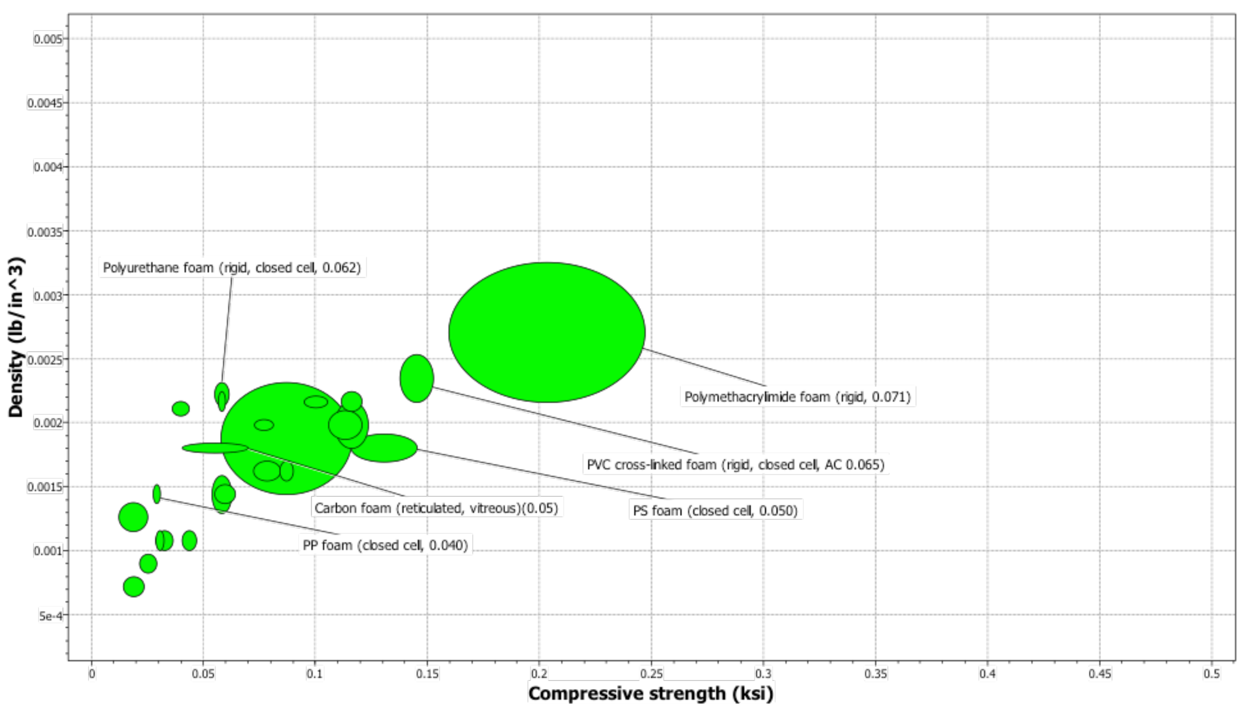

Figure A4: CES Foam Graph of density versus compressive strength. This shows the comparison of foams that meet both standards. Foams of interest are labeled.

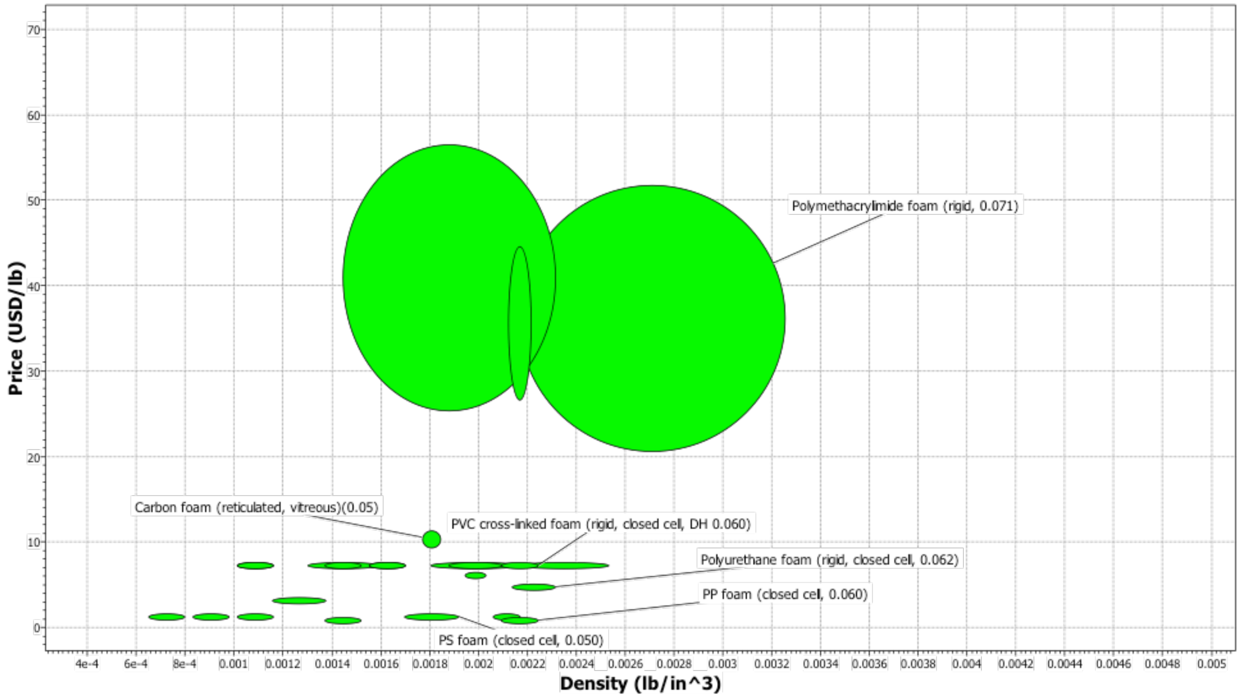

Figure A5: CES Foam Graph of price versus density. This shows the comparison of foams that meet both standards. Foams of interest are labeled.

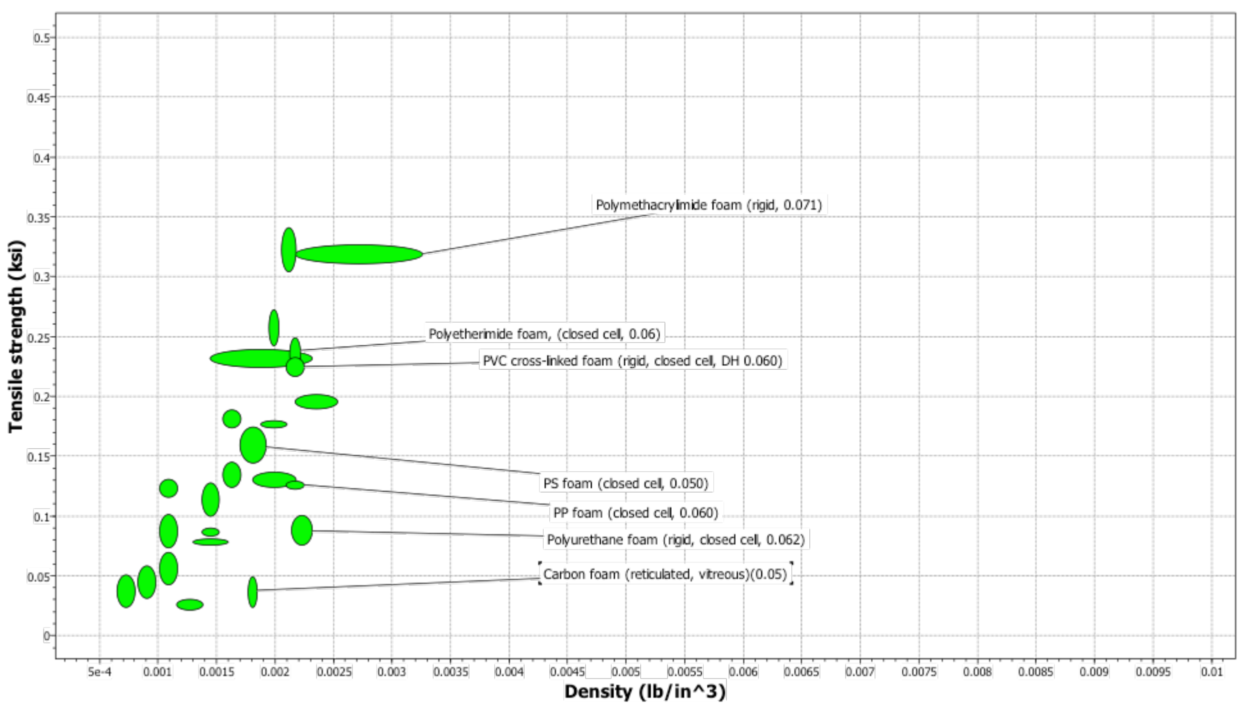

Figure A6: CES Foam Graph of tensile strength versus density. This shows the comparison of foams that meet both standards. Foams of interest are labeled.

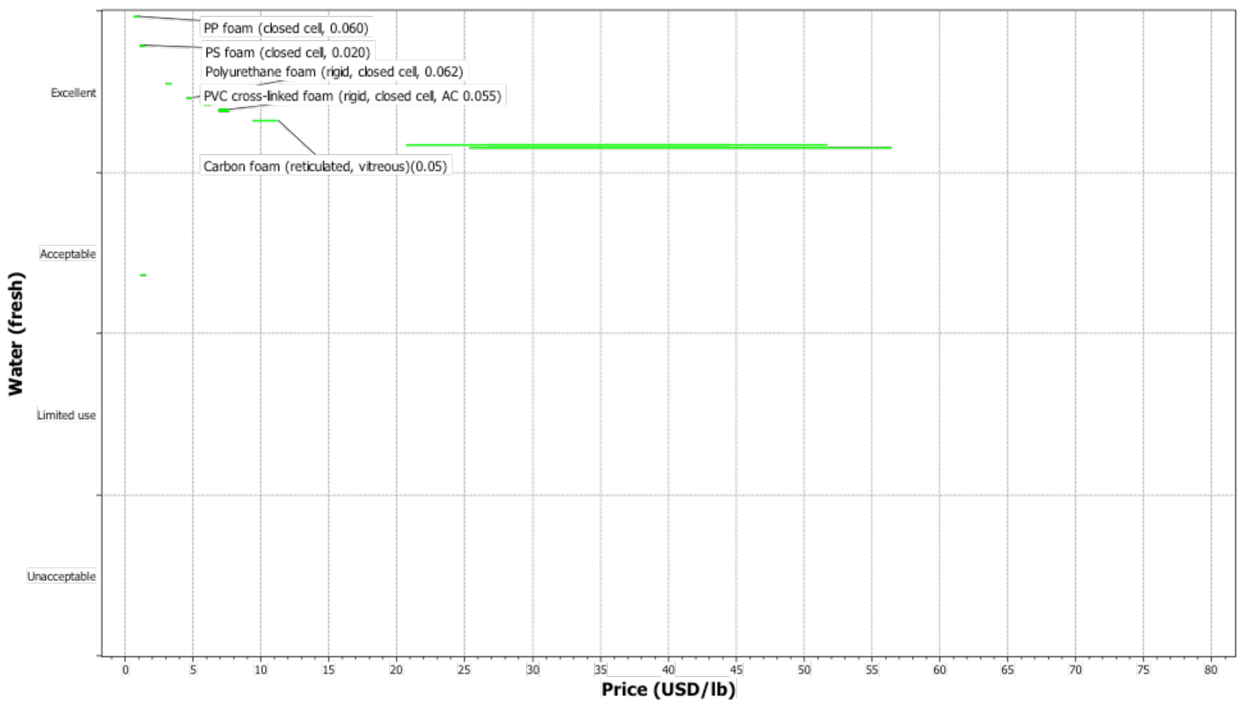

Figure A7: CES Foam Graph of water acceptability versus price. This shows the comparison of foams that meet both standards. Foams of interest are labeled.

APPENDIX B

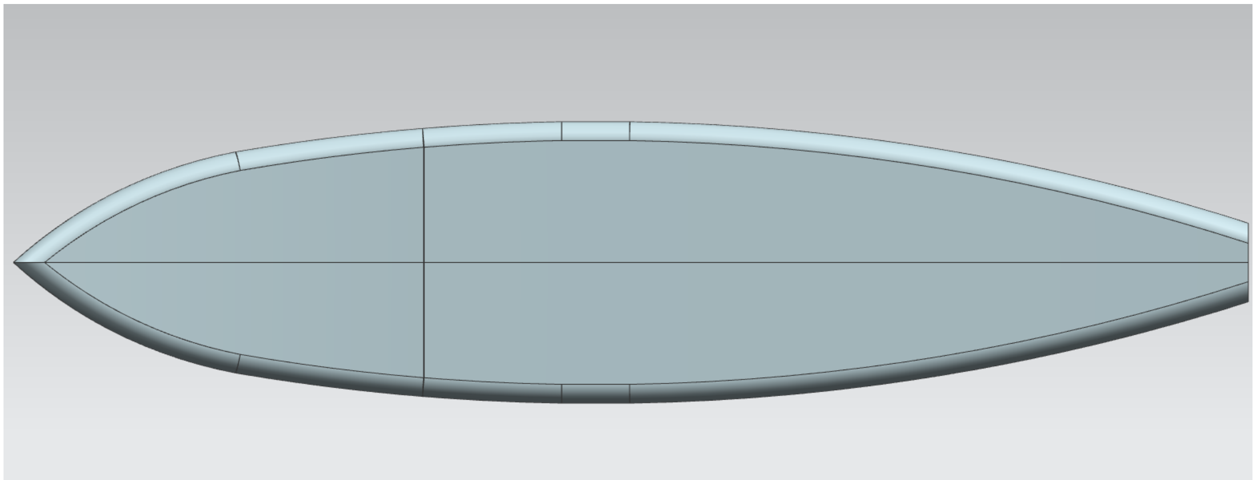

Figure B1: Top view of the SUP model.

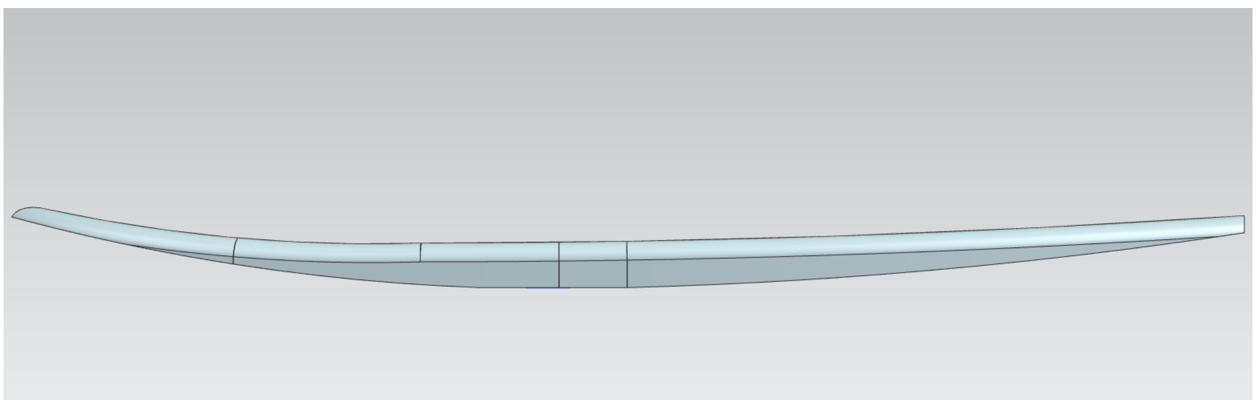

Figure B2: Side view of the SUP model.

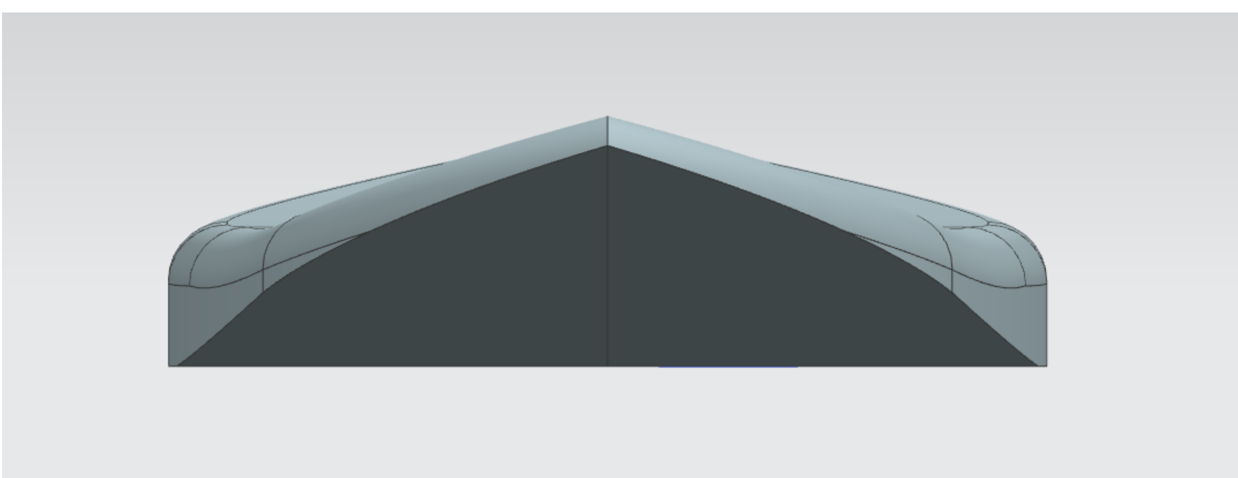

Figure B3: Front view of the SUP model.

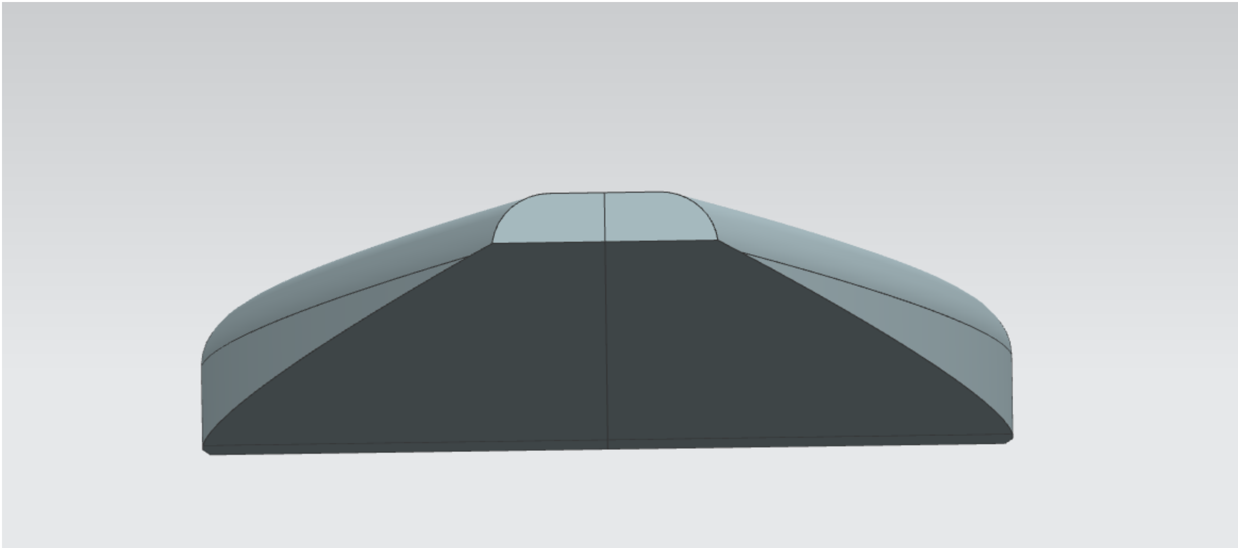

Figure B4: Rear view of the SUP model.

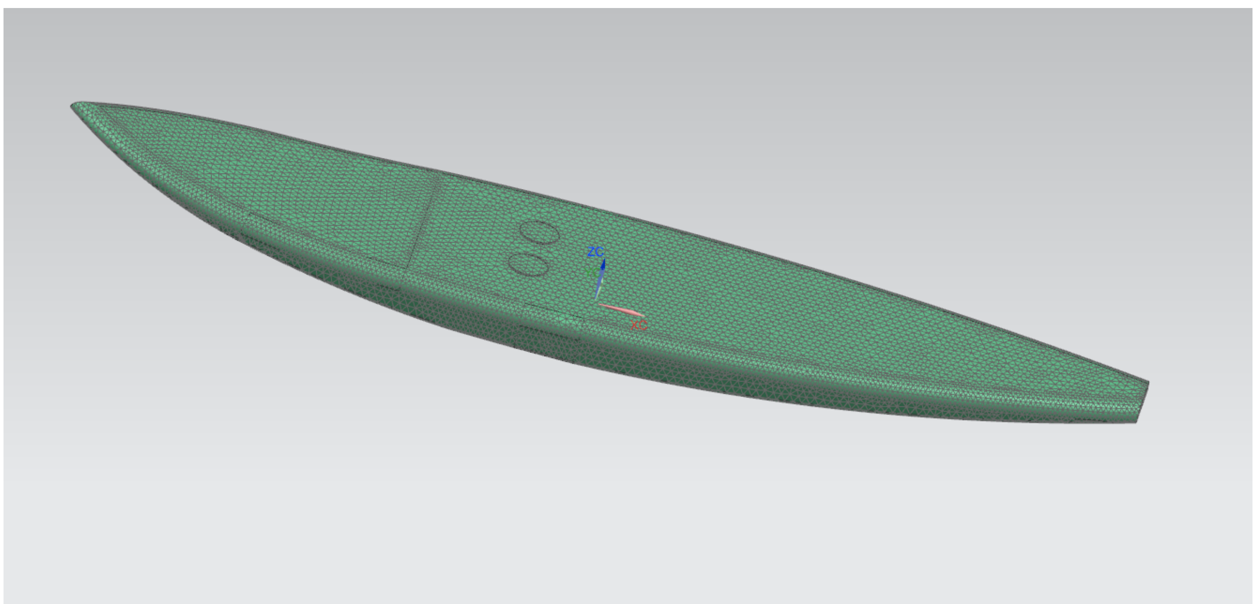

Figure B5: Meshed FEA of the SUP model. The circular extrusions are the expected foot positions of a rider.

APPENDIX C

Figure C1: Composite samples prior to testing

APPENDIX D

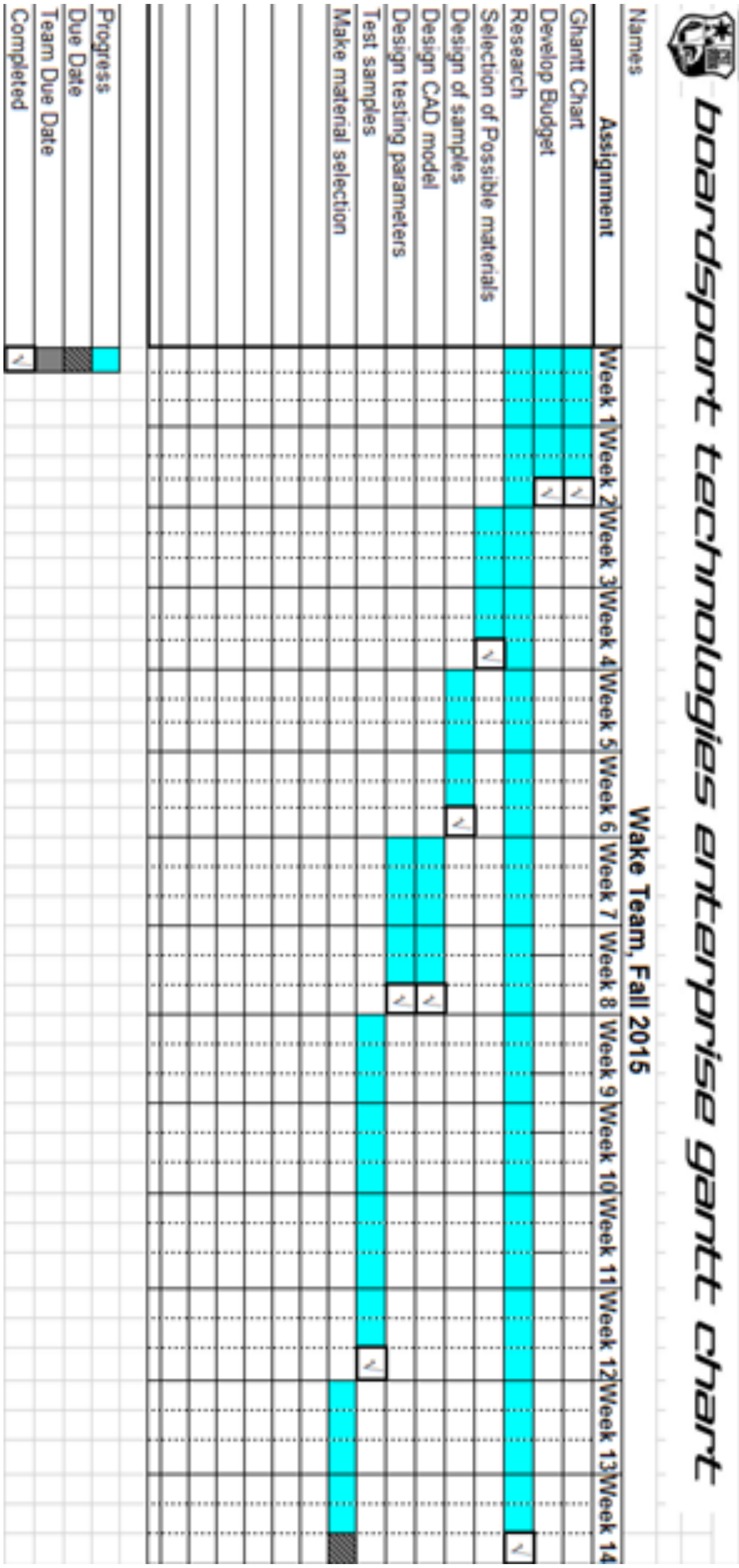

Figure D1: Gantt chart for the fall semester

Composite Paddleboard Budget

Cleyton Cavallaro
Chris Grace
David Swanson

Item	Estimated Cost	Description
Foam Blank	$200	Marko SUP Foam Blanks
Sample Materials	$100	Materials used for testing composites, fibers and foam
Final Materials	$60	Fiber
Sample Testing	$60	All machines needed for testing are pay by the hour. $20/hr for mechanical testing. expected use - 3 hours
Paddleboard Fin	$23	FCS Longboard Series Dolphin Glass Flex SUP fin black 8 in.
Hardware	$22	Bolts for fin, handle for carrying
Paddleboard grip	$40	Dakine Longboard Pad
Paddleboard paddle	$55	Blue Wave Sports 2-piece Adjustable Aluminum Stand Up Paddleboard Paddle
Epoxy	$240	Super SAP INF 3 gallons
TOTAL	$800	

Figure D2: Estimated budget for the entire year.