EML4551-2

Team 511: Intrepid Hardtop

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Abstract

Intrepid is always working to produce custom boats with the latest innovations. The Intrepid 409 Valor is a popular boat model among consumers. Intrepid wants to further improve this boat by lessening the weight and increasing the aerodynamic abilities of the 409 Valor hardtop. The hardtop weight and shape lower fuel efficiency and vessel range. The weight and shape also negatively affect the stability, top speed, and acceleration of the boat. We are discovering how much we can improve performance through weight and aerodynamic changes to the hardtop.

Our goal is to improve boat performance by making the hardtop lighter and more aerodynamic. We are comparing the current hardtop to airfoils to understand the effects of improved aerodynamic properties on the 409 Valor. Changing the shape of the hardtop to model an airfoil improves lift and decreases drag. Increased lift allows the boat to sit higher in the water when traveling at speed which lessens the wetted surface of the hull. Less hull surface area in the water lowers friction and resistance from water while improving fuel efficiency. The lower friction may also improve acceleration and top speed while adding stability from the air under the hull sides. However, total hardtop shape changes provide no meaningful improvements to vessel performance because a total change adds weight.

Intrepid does not use exotic materials like carbon fiber. Using lower density fiberglass and core foam in the new design will lessen the hardtop weight and lower the center of gravity of the boat. The lower center of gravity lessens the thrust needed during use of the boat, saving fuel. We discovered that switching the fiberglass and core materials used can lessen the hardtop weight by 60%. Combining lightweight materials with a leading and trailing edge shape changes, the boat performance improves.

Keywords: Boat, Hardtop, COMSOL, Simulink, Light weighting

Disclaimer

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Acknowledgement

We would like to thank our sponsor company Intrepid Powerboats for allowing us to use their 409 Valor for our senior design project. Specifically, we would like to thank the president, Ken Clinton, and the vice president of engineering, Richard Ahl, for their help, advice, and continued interest during this project. Without Intrepid, our senior design project would not have been possible, as the whole project is based on the 409 Valor hardtop design and other vessel parameters.

We would also like to thank our advisor, Dr. William Oates, for his counseling and advice throughout the process of this design project. Though meetings with him were scarce due to the business of this year, he provided us with helpful insight we did not have and ideas we did not think about. Dr. Oates provided us with very useful information as well as his personal opinions and both went a long way to aid in the progression of our project.

We would like to thank our senior design coordinator, Dr. Shayne McConomy, not only for teaching the class, but for being so close to each project. His understanding of our project allowed for him to guide us and provide crucial opinions and information that helped tremendously to shape our project. Without him, we would not have completed this project. Dr. McConomy also provided us with materials we could physically test with, as we were not provided funding. Though some of the materials never shipped, we are still grateful for the opportunity to build a testing apparatus for further validation of our project. The hands-on part of the project helped us to stay engaged in our project and further the validation of our final recommendation to Intrepid. Thank you!

Lastly, we would like to thank fellow students in our degree program as well as teaching assistants and all others who showed interested in our project. This interest helped us to further our project and stay the course to completion.

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Notation

A	Hardtop Area
ABYC	American Boat & Yacht Council
AHP	Analytical Hierarchy Process
CAD	Computer Aided Design
C_D	Coefficient of Drag
C_L	Coefficient of Lift
COG	Center of Gravity
FEA	Finite Element Analysis
L	Hardtop Length
L-D	Lift to Drag Ratio
NACA	National Advisory Committee for Aeronautics
NMMA	National Marine Manufacturer's Association
t	Material Thickness
V	Boat Velocity
W	Hardtop Width
ρ	Fluid or Material Density
σ	Tensile Strength
τ	Shear Stress

Chapter One: EML 4551C

1.1 Project Scope

Project Description

"The objective of this project is to improve on water performance for the Intrepid 409 Valor."

An issue faced within Intrepid Powerboats is the weight of their hardtops and their aerodynamic properties. These issues cause excess fuel consumption, lower top speed, and reduce the overall performance of the boat. Our team has been tasked with coming up with a solution or series of solutions to solve the issues within the current hardtops. For this specific project, the hardtop we will be using is on the Intrepid 409 Valor boat model and the design changes will then be implemented within Intrepid for the rest of their fleet.

Key Goals:

The primary goal, according to Intrepid, is improving vessel performance on water. Weight reduction for the hardtop assembly can be a contributing factor to improvements in on water performance. Another goal of this project is improving fuel efficiency. Analyzing and possibly altering hardtop shape and angle of attack may affect trim angle, plane speed, fuel efficiency, and on water performance. Once analysis of the current hardtop is done, improvements to the shape, angle of attack, and aerodynamics may be possible. Another goal is to improve lift and reduce hull-water friction. Changes to the characteristics above can positively affect the boat in the areas of running angles, fuel efficiency, plane speed, and lift generated. Also, if more lift is generated by the hardtop, the boat will run higher out of the water causing less hull surface area to be in contact with the water which reduces friction, improving running capabilities and fuel efficiency of the vessel. Another goal is to stay within Intrepid's manufacturing tolerances and capabilities. This will allow Intrepid to continue to manufacture their own hardtops while keeping the design feasible, which in turn reduces cost and manufacturing time. Though not desired, an increase in cost may be acceptable if the cost incurred is outweighed by the improvement in weight savings, aerodynamic characteristics, and other areas, because the main goals are performance oriented.

Assumptions:

We are assuming that cost constraints will be considered at all phases of design. Therefore, the budget needs to be kept to a minimum, so most analysis may be done virtually. Furthermore, one must assume that this improved design will be accepted and implemented by Intrepid. We can assume that these performance changes will be applied solely to the hardtop. The current hardtop supports, like the fiberglass arches and the aluminum support structures, will not be changed or altered in this project. We can assume that the improved hardtop will be attached to the 409 Valor mounting points. We can assume that we will not be altering anything on the boat other than the hardtop. We can assume that we will not physically produce the improved hardtop within the given time frame. We assume manufacturing processes similar to current Intrepid methods will be implemented to produce the new model. We can assume we will be using similar materials to ones currently used and will be focusing on geometric shape of the hardtop more than research of materials.

Stakeholders:

Intrepid Powerboats is a stakeholder for this project as our sponsor. The President of Intrepid, Ken Clinton, and Vice President of Engineering, Richard Ahl, are stakeholders who represent the company. The team advisor, Dr. William Oates, and the Senior Design professor, Dr. Shayne McConomy, are both stakeholders. Other stakeholders include aerodynamics professor Dr. Rajan Kumar, thermal fluids professor Dr. Mohd Yousuf Ali and all members of this senior design team tasked with this project.

Primary Market:

The key markets for these solutions are current and future Intrepid Powerboats customers and the company itself. Since this project is primarily a solution within Intrepid, they are the primary market.

Secondary Market:

Developments in this project have several potential secondary markets. These solutions could be implemented into government projects that require boats to be more fuel efficient and have a higher top speed for agencies such as the Coast Guard, Fish and Wildlife Conservation and other federal bureaus that require powerboat use. Other potential markets would be competitors within the consumer boating industry. Further, lightweight advancements in fiberglass building could be adapted for other industries such as aerospace and defense where strong and lightweight materials are extremely important. Lastly, the improvements found in this project can be applied to the automotive industry to automakers who use fiberglass materials in their vehicles and potentially desire lightweight characteristics.

1.2 Customer Needs

Statement Gathering:

Statement gathering was done via meeting with our project sponsor, Richard Ahl, via Zoom. During this meeting, the team asked a series of questions and recorded his responses to be interpreted for use during our project. The team questioned him about the various technical aspects of the project as well as the parameters that the team should work within. We also requested data pertaining to the project. With these statements taken into consideration, we crafted need statements and a plan on how to address those needs.

Customer Statements & Interpreted Needs:

After speaking with Richard and asking a series of questions, we gained background knowledge necessary to begin this project as well as helpful clues to identify the scope of this project. We acknowledged the customer needs and interpreted them, thus figuring out what is needed to fill those needs. Below is a summary of the questions, customer statements, and interpreted needs. Reference Appendix C for a table with all questions and answers.

Q: What are your objectives for this project?

A: Weight reduction for hardtop assembly and improvements on shape and aerodynamics.

N: The new hardtop will improve boat performance.

The above question directly addresses the key goals of this project, and spurs further thinking on the matter. Richard expressed that Intrepid is always looking for ways to increase boat performance, top speed, efficiency, and quality engineering. Therefore, the improved hardtop will improve boat performance.

Q: What materials need to be considered?

A: Consider materials already being used by Intrepid.

N: The improved hardtop will incorporate materials used within Intrepid's manufacturing constraints.

The above question helps narrow the scope of the project regarding what to consider during material changes within the project itself. Keeping the materials similar to those currently used within Intrepid will help reduce cost during implementation of our solution while keeping the improved hardtop within Intrepid's manufacturing capabilities.

Q: What are the parameters of the current hardtop models in use?

A: Current parameters can be considered through further analysis of the cad model and software highlighted.

N: The improved hardtop dimensions will be similar to the current hardtop dimensions.

This question and the gathered statement shed light on the customers need for us to stay within current hardtop design parameters. This is important for cost and time saving needs and allows the changes to be implemented within current Intrepid manufacturing standards. Keeping dimensions similar allows Intrepid to use the same molding process.

Q: Can we alter the wire/chase tubes layout?

A: The layout can be altered if exit points for the wires are kept the same.

N: The improved hardtop may alter the wire layout while retaining exit points.

This question addresses the topic of if we can make changes to wire/chase tubes in order to accomplish the customer's needs. While we can make changes to the layout, the wires exit points will remain where they are. Therefore, the improved hardtop will retain exit points even if changes occur.

Q: Do you want a generic hardtop, or a design for a specific boat?

A: Use Intrepid 409 Valor hardtop as reference, it is very large and is the best supported hardtop we have. Use it to derive a new design.

N: The improved design will be made for the Intrepid 409 Valor.

This question provides the team with additional parameters when it comes to design. The Intrepid 409 Valor has the largest and most well supported hardtop which will allow us to make changes that can possibly be applied to other hardtops throughout their fleet.

Q: Is there a certain weight that the hardtop needs to be able to withstand?

A: The weight/force of aerodynamic forces and support service techs who stand on top.

N: The improved design will withstand nominal running conditions and loading conditions including a factor of safety.

The hardtop needs to be able to withstand all environments it will encounter as well as all dynamic forces and loads. The hardtop will support a serviceperson who will be working on the boat. This will aid analysis because of these guidelines given by Intrepid.

Explanation of Results:

From what Intrepid gave us, functions we need to focus on are the weight, the shape, the materials, and the design of the hardtop. We started by gathering our statements from our sponsor during our initial meeting. We generated questions to ask during this meeting for use in developing our customer needs. The key takeaway is that we need to focus on light weighting the hardtop while increasing the aerodynamic properties of the hardtop. These changes need to be considered with the new design while retaining manufacturability, keeping cost to a minimum, and staying true to Intrepid’s styling and quality.

1.3 Functional Decomposition

Introduction:

Tasked with improving Intrepid's current hardtop design, we realized that some of the current problems with the hardtop design are the weight and the aerodynamic characteristics and how they affect the vessel performance. Improving the hardtop design will allow us to achieve our key goal of enhancing boat performance among others.

We used the interpreted needs to help shape our functional decomposition process regarding the improvement of the hardtop. Aerodynamics, vessel capability, and weight reduction were among the top areas of discussion. Considering this, our design should be lighter, enhance aerodynamic properties, and advance vessel performance.

Data Generation:

Data was gathered for this project through meeting with our sponsor, Richard Ahl. We asked Richard a series of questions and through his responses were able to interpret his needs and gather the required data to complete the functional decomposition for this project. Richard made it clear that our goal is to lighten the 409 Valor's hardtop while increasing its aerodynamic properties. Richard wants us to accomplish these goals while keeping cost to a minimum. Through this meeting, we were given parameters to work within to meet our customers goal.

Action and Outcome:

The expected action of this project is the improvement of the current hardtop used on the 409 Valor. This action is expected to give outcomes of decreased hardtop weight, improved aerodynamic properties and increased on water performance. The main goal is improving on water performance. This will be accomplished by decreasing the hardtop's weight and improving the hardtop's aerodynamic properties. The lightened hardtop must still maintain enough structural rigidity to support the weight of a service person working on the vessel as well as the aerodynamics forces and loads. The aerodynamic properties needed to be advanced in such a way that any cost expended has a high return on investment in order to keep the improvements practical. Figure 1 below shows our flow from taking actions and outcomes and turning them into systems and functions.

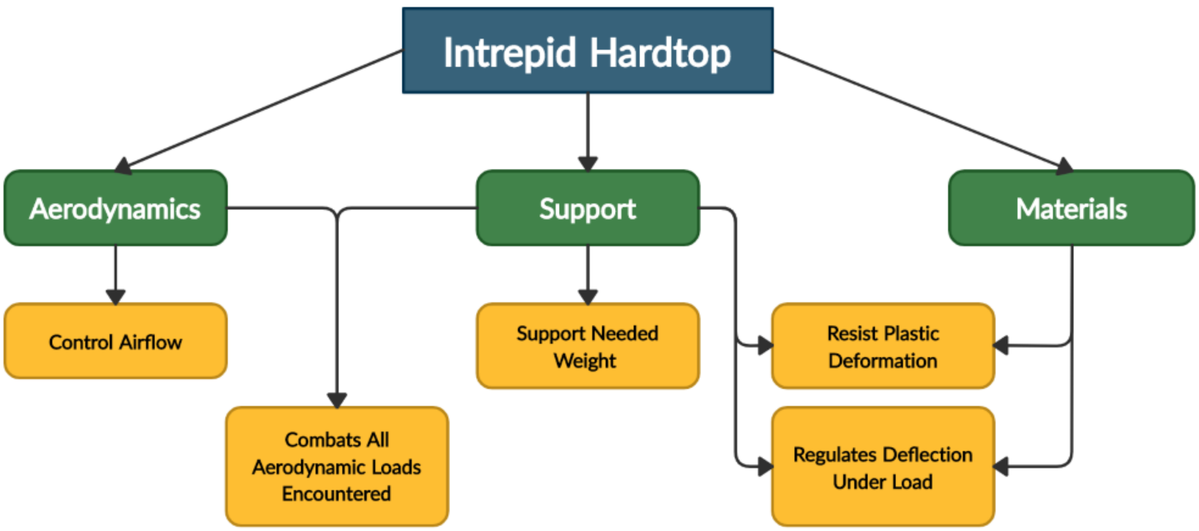


Figure 1: Flow Chart

Smart Integration:

Smart integration shows which functions are interrelated with other systems. This allows for innovating solutions and shows how more can be done with less. Figure 2 below lists all functions and systems and shows which functions impact multiple systems and which functions are singular to one system. The 'Resists Plastic Deformation' function connects the 'Materials' and 'Support' systems. Cyclic plastic deformation could occur overtime from environmental conditions or from increased loading on top of the hardtop from service persons or equipment. Selecting materials that maintain their rigidity overtime when exposed to the elements can possibly help in our improved hardtop. The mechanical properties of the materials will also be important when considering support in the hardtop. The 'Regulates Deflection Under Load' function is a component of both the 'Support' and

‘Materials’ systems. Resisting deflection will help a service technician feel stable and maintain balance while on the hardtop conducting repairs or upgrades. Keeping deflection low can be a result of the materials used to manufacture the hardtop. The ‘Combats All Aerodynamic Loads Encountered’ function relates the ‘Aerodynamics’ and ‘Support’ systems. The design may incorporate certain geometrical changes that allow the hardtop to generate lift or reduce drag while also providing for a more reliable mode of mounting. The hardtop could include shape changes that allow more surface area for mounting, making the hardtop more secure, while contributing to improved aerodynamics in those areas.

Functions / Systems	Supports Needed Weight	Resists Plastic Deformation	Regulates Deflection Under Load	Combats All Aerodynamic Loads Encountered	Controls Airflow
Support	X	X	X	X	
Aerodynamics				X	X
Materials		X	X		

Figure 2: Cross Reference Table

Connection to Systems:

The figure above gives a good visual representation of how the systems and functions are related. For the ‘Support’ system, it is expected that the changes will not affect the hardtop’s ability to hold the necessary weight required by Intrepid. The ‘Support’ system shares functions with the other two systems. The first is the resistance to plastic deformation within both the materials system and the support system. The second is the regulation of deflection under load within both the materials system and the support system. The third function shared between systems is the hardtops ability to combat all aerodynamic loads that are encountered by the vessel while on the water. The system of ‘Aerodynamics’ has a function that is not shared with other systems. This function is controlling airflow during operation. This is important for satisfying our customer’s needs.

The system with the highest priority is the ‘Support’ system. It has the most functions within it as well as sharing the most functions across multiple systems. The reason this system is the highest priority is because without thoroughly achieving these functions, the hardtop will not be able to be implemented onto the vessel. The second highest priority system is the ‘Materials’ systems because it shares multiple functions with the highest priority system and requires all functions in order to complete our project effectively. The ‘Aerodynamics’ function is the lowest priority but is still extremely important to our project because it contains the functions regarding on water performance, a focus of Intrepid’s design.

Function Resolution:

Through innovation and analysis, a hardtop will be developed that withstands all loads while remaining aerodynamic and manufacturability. The hardtop will be mounted in the same fashion as the current design so that it will retain its use on the current Intrepid 409 Valor. Using certain materials to the design’s advantage, we can manipulate the hardtop’s rigidity, structural integrity, and weight to get desired engineering characteristics. The materials used in the design will play a big part in the overall success of the design, and when combined with geometry changes, aerodynamics and airflow can be tailored to the customer’s needs.

1.4 Target Summary

Critical Targets and Metrics:

Function:	Metric:	Target:
Control Airflow	Increased lift-to-drag ratio	Increase by 10%
Combats Aerodynamic Load	Remain below failure strength during operation	Using a safety factor, the hardtop has no failure during all operating conditions.
Support Needed Weight	Remain below failure strength during service and maintenance	Using a safety factor, support the weight of a 200 lb. serviceperson.
Resist Plastic Deformation	Remain within elastic region Stress Induced (sigma = P/A)	Shear stress < Ultimate Tensile stress < Ultimate Max Stress Induced (when considering whole hardtop area): 153 Pascals or 0.022 psi Max Stress Induced (when considering rough area of service person (2ft x 2ft area): 4788 Pascals or 0.694 psi
Regulate Deflection Under Load	Deflection	Support needed force/mass without failure Max deflection 0.25”

Derivation of Targets/Metrics:

We determined the critical targets and metrics through our functions determined previously. These critical targets and metrics are the most important to ensure we can satisfy our customer's needs. Ensuring that the lift-to-drag ratio is increased was a direct request from Intrepid. The ability to withstand all forces is also crucial to ensure that the hardtop can be implemented. We also determined non-critical targets and metrics that are listed in the appendix of this evidence manual. These non-critical targets and metrics are required in order to ensure the new hard top works with the 409 Valor, allowing for success of the design.

How Targets and Metrics Were Determined:

For the “Control Air flow” function, the metric was determined since the new design must be improved compared to the current hardtop. Through calculations and modeling of a similar NACA airfoil we determined that the target for this function would be an increase in lift-to-drag ratio of 10%. We will adjust this value as we research more. We must also consider channel flow between the vessel and the hardtop during these calculations.

The function “Combats Aerodynamic Load” has its metric defined by taking into consideration the safety of the individuals in the boat since the hard top must not fail during operation. This includes a factor of safety of 2, according to Intrepid.

The metric for “Support Needed Weight” was derived by knowing that a service person will have to operate while being on the hardtop, leading to the testing method with the respective factor of safety of 2 to avoid failure. The weight of the service person as well as necessary equipment for maintenance and equipment already attached to the hardtop for operation.

For “Resist Plastic Deformation”, we calculated values for the area of the current hardtop and for the load generated from the service person plus a factor of safety of two. To calculate the stress over the correct amount of hardtop area, we considered a 2-foot by 2-foot section to be representative of the amount of area that the service person’s load would be distributed over, and consequently generated stress values by using the expression shown above in the targets and metrics table. Given the calculated stress values, we can ensure that the new design will not fail, as the calculated stress does not come close to reaching the yield stress of the current materials. Even when considering extraneous load sources like the service person’s tools or the radar equipment that will be mounted on the hardtop, the stresses generated stay below the limits.

We derived the metric for "Regulate Deflection Under Load" to be measuring the stress values with apparatuses, the values for stresses and the required resistances were provided by Intrepid. We chose 0.25" for the deflection value because this is the manufacturing tolerance used by Intrepid.

Discussion of Measurement:

Most of the resources needed to test and validate the above targets will be mathematically oriented. This means that we will need to reference textbooks, class notes, and other educational information to find relationships for the many parameters we are testing and validating. For withstanding the weight of a service person while accounting for the safety factor, we will need to conduct force analysis using free body diagrams as well as test the current and prospective materials for their respective engineering characteristics. For the increased lift-to-drag ratio target, we will need to find a relationship for lift against the hardtop, modeled as a NACA airfoil, to get a number for the current hardtop. We can validate the target of increased lift-to-drag ratio once these numbers are calculated and changes are made.

Method of Validation:

Various testing procedure will be used for the targets and metrics listed above. We will compare the current hardtop used and find a NACA airfoil with a similar profile and improve on it in order to increase the lift-to-drag ratio (sometimes called the aerodynamic or L/D ratio) generated by the hardtop. Using the same profile, analysis will be performed using equations learned in aerodynamics to ensure the new hardtop can withstand the loads encountered during operation. Further, we will perform analysis on the materials selected to ensure that the hardtop can support the weight of the service person performing maintenance. The hardtop needs to resist plastic deformation and we will perform deflection calculations to ensure the hardtop has the proper rigidity.

In order to test lift-to-drag ratio increase, we will find an airfoil with similar properties to the current hardtop and calculate current lift generated for comparison. The coefficient of lift can be increased because density, speed and area should all be kept constant during our experiment. A higher coefficient of lift can be completed from changing airfoil characteristics. This testing will also require testing drag because that is another aspect of lift-to-drag ratio. We must also ensure we avoid flow separation during operation to avoid detrimental air effects.

Calculating the coefficient of drag and the area of the hardtop will be important. The area of the hardtop that encounters air flow will need to be kept to a minimum to achieve the most efficiency. If less area is encountered, the overall force due to drag will be lower. This can be achieved by optimizing the angle of attack that the hardtop is oriented in during the regular usage of the boat or under acceleration or constant speed conditions, so it may be more beneficial to keep the drag coefficient and area exposed to wind to a minimum rather than increase coefficient of lift. Increasing the coefficient of lift may help the vessel to stand out of the water, however, it may also increase the overall drag due to the increased area of the hardtop exposed to wind and may cause the boat to accelerate at a slower rate or lower stability at higher speeds. Values must be calculated to validate whether increasing lift or decreasing drag will be more beneficial for the boat running performance. Overall, we must find the highest lift-to-drag ratio that is achievable for the hardtop.

Further, testing whether it fails during regular operation, we will need to perform analysis of the aerodynamic forces and moments on the hardtop. This should be performed at the highest velocity currently achievable by the vessel to make sure it can handle the most extreme conditions. The lift, drag, axial and normal forces will all need to be calculated and these forces will be carried forward to find moment about the leading edge and quarter chord length. Similarly, calculating failure during service and maintenance requires analysis of forces and moments on the most extreme parts of the hardtop and making sure that the materials are well below failure during this process. For testing deflection, we will assume a small distributed load of the force calculated previously, whether weight of service person or forces during operation, and use deflection equations to calculate the theoretical deflection on the hardtop.

Summary:

The table below shows a summary of all the critical targets our project is expected to hit. A complete catalog of targets, metrics and functions is in the appendix for more detail. These targets are the most critical to this project. The first target is necessary to ensure our design improves on the aerodynamics of the hardtop. The second is to ensure that it does not fail during normal operation. The third ensures that maintenance workers can safely perform their jobs when required to stand on the hardtop. The fourth target ensures that the hardtop has a similar lifecycle to the boat and the last one ensures that the hardtop does not deform.

Increase lift-to drag ratio by 10%	Using a safety factor, the hardtop has no failure during all operating conditions	Using a safety factor and an estimated service person's weight of 200lbs, the hardtop will not fail	Shear stress < Ultimate Tensile stress < Ultimate Max Stress Induced: 4788 Pascals or 0.694 psi	Support needed force/mass without failure Max deflection 0.25"

1.5 Concept Generation

After generation of our 100 concepts (see appendix for full table), we recognized five medium fidelity concepts and three high fidelity concepts. The three high fidelity concepts developed were light weighting the hardtop with less dense fiberglass and resin, altering aerodynamic capabilities (lift, drag, orientation, geometry) to improve boat performance, and the third being a combination of optimization from minimizing material use, aerodynamic changes, and material changes all into one design. The five medium fidelity concepts were to use S-2 glass instead of E-glass, use lightweight thermoplastics instead of fiberglass and foam, install active aero, use a less dense core material to reduce hardtop weight, and to model the hardtop to be a high lift wing.

Concept Generation Tools:

The two concept generation tools we used the most when determining our 100 concepts were the Anti-problem and the Battle of Perspective methods. This is because the nature of our project is that of a non-mechanical design problem. In order to stay creative and generate many ideas, none of the ideas generated were discarded and ideas were thought aloud with the group members. For the 'Anti-problem' we said to ourselves 'We want a hardtop that is heavier and reduces boat performance' and brain stormed ways to avoid this problem and used these in our chart. Thinking of how NOT to solve the problem of improving boat performance helped us to generate many ideas that could potentially solve our problem. For the Battle of Perspectives, we took the perspectives of "Lighter hardtop vs Faster boat" and "Boat buyer vs Boat manufacturer" and created solutions for each side of the perspectives and tried to find common ground while discussing the pros and cons of each.

Medium Fidelity Designs:

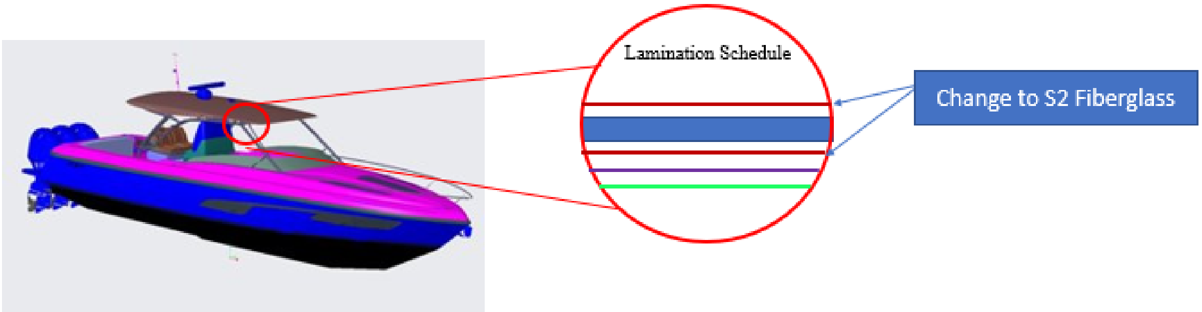


Figure 1: This design replaces the current e-glass with lighter and stronger S2 fiberglass. This was chosen as a medium fidelity item because we believe it will satisfy our customer requirements.

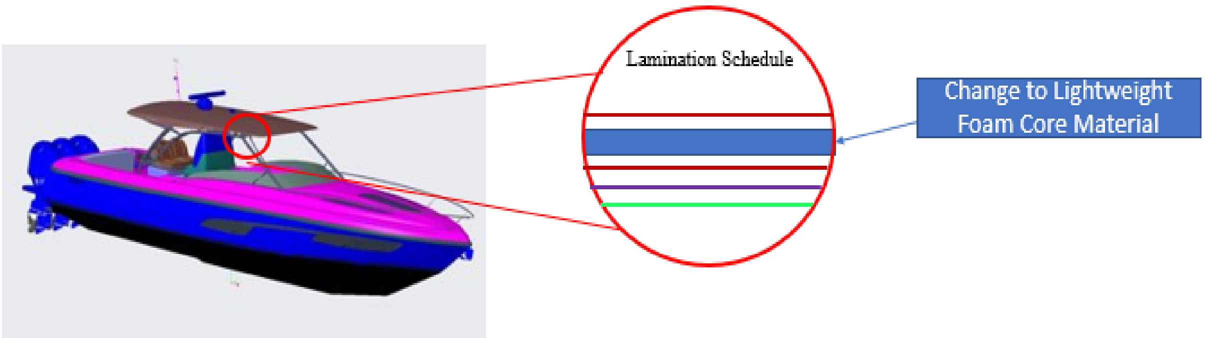


Figure 2: This design replaces the current foam core with a lower density one. This was chosen because the current foam core takes up a lot of volume and using a much lower density core foam will lighten the hardtop significantly.

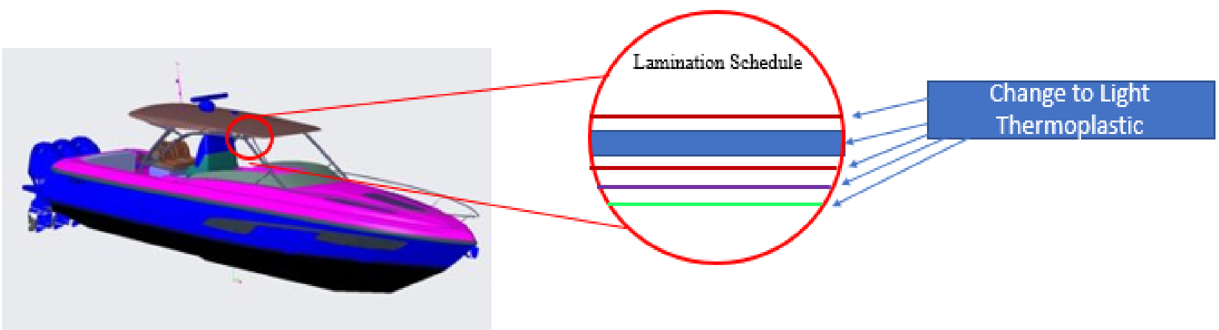


Figure 3: This design replaces the current hardtop materials with a lighter thermoplastic. This was chosen because of the lightweight nature of thermoplastics when compared to resin, foam and fiberglass that is currently used.

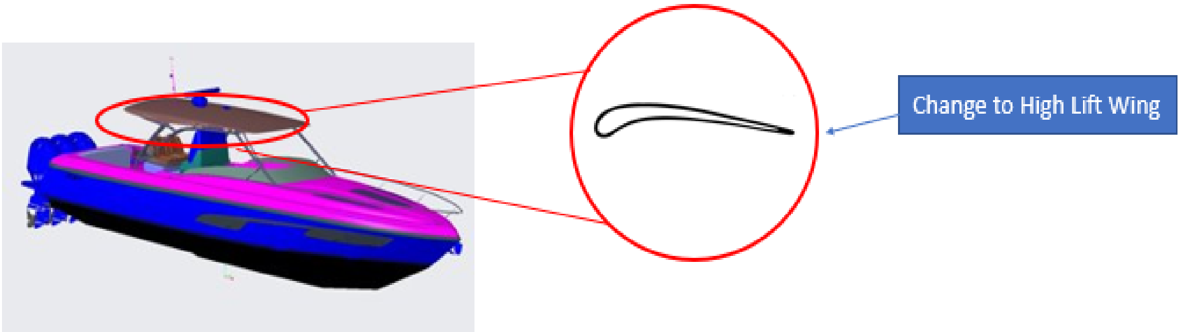


Figure 4: This design replaces the hardtop with a high lift wing design. This was chosen because Intrepid wants the improvements to the hardtop to increase lift generated. This will increase vessel performance by helping get the boat out of the water to reduce friction.

Figure 5: This design implements an active aerodynamics system to help generate lift and decrease drag. While lift generation is important for top speed, having increased drag will have a detrimental effect on performance. The active aero addresses both problems by changing shape to produce lift and changing shape to reduce drag.

High Fidelity Designs:

For the aerodynamic improvements to the hardtop, we will use NACA airfoils to determine benchmarks and compare it to the current hardtop model and the improved hardtop model. The four airfoils we are using for modeling are shown below. These were all found to be airfoils with high lift-to-drag ratios. This design will require several iterations and testing across many different attack angles.

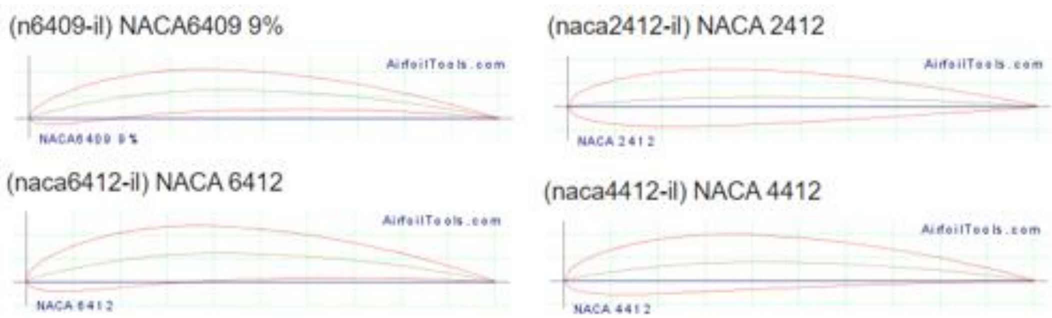


Figure 6: Potential NACA airfoil choices

This can be roughly shown by the picture of the model below where the red colored surface highlights the difference in the mounting surface that offers a different angle of attack and models the hardtop more closely to a NACA 2412 wing, giving it more ability to generate lift. The red surface along with the curvature of the hardtop extends and creates a larger area that is exposed to wind flow, directing the air down and creating lift.

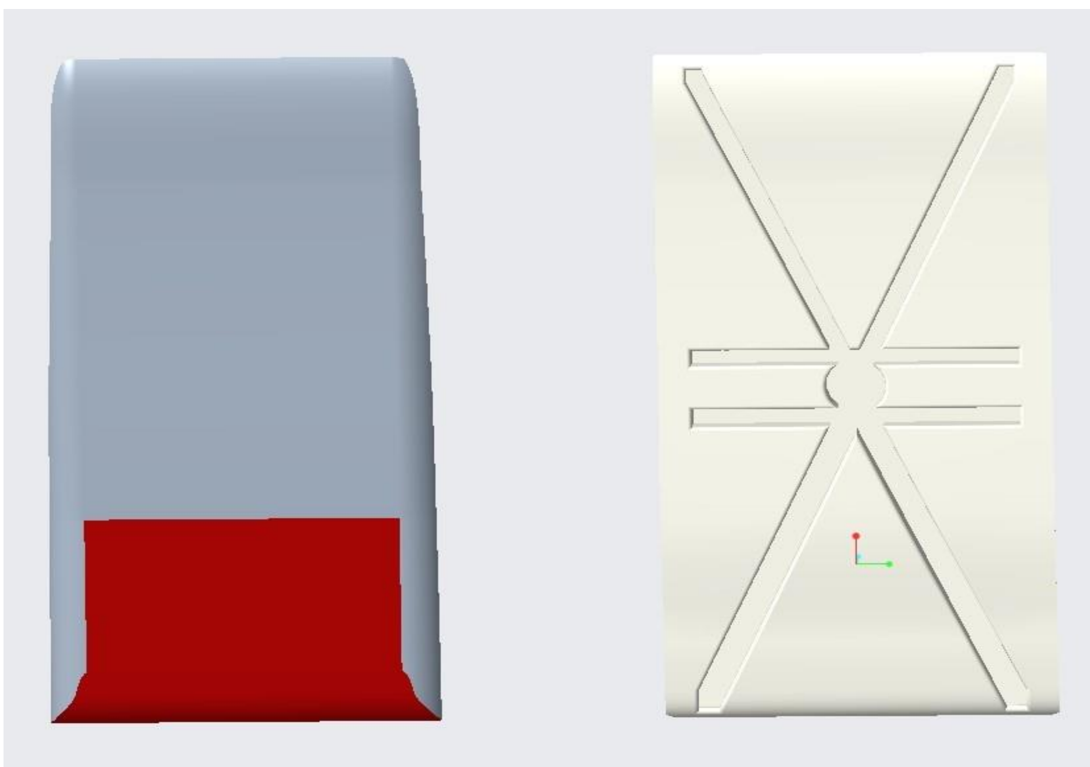


Figure 7: Two high fidelity concepts bottom view. Aerodynamic (left) and optimized (right).

Our second high fidelity design is light weighting the hardtop. This will be accomplished by selecting lower density fiberglass and resin. Our customer specifically requested we light weight the hardtop and that is part of the reason why we chose to move forward with this design. A basic model is shown below in the following pictures attached to the model 409 Valor. Though material changes cannot be seen in the model as the overall hardtop shape is the same, this will cause the hardtop to be lighter, promoting the improvement of on water performance.

Our third high fidelity design is optimizing the hardtop. Shown above next to the aerodynamically enhanced hardtop, the white model shows areas where the wire and chase tubes have been reduced to reduce material and save weight. This can also account for areas of low stress where material can be minimized. This model is a crude model and visualizes the basic concept that will result from optimization. This will be done by performing FEA on the hardtop to check where stress concentrations are and remove material where it is not. This will help reduce overall weight and material cost of the hardtop.

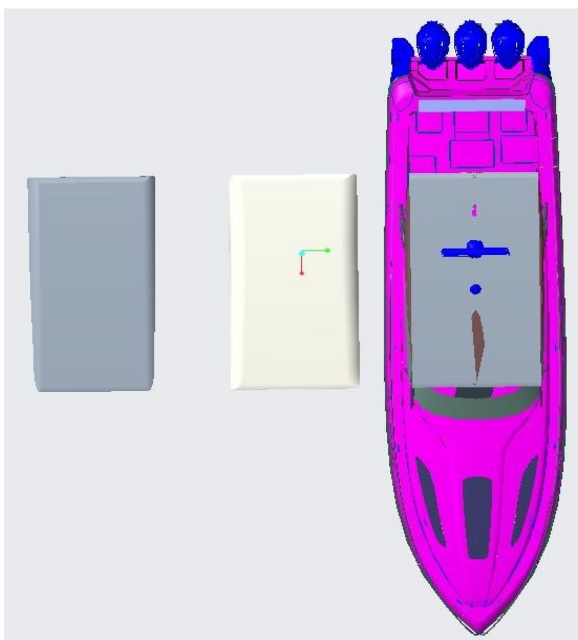


Figure 8: Three high fidelity concepts top down view.
Left is aerodynamic. Middle is optimized. Right is lightweight.

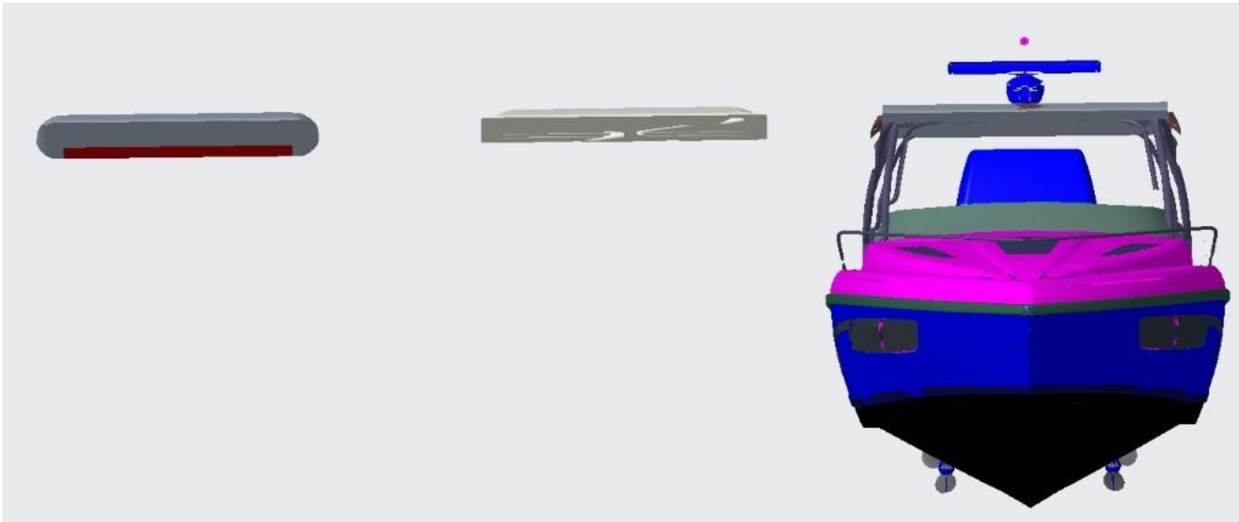


Figure 9: Three high fidelity concepts front view looking aft

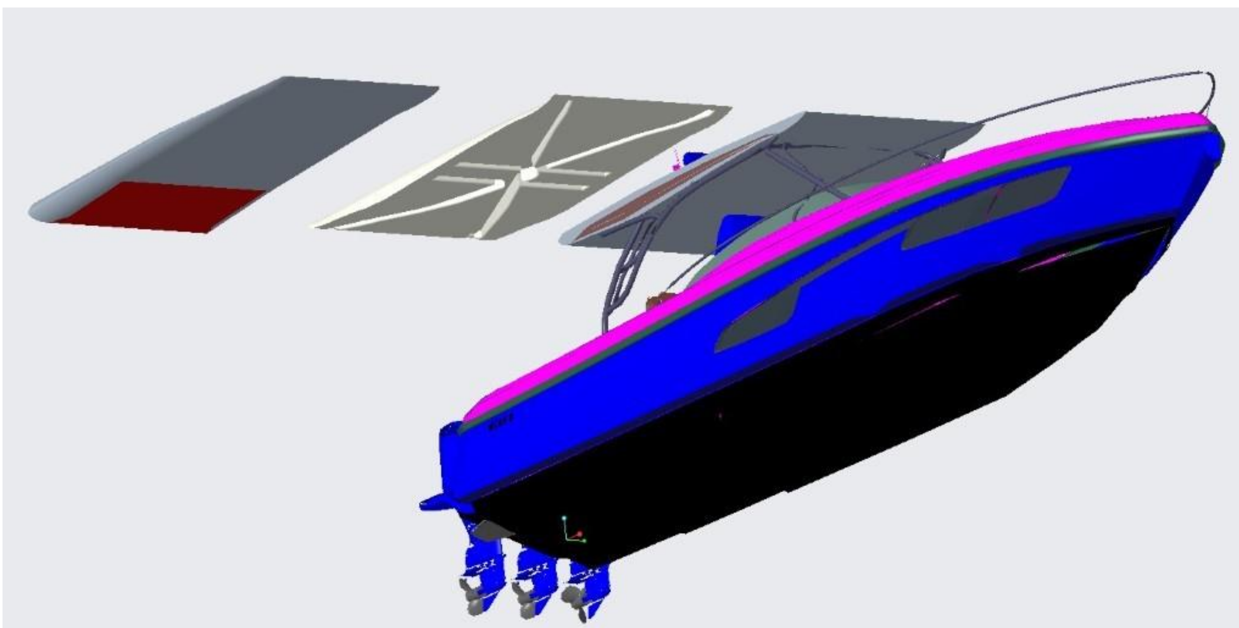


Figure 10: Three high fidelity concepts bottom angle with profile shown

1.6 Concept Selection

Concept Selection:

Following concept generation and selecting five medium and three high fidelity designs, we moved forward to further analyze the designs to ultimately select the one best for our application and project. To do this, we performed multiple analysis and comparison tests. First we started by comparing all the engineering requirements of the designs we were moving forward with in a binary pairwise matrix to find how they are weighted against each other. Following that, we compared the engineering requirements in the house of quality to see how their raw scores compared to each other. From the raw scores, we ranked the engineering requirements to understand which requirements are the most critical to the design success. Pugh charts were then used to show which designs provide the best improvement or meet each engineering requirement the best and allowed us to narrow down the designs we moved forward with after concept generation so that we could perform the analytical hierarchy process. After moving through three iterations of Pugh charts and eliminating three out of the six concepts we moved forward with, we performed the AHP to find which design is best suited for this project.

House of Quality:

For house of quality, we started by finding the importance weight factor for each customer requirement. This was done using the Binary Pairwise Matrix below (moved onto next page to keep together):

Binary Pairwise Matrix	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Total**
1. Supports Needed Weight	-	1	1	0	1	0	0	**3**
2. Resists Plastic Deformation	0	-	0	1	0	0	0	**1**
3. Regulates Deflection Under Load	0	1	-	0	0	1	1	**3**
4. Combats All Aerodynamic Loads	1	0	1	-	1	1	1	**5**
5. Controls Airflow	0	1	1	0	-	1	0	**3**
6. Implementation Cost	1	1	0	0	0	-	0	**2**
7. Manufacturability	1	1	0	0	1	1	-	**4**
Total	3	5	3	1	3	4	2	

Table 1: Binary Pairwise Comparison

The binary pairwise comparison in Table 1 above resulted in weight factors of all the customer requirements ranked by importance. The customer requirements that have the greatest weight are ‘Combats All Aerodynamic Loads’, with the overall highest importance with a ranking of 5. Then ‘Manufacturability’ coming in as the second highest importance with a ranking of 4. These weighed the most because the hardtop needs to achieve both factors for Intrepid to be satisfied with our design. The second highest priority importance weight factors were ‘Controls Airflow,’ ‘Regulates Deflection Under Load,’ and ‘Supports Needed Weight.’ These three shared the same importance weight factor and all three are required in order to meet our customers' needs but they play a slightly less pivotal role than ‘Combats All Aerodynamic Loads’ and ‘Manufacturability.’ Controlling airflow, regulating deflection under load, and supporting the needed weight are all necessary functions to create a successful design, but are easier to achieve than airflow control and manufacturability. Therefore, these three are rated lower in the binary pairwise matrix, but still important. The requirements with the lowest importance weight factors are 'Implementation Cost' and 'Resists Plastic Deformation'. Cost is important and if the design returns high improvements in some areas than cost increase can be justified. The hardtop must resist plastic deformation but if it can withstand all the forces and satisfy the previous customer requirements, then it shouldn't plastically deform. Therefore, other requirements are rated higher than resisting plastic deformation because if they are achieved, they most likely account for deformation resistance as well.

Once the importance weight factors were determined, we constructed the House of Quality table below, translating our customer needs into engineering characteristics:

House of Quality	**Units**	lbs.	(in/in) Unitless	inches	lbs	(L/D) Unitless	Dollars ($)
Customer Requirements	**IWF**	Load Bearing Capacity	Strain	Deflection	Hardtop Weight	Lift-to-Drag ratio	Cost
Supports Needed Weight	**3**	9	1	1			
Resists Plastic Deformation	**1**	3	9	1	3		
Regulates Deflection Under Load	**3**	3	1	9	3		
Combats All Aerodynamic Loads	**5**	3				3	
Controls Airflow	**2**					9	
Implementation Cost	**1**						9
Manufacturability	**4**				3		9
Raw Score	202	54	15	31	24	33	45
Relative Weight	-	26.7	7.4	15.4	11.9	16.3	22.3
Rank Order	-	1	6	4	5	3	2

Table 2: House of Quality

The house of quality table is shown above. In this table, the engineering characteristics can be compared to the customer requirements found from functional decomposition on a 1, 3, 9 scale. A rating of 1 means that the characteristic and the customer requirement have a weak relationship, 3 means they have a medium relationship, and 9 means they have a strong relationship and impact on each other. The ranking was left blank if no relationship existed. The ranking order of each characteristic will help us when eliminating concepts from our medium and high-fidelity concepts and selecting the final design, showing which concepts meet the most requirements or create the best resulting boat performance.

Out of the 100 concepts generated earlier during concept generation, we highlighted three high fidelity concepts and five medium fidelity concepts. We further dwindled the list of concepts down to six concepts to move forward with and further analyze for selection, being:

1. Lightweight Hardtop- less dense fiberglass and resin usage.
2. Aerodynamic Hardtop- aerodynamic enhancements regarding lift-to-drag ratio.
3. Optimal Hardtop- FEA used to minimize material in low stress areas for light weighting.
4. Combination Hardtop- light weight, aerodynamic, and optimal changes implemented.
5. S-2 Glass Hardtop- S-2 glass and resin takes place of current fiberglass and resin.
6. High Lift Wing Hardtop- hardtop modeled as high lift wing.

		Concepts					
Selection Criteria	Existing Hardtop	1	2	3	4	5	6
Load Bearing Capacity	DATUM	+	-	s	s	-	s
Strain		s	-	+	-	-	-
Deflection		-	+	+	s	+	+
Hardtop Weight		+	+	+	s	s	+
Lift-to-Drag Ratio		s	+	+	+	+	-
Implementation Cost		s	s	s	s	-	-
Manufacturability		s	s	-	-	-	s
Number of +		**2**	**3**	**4**	**1**	**3**	**2**
Number of -		**1**	**2**	**2**	**2**	**4**	**3**

Table 3: Pugh Chart 1

The first iteration of the Pugh Chart is shown above. This Pugh Chart uses the current hardtop as the datum and compares the new concepts with the current hardtop against our selection criteria. From this Pugh Chart we decided to not move forward with concepts 5 and concepts 6 because they had the most negatives. We did, however, decide to use concept 5 as our datum for the next Pugh Chart because it did have several pluses.

		Concepts			
Selection Criteria	Concept5	1	2	3	4
Load Bearing Capacity	DATUM	+	s	+	+
Strain		+	s	+	s
Deflection		-	s	s	-
Hardtop Weight		+	+	+	s
Lift-to-Drag Ratio		s	+	+	+
Implementation Cost		+	s	s	s
Manufacturability		+	+	s	-
Number of +		**5**	**4**	**4**	**2**
Number of -		**1**	**0**	**0**	**2**

Table 4: Pugh Chart 2

The second iteration of the Pugh Chart shown above uses the fifth concept, using S-2 glass in place of current fiberglass, as the datum and compares the first 4 concepts. From this Pugh Chart we decided that we will move forward in our final Pugh chart with concepts 1,2 and 3. In the following Pugh Chart, we will use concept 4 as the datum. We decided to move forward with the fourth concept as the datum because it had the least number of pluses and the most minuses.

Selection Criteria	Concept 4	1	2	3
Load Bearing Capacity	DATUM	s	-	s
Strain		s	s	s
Deflection		s	s	s
Hardtop Weight		+	s	+
Lift-to-Drag Ratio		-	+	-
Implementation Cost		+	+	+
Manufacturability		+	+	+
Number of +		**3**	**3**	**3**
Number of -		**1**	**1**	**1**

Table 5: Pugh Chart 3

For this final iteration of the Pugh Chart, we compared our first three designs against the fourth design. From this Pugh Chart we ended up with all three concepts having the same number of pluses and minuses. This will be taken into consideration when we begin our Analytical Hierarchy Process (AHP). All three designs had 3 pluses and one minus when compared with the fourth design datum.

Analytical Hierarchy Process:

Final Rating Matrix			
Selection Criteria	Lightweight Hardtop	Aerodynamic Hardtop	Optimal Hardtop
L.B.C.	0.1996	0.6008	0.1996
Strain	0.1996	0.6008	0.1996
Deflection	0.1996	0.6008	0.1996
Hardtop Weight	0.1429	0.7143	0.1429
L-D Ratio	0.7143	0.1429	0.1429
Overall Cost	0.0858	0.42929	0.42929
Manufacturability	0.1429	0.1429	0.7143

Table 6: Final Rating Matrix

The table above shows the final rating matrix that the analytical hierarchy process allowed us to create. The complete analytical hierarchy process can be seen in the appendix. For load bearing capacity, strain and deflection, the optimized hardtop and the light weighted hardtop were the top performers for those selection criteria. The optimized and lightweight hardtops also performed best when it came to hardtop weight. This is because the aerodynamic hardtop does not directly address hardtop weight while both the optimized hardtop and lightweight hardtop designs do. However, the aerodynamic hardtop design may greatly increase the lift-to-drag ratio which is a major criterion that Intrepid wants focused on. For overall cost, the lightweight hardtop has the best rating because the other two require significant mold changes and tooling hours. For manufacturability the lightweight hardtop and the aerodynamic hardtop are deemed the most manufacturable because they share the most similarities to the current hardtop model so require less changes to be made.

The rating for each engineering characteristic were considered and through several matrix operations that can be seen in the appendix, alternative values were generated. These alternative values are shown below and played a pivotal role in selecting the design we chose to move forward with:

Concept	Alternative Value
Lightweight Hardtop	0.27235
Aerodynamic Hardtop	0.39712
Optimal Hardtop	0.31943

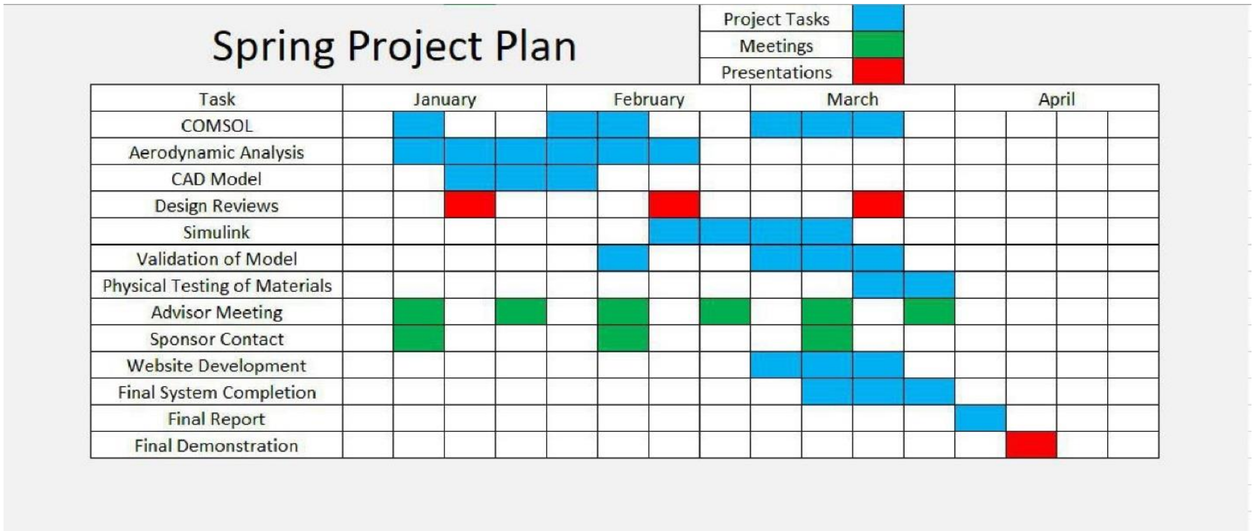
Table 7: Alternative Value Table

The alternative values table above shows which design best fits our selection criteria. From this we decided to move forward with a combination of the three because of how close the alternative values all were. While the aerodynamic hardtop has the highest alternative value, it is important to intrepid that we lightweight and optimize the hardtop as well. The most improvement will come from the aerodynamic properties of the hardtop but light weighting the hardtop is paramount to ensuring customer satisfaction. Given these alternative values and the ratings of our high fidelity designs, we have selected a final design.

Final Selection:

We wish to combine all three possible ways of improvement into one ideal design. The final design using the different methods above can be optimized for material minimization using FEA and mathematical methods, can be light weighted through different material usage, and aerodynamically enhanced through geometric or orientation changes. This design that could be crafted combining all designs mentioned in the AHP adequately fulfills both the engineering characteristics and the customer requirements and brings about the new model that will most improve the performance of the 409 Valor. This model will continue to be improved on during the iteration process. While not selected, we may still consider moving forward with the creation of 3 subset models for each individual characteristic of the combined ideal hardtop as well as with the ideal hardtop. We may consider creating full designs for just light weighting from material changes, aerodynamic enhancements from geometrical and orientation changes, and optimization through material minimization, so that there may be a plethora of design options at the end that may range in performance ability and cost.

1.8 Spring Project Plan



Chapter Two: EML 4552C

2.1 Restated Project Definition and Scope

Project Description:

"The objective of this project is to improve on water performance for the Intrepid 409 Valor by manipulating hardtop parameters."

An issue faced within Intrepid Powerboats is the weight of their hardtops and their aerodynamic properties. These issues cause excess fuel consumption, lower top speed, and reduce the overall performance of the boat. Our team has been tasked with coming up with a solution or series of solutions to solve the issues within the current hardtops. For this specific project, the hardtop we will be using is on the Intrepid 409 Valor boat model and the design changes will then be implemented within Intrepid for the rest of their fleet.

Key Goals:

The primary goal, according to Intrepid, is improving vessel performance on water. Weight reduction for the hardtop assembly can be a contributing factor to improvements in on water performance. Another goal of this project is improving fuel efficiency. Analyzing and possibly altering hardtop shape and angle of attack may affect trim angle, plane speed, fuel efficiency, and on water performance. Once analysis of the current hardtop is done, improvements to the shape, angle of attack, and aerodynamics may be possible. Another goal is to improve lift and reduce hull-water friction. Changes to the characteristics above can positively affect the boat in the areas of running angles, fuel efficiency, plane speed, and lift generated. Also, if more lift is generated by the hardtop, the boat will run higher out of the water causing less hull surface area to be in contact with the water which reduces friction, improving running capabilities and fuel efficiency of the vessel. Another goal is to stay within Intrepid's manufacturing tolerances and capabilities. This will allow Intrepid to continue to manufacture their own hardtops while keeping the design feasible, which in turn reduces cost and manufacturing time. Though not desired, an increase in cost may be acceptable if the cost incurred is outweighed by the improvement in weight savings, aerodynamic characteristics, and other areas, because the main goals are performance oriented. The final key goal is to be able to provide a recommendation to Intrepid on what direction would be best for hardtop improvements.

Assumptions:

We are assuming that cost constraints will be considered at all phases of design. Therefore, the budget needs to be kept to a minimum, so most analysis may be done virtually. Furthermore, one must assume that this improved design will be accepted and implemented by Intrepid. We can assume that these performance changes will be applied solely to the hardtop. The current hardtop supports, like the fiberglass arches and the aluminum support structures, will not be changed or altered in this project. We can assume that the improved hardtop will be attached to the 409 Valor mounting points. We can assume that we will not be altering anything on the boat other than the hardtop. We can assume that we will not physically produce the improved hardtop within the given time frame. We assume manufacturing processes like current Intrepid methods will be implemented to produce the new model. We can assume we will be using similar materials to ones currently used and will be focusing on geometric shape of the hardtop more than research of materials.

Stakeholders:

Intrepid Powerboats is a stakeholder for this project as our sponsor. The President of Intrepid, Ken Clinton, and Vice President of Engineering, Richard Ahl, are stakeholders who represent the company. The team advisor, Dr. William Oates, and the Senior Design professor, Dr. Shayne McConomy, are both stakeholders. Other stakeholders include aerodynamics professor Dr. Rajan Kumar, thermal fluids professor Dr. Mohd Yousuf Ali and all members of this senior design team tasked with this project. Dr. Shih is also a stakeholder and may help with testing and methods of numerical validation.

Primary Market:

The key markets for these solutions are current and future Intrepid Powerboats customers and the company itself. Since this project is primarily a solution within Intrepid, they are the primary market.

Secondary Market:

Developments in this project have several potential secondary markets. These solutions could be implemented into government projects that require boats to be more fuel efficient and have a higher top speed for agencies such as the Coast Guard, Fish and Wildlife Conservation and other federal bureaus that require powerboat use. Other potential markets would be competitors within the consumer boating industry. Further, lightweight advancements in fiberglass building could be adapted for other industries such as aerospace and defense where strong and lightweight materials are extremely important. Lastly, the improvements found in this project can be applied to the automotive industry to automakers who use fiberglass materials in their vehicles and potentially desire lightweight characteristics.

2.2 Results & Discussion

The material switches examined were that of fiberglass and core materials. The gelcoat and chopped strand mat were not examined for material changes as well as resin because the gelcoat and CSM are necessary for retention of surface finish and are directly related to mold security and waterproofing. All resins have similar densities and absorption properties, so the same resin was retained.

When the fiberglass was switched from E-BXM 1208 Fiberglass to S-2 Fiberglass, the overall hardtop weight was lessened by 18.3%. A cost increase was noticed due to the material switch but offset because of desirable reduction in overall hardtop weight. When the core was changed from Aircell T-100 to Divinycell H-45, a 42.7% weight reduction in overall hardtop weight was experienced as well as a cost reduction between materials. When both materials were changed, a total weight reduction of 60.1% was noticed, bringing the total hardtop weight from 327 pounds down to 127 pounds. A total weight difference of 200 pounds was seen with material switches.

When examining the current hardtop geometry aerodynamic characteristics, it was found that the current geometry has a beneficial L-D ratio compared to other geometries with similar thickness. Airfoil geometry at the chord length of 15 feet, which is the length of the hardtop, has far better L-D ratio ability, however this is undermined by the parasitic increase in hardtop weight. At full thickness, airfoil geometry retains a much more desirable L-D ratio when compared with the current hardtop L-D ratio but is far thicker and more than quadruples in overall weight. This directly goes against Intrepid's goal of lessening the hardtop weight. Not only does it work against the goal of lessening weight, the performance of the 409 Valor would not improve because of this change either. The benefits seen from increasing the lift would be squashed by the large increase in total weight; not to mention the shift of the boat center of gravity upward, which would reduce stability of the boat and increase the thrust necessary to travel at speed. The current hardtop cross-sectional thickness makes a total geometry change difficult to realize, and analysis conducted in this design project points away from doing so.

Small changes to the leading and trailing edges of the hardtop geometry can be seen to make marginal improvements on the current hardtop L-D ratio. The frontal edge does not do much to contribute to the lift that the current geometry generates during usage of the boat, so it is best to examine the frontal edge for changes that would reduce the overall drag caused by the hardtop. Modeling the frontal edge to more closely follow the radius of curvature that the rest of the hardtop geometry follows would not only reduce the overall frontal area the hardtop currently has, but it would also work to reduce the drag produced by the hardtop. This change would also encourage the airflow to stay uniform while reducing the possibility for flow separation along the bottom of the frontal edge. The trailing edge contributes to the overall lift that the hardtop generates. Highlighting the optimal angle for the trailing edge where it is contributing to the highest L-D ratio when the vessel is planning will work to make the hardtop better overall and improve boat performance. Marginal improvements in performance are seen after these changes are considered as the hardtop is not traditionally considered in a manner where it improves performance through affecting the airflow. The hardtop has a small impact on boat performance overall also because it only accounts for around 1% of the total boat weight before and after material changes. When taking into consideration the hull and the fact that it travels through water which is denser than air, the aerodynamics of the hardtop only affect the boat performance at a fraction of what the hull does. This is also because the hull surface area in contact with the water and surrounding air is far larger than the surface area of the hardtop that is exposed to air.

All parameters considered; the changes we suggest lessen the weight of the hardtop while also increasing boat performance. Fuel can be saved by implementing these changes and top speed will marginally increase as well. Though the increases to the performance were small, this was expected because of the reasons considered above. The improved hardtop hits all goals this design project set out to accomplish.

2.4 Conclusions

The objective of this project was to improve the overall performance of the Intrepid 409 Valor by manipulating the hardtop parameters. This was accomplished by lessening the weight of the hardtop and studying overall geometry and adjusting the geometry to improve the aerodynamic function of the hardtop. To lessen the weight, two material switches are suggested.

The current fiberglass used is a E-BXM 1208 Fiberglass, which is recommended to be switched to S-2 Fiberglass. This switch not only improves the engineering characteristics in all areas of the fiberglass and overall hardtop, it lessens the weight of the hardtop by 18.3%. Switching to S-2 fiberglass also lengthens the lifetime of the hardtop and provides extra fiber strength in hot daily environments where 1208 fiberglass fiber strength lacks. S-2 fiberglass also allows for potential radar integration into the hardtop further reducing the drag caused by the hardtop.

The core material should be switched from the current Aircell T-100 to its lighter option of Divinycell H-45. Switching to this fiberglass reduces overall hardtop weight by 42.7%. Not only does Divinycell absorb less resin and weigh less, it also functions at the same or better engineering characteristics, allowing for the strength of the hardtop to be uncompromised by the core switch. Divinycell also costs less than its competitor Aircell T-100.

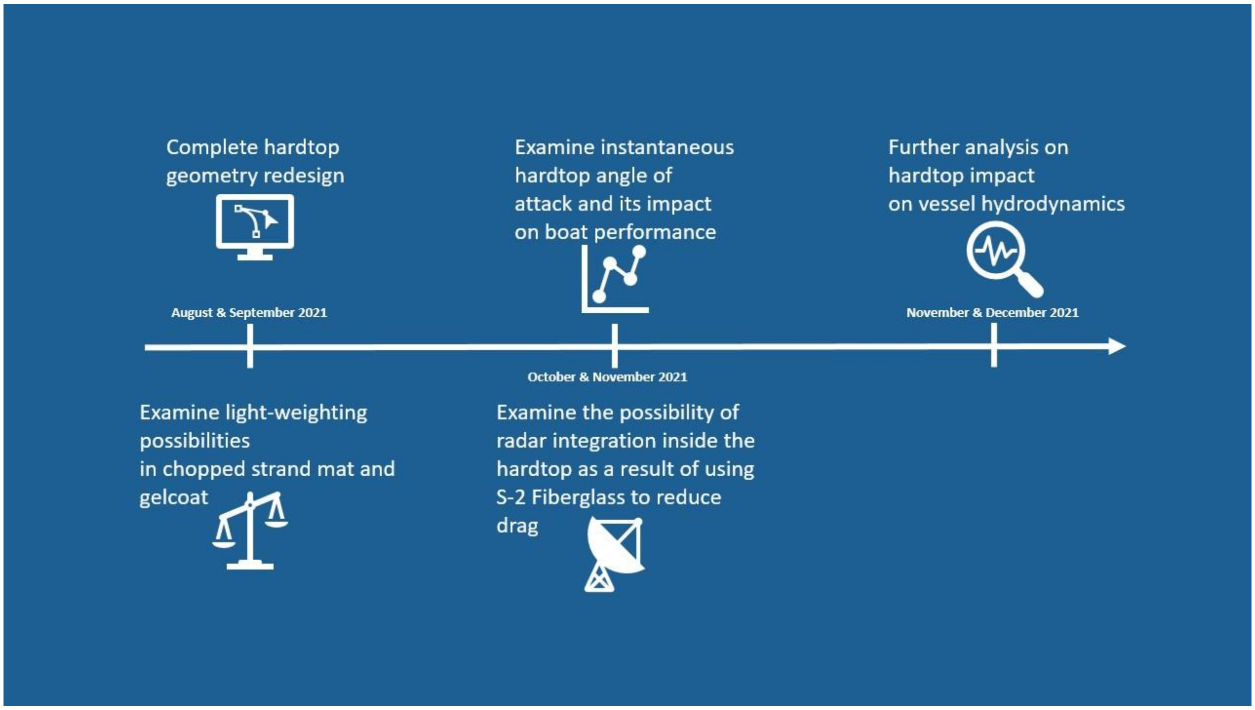
Together, when both material changes are considered, it lessens the weight of the hardtop by 60.1% and the cost is reduced by over 3%. This is extremely beneficial and exceeds the goals set by our team.

The overall hardtop geometry, through aerodynamic analysis performed using COMSOL and using finite element analysis, was found to have desirable characteristics when considering coefficients of lift and drag. This is largely due to the current geometry thickness of 1.5 inches. Though airfoil geometries at the chord length of the current hardtop have more desirable L-D ratios, the weight of those airfoils undermines the benefits gained by the desirable geometry. Even at reduced thicknesses, the airfoils still weigh far more than the current hardtop geometry and in fact lose their desirable L-D ratio at reduced thicknesses. One could argue to reduce the thickness until the average thickness is equal or less than that of the current hardtop geometry, however, with the manufacturing processes Intrepid uses, it would not be possible to create these geometries as the majority of the airfoil geometry would be too thin to withstand all loads and running conditions, nor would the geometry be moldable using a two-sided molding process. Even if it were acceptable to reduce the thickness of these desirable airfoil geometries to that of the current hardtop and even if they were manufacturable, the L-D ratios are still lost in the process, validating the benefits of the current geometry. The best recommendation we can make is to modify the frontal edge geometry to resemble an airfoil with maximum thickness of 1.5 inches, as to marginally decrease the drag created by the current geometry.

We are also recommending that Intrepid make changes to their next model hardtop because it makes far more sense when performing cost benefit analysis. The expenses Intrepid will incur to make the adjustments to their current hardtop mold as well as other parameters far outweigh the benefits from the reduction in weight of the hardtop and reduction in fuel consumption. The only change Intrepid may make without prior tooling and mold changes would be to the core material Divinycell H-45 as the thickness of the core remains the same. Intrepid would still see improvements in vessel performance and lessen their hardtop weight by 40+% and see a slight reduction in production costs due to the less expensive material.

However, Intrepid would not see full improvements in weight or vessel performance until making all recommended changes to materials and edges. Lastly, the geometry switch and frontal edge change reduce energy consumption by around 1% overall, improving the vessel performance. This is directly due to a reduction in the center of gravity of the vessel, a manipulation of airflow due to the frontal edge change, and the reduction of the wetted surface of the hull, which saves fuel over time.

2.5 Future Work



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Appendices

Appendix A: Code of Conduct

Mission Statement:

"To work in a collaborative manor to accomplish goals and solve problems in an efficient and effective manner."

Project Description:

To improve the current basic Intrepid hardtop design in the areas of weight reduction, aerodynamics, product costs, and materials.

Team Roles:

John – Lead Design Engineer; Team manager and overall design
Cory – Mechanical Engineer; Aerodynamic analysis and design
Erika – Marine Engineer; Technical analysis and marine design
Juan – Materials Engineer; Material selection and analysis

John will be responsible for the overall vision of the project with an emphasis on the design while assisting the team with various tasks as needed. Cory will be responsible for development and analysis of the aerodynamics components and assist with necessary design. Erika will oversee the marine application of the project and adjust design in order to facilitate efficient use on the vessel. Juan will be responsible for analysis of the materials used during the project as well as analysis of cost and manufacturing details.

For duties outside the scope of individual roles, the team will determine whose strengths are best suited to accomplish the task. The above roles will be amended when more is known about the project.

Communication:

We will communicate within our group through GroupMe, BaseCamp, Zoom and email. We will have weekly in person meetings once a week. (Tentatively Tuesday/Thursday during SD)

We will also have a weekly zoom meeting. (Scheduled meeting time is TBD)

We will communicate with our advisors and our company POC via email. Communication with Dr. McConomy will also include BaseCamp along with email.

Response to group related messages (email, BaseCamp, etc.) will be completed within 24hrs of initial posting. John will be the primary point of contact between our team and Intrepid Powerboats.

Dress Code:

During group meetings and group work, no dress code is necessary. For presentations, we will wear business attire. For sponsor, advisor, and professional interactions one must wear business casual.

Attendance Policy:

We will all try to attend all classes and group meetings unless emergency or health concerns arise. If for any reason a meeting time cannot be met; 24 hours advanced notice will be needed. Exceptions being an emergency. Attendance must be logged during every meeting (logging method TBD). Three or more excessive absences will be addressed in a team meeting setting to ensure efficient use of everyone's time. Unacceptable numbers of absences will result in lower grades through the team grading system in the senior design class.

Code of Conduct Amending Policy:

To amend this code of conduct, one must contact the entire team and present their possible change. The majority of the team must agree to have the code of conduct revised, and an announcement in Basecamp regarding the new revision must be made for our records. If a majority agreement is not met, reference conflict procedure.

Conflict Procedure:

We believe open communication lines are the key to success. In order to resolve any conflicts, whether conflicts in personality, ideas or otherwise, we as a team will ensure an open dialogue is present to resolve any issues that may arise. While we are clearly a team of motivated and like-minded individual it's important to keep an open minded to everyone's ideas and opinions. Conflicts will be resolved through democratic voting procedure. In the case of a tie vote, further discussion will be made until a majority vote is completed. If a majority vote is not able to be successfully done, our advisors will be brought in.

Statement of Understanding:

We acknowledge the above requirements and will work swiftly and diligently to abide by them. We understand that the team is responsible as a whole for any and all actions and outcomes- we start and finish together.

Electronic Signature Acknowledgements:

John Karamitsanis: John Karamitsanis
Cory Stanley: Cory Stanley
Erika Craft: Erika Craft
Juan Tapia: Juan Diego Tapia.

Submitting Assigned Work:

Work will be submitted after all four members of the Intrepid team have agreed that the work is up to our standard and we are all proud of the work being submitted. The team member tasked with submitting all assignments, presentations, and other team works is to be determined.

Team Member Tentative Weekly Schedules (Class/Jobs/Extracurriculars)

John:

Class:
MW 8:00-9:15, 11:00-1:45 - TTH 3:30-7:45 - F 8:00-10:45
Work:
MW 5:30-7:30 - TH 1:00-3:00 - SU 4:00-6:00
Gym:
MTWTHSSU 9:00-12:00 - F 10:45-1:00 (if not before)

Cory:

Class:
MW 12:30-1:45 - W 2:30-5:45 - TTH 3:30-7:45 - F 11:00-11:50
Work:
MTWTHS 7:00-12:00 - F 7:00-11:00

Erika:

Class:

MW 8:00-9:15, 12:30-1:45 - TTH 3:30-7:45 - F 8:15-10:45

Work:

TTH 8:00-10:00, 10:30-12:00

Juan:

Class:

MW 8:00-9:15, 12:30-1:45 - W 2:30-5:15 - TTH 3:30-7:45 - F 8:15-10:45, 11:00-11:50

The above rough outlines of each team members schedule are to highlight times that team members are not available and to provide record of times they should be available, should no other commitments arise during the school year. These schedules may be amended should any commitments change or be added.

Appendix B: Work Breakdown Structure

Milestone #	Milestone and Breakdown			Person Responsible for Completing the Work
1	Team Initialization			
		1.1 Code of Conduct		
			1.1.1 Mission Statement	John Karamitsanis
			1.1.2 Team Roles	Cory Stanley
			1.1.3 Methods of Communication	Erika Craft
			1.1.4 Dress Code	Juan Tapia
			1.1.5 Attendance Policy	Erika Craft
			1.1.6 Statement of Understanding	Juan Tapia
			1.1.7 Rubric/Grammar/Quality Check	John Karamitsanis
			1.1.8 File Submission	Cory Stanley
		1.2 Work Breakdown Structure		
			1.2.1 Excel Sheet Made	Cory Stanley
			1.2.2 Table Formulation	Juan Tapia
			1.2.3 Rubric/Grammar/Quality Check	Erika Craft
			1.2.4 File Naming	Cory Stanley
			1.2.5 File Submission	John Karamitsanis
2	Project Basics			
		2.1 Project Scope		
			2.1.1 File Creation	John Karamitsanis
			2.1.2 Format Made	Cory Stanley
			2.1.3 Project Description	John Karamitsanis
			2.1.4 Key Goals Listed	Erika Craft
			2.1.5 Four Markets Identified	Juan Tapia
			2.1.6 Clearly Identify Assumptions	John Karamitsanis
			2.1.7 Mention all Stakeholders	Cory Stanley
			2.1.8 Rubric/Grammar/Quality Check	Erika Craft
			2.1.9 File Naming	Juan Tapia
			2.1.10 File Submission	John Karamitsanis
			2.1.11 Transfer Info. to Powerpoint	Cory Stanley
		2.2 Customer Needs		
			2.2.1 File Creation	John Karamitsanis
			2.2.2 Formatting	Cory Stanley
			2.2.3 Gather Customer Statements	John Karamitsanis
			2.2.4 Include Interpreted Needs	Juan Tapia
			2.2.5 Explain Results	Juan Tapia
			2.2.6 Ensure 'Why' Not 'How'	Erika Craft
			2.2.7 Check for Simple Concise Language	Cory Stanley
			2.2.8 Rubric/Grammar/Quality Check	Cory Stanley
			2.2.9 File Naming	Erika Craft
			2.2.10 File Submission	John Karamitsanis
			2.2.11 Transfer to PPT	Cory Stanley

3	Advanced Project Analysis			
		3.1 Functional Decomposition		
			3.1.1 File Creation	John Karamitsanis
			3.1.2 Formatting	Cory Stanley
			3.1.3 Abstract Written	Juan Tapia
			3.1.4 Introduction Written	Erika Craft
			3.1.5 Data Generation Explained	John Karamitsanis
			3.1.6 Action and Outcome to Introduce Graphics and State Project Requirements	John Karamitsanis
			3.1.7 Functional Decomposition Chart Made	Cory Stanley
			3.1.8 Chart Check for Relevant Information	Erika Craft
			3.1.9 Connection to Systems: clearly relate functions to subsystems	Cory Stanley
			3.1.10 Smart Integration to show how functions relate to one another	Erika Craft
			3.1.11 Make Functional Decomposition Table to strengthen Smart Intregration	Juan Tapia
			3.1.12 Function Resolution: clearly identify what the project has to do	Erika Craft
			3.1.13 Rubric/Grammar/Quality Check	John Karamitsanis
			3.1.14 File Naming	John Karamitsanis
			3.1.15 File Submission	Juan Tapia
			3.1.16 Transfer Information to Powerpoint	Juan Tapia
		3.2 Target Summary		
			3.2.1 File Creation	Cory Stanley
			3.2.2 Formatting	John Karamitsanis
			3.2.3 Indentify Necessary Functions	Erika Craft
			3.2.4 Derive Targets and Metrics	Juan Tapia
			3.2.5 Ensure Targets Match or Exceed Functions	Cory Stanley
			3.2.6 Develop Method of Validation	Cory Stanley
			3.2.7 Find Tools to Validate/Measure	Cory Stanley
			3.2.8 Indentify Critical vs Non-critical Targets	John Karamitsanis
			3.2.10 Rubric/Grammar/Quality Check	Juan Tapia
			3.2.11 File Naming	Erika Craft
			3.2.12 File Submission	John Karamitsanis
			3.2.13 Transfer to PPT	Juan Tapia

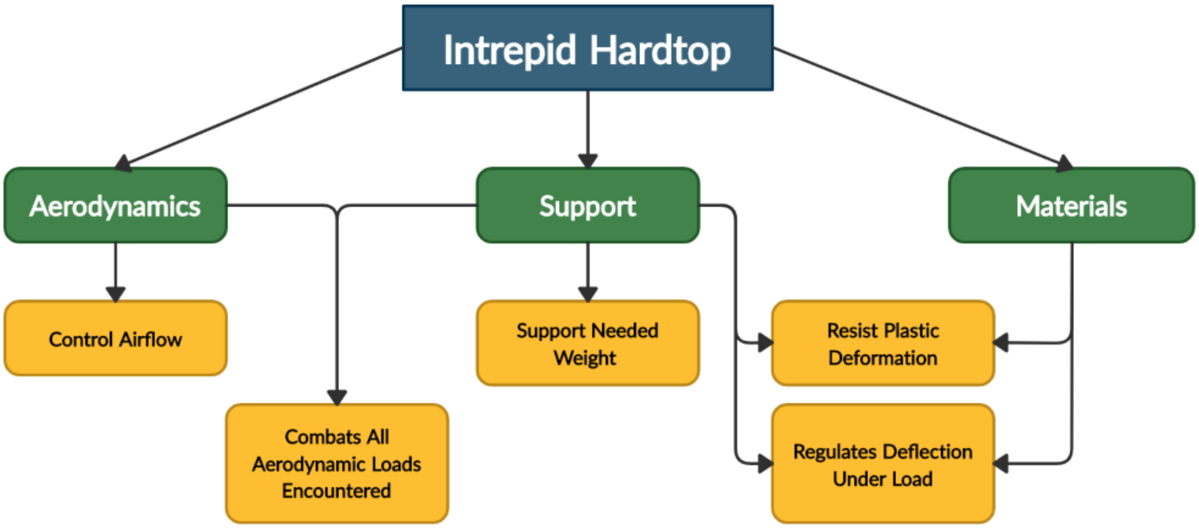
4	Concept and Execution	4.1 Concept Selection & Generation		
			4.1.1 File creation	John Karamitsanis
			4.1.2 Define Problem	Cory Stanley
			4.1.3 Gather Information	John Karamitsanis
			4.1.4 "100" Concepts	Erika Craft
			4.1.5 5 Medium Fidelity	Juan Tapia
			4.1.6 3 High Fidelity	John Karamitsanis
			4.1.7 Use Generation Tools	Cory Stanley
			4.1.8 House of Quallity chart	Juan Tapia
			4.1.9 Pugh Chart	John Karamitsanis
			4.1.10 AHP(Analytical hierarchy Process)	Erika Craft
			4.1.11 Final Selection	Cory Stanley
			4.1.12 Rubric/ Grammar/Quality check	Erika Craft
			4.1.13 File Name	Juan Tapia
			4.1.14 File Submission	John Karamitsanis
			4.1.15 Transer Info. to Powerpoint	Cory Stanley

Appendix C: Customer Needs Table

Question	Customer Statement	Interpreted Need
What are your objectives for this project?	Weight reduction for hardtop assembly and improvements on shape and aerodynamics.	**The new hardtop will improve boat performance.**
What materials need to be considered?	Consider materials currently used by Intrepid.	**The improved hardtop will incorporate materials used within Intrepid's manufacturing constraints.**
Can the team alter the hardtop material?	Understand how the current hardtops are constructed, then consider design and materials.	**The designed hardtop will improve upon the current hardtop's design and make advancements in materials.**
What are the parameters of the current hardtop models in use?	Current parameters can be considered through further analysis of the cad model and software highlighted.	**The improved hardtop dimensions will be similar to the current hardtop dimensions.**
Can we alter the wire/chase tubes layout?	The layout can be altered if exit points for the wires are kept the same.	**The improved hardtop may alter the wire layout while retaining exit points.**
What else besides weight would you like to improve?	Consider shape, space, aerodynamics, and how they affect the running performance of the boat. Also, find how lift or drag affects the vessel stability, performance, and friction of the hull within the water.	**The improved hardtop will advance the boat performance.**
Have you tried reducing the weight of the hardtop before?	No, though we have made advancements in the past, we have not tried to reduce the weight of the current hardtop model before.	**The improved design will incorporate a reduction in weight.**

Do you want a generic hardtop, or a design for a specific boat?	Use Intrepid 409 Valor hardtop as reference, it is very large and is the best supported hardtop we have. Use it to derive a new design.	**The improved design will be made for the Intrepid 409 Valor.**
Is there a certain weight that the hardtop needs to be able to withstand?	The weight/force of all the aerodynamic forces and support service techs who stand on top.	**The improved design will withstand nominal running conditions and loading conditions including a factor of safety.**
Are modular mounts for various pieces of equipment a consideration for this project?	Modular mounts are not necessary because Intrepid does not use mounts for equipment on the hardtops.	**The improved hardtop will align with the styling and quality of all Intrepid made parts.**

Appendix D: Functional Decomposition



Functions / Systems	Supports Needed Weight	Resists Plastic Deformation	Regulates Deflection Under Load	Combats All Aerodynamic Loads Encountered	Controls Airflow
Support	X	X	X	X	
Aerodynamics				X	X
Materials		X	X		

Increase lift-to drag ratio by 10%	Using a safety factor, the hardtop has no failure during all operating conditions	Using a safety factor and an estimated service person's weight of 200lbs, the hardtop will not fail	Shear stress < Ultimate Tensile stress < Ultimate Max Stress Induced: 4788 Pascals or 0.694 psi	Support needed force/mass without failure Max deflection 0.25"

Appendix E: Target Catalog

Function:	Metric:	Target:
Control Airflow	Increased lift-to-drag ratio	Increase by 10%
Combats Aerodynamic Load	Remain below failure strength during operation	Using a safety factor, the hardtop has no failure during all operating conditions.
Support Needed Weight	Remain below failure strength during service and maintenance	Using a safety factor, support the weight of a 200 lb. serviceperson.
Resist Plastic Deformation	Remain within elastic region Stress Induced (sigma = P/A)	Shear stress < Ultimate Tensile stress < Ultimate Max Stress Induced (when considering whole hardtop area): 153 Pascals or 0.022 psi Max Stress Induced (when considering rough area of service person (2ft x 2ft area): 4788 Pascals or 0.694 psi
Regulate Deflection Under Load	Deflection	Support needed force/mass without failure Max deflection 0.25”
Length	Analyze current length vs new design length	Retain current hardtop length value (15.25 feet)
Width	Analyze current width vs new design width	Retain current width (8.25 feet)
Mass	Analyze current mass vs new design mass	Less mass than current hardtop

Appendix F: Concept Generation

100 Concepts

Attach winglike mechanism to the hardtop that generates lift	Lightweight hardtop with less dense fiberglass and resin	Implement light Plexiglas 'sunroof'	Use thinner airfoil for hardtop profile to reduce drag	Attach birds on top of the hardtop to help with lift
Carbon fiber hardtop	Alter aerodynamic capabilities of hardtop to improve performance	Make hardtop out of lightweight aluminu m	Make water denser to reduce surface area of hull in contact with water, increasing boat performance	Attach rotors to the top of the hardtop to produce lift
Delete the hardtop	Run FEA procedure to optimize hardtop and minimize material in low stress locations	Turn the hardtop into a high lift wing	Extend hardtop into water on either side of the boat creating hydrofoils which will bring the boat hull out of the water at higher speeds & stabi lize the boat when turning	Swim....it's cheap er
Strong light weight plastic material usage	Combine all 3 above ideas to get benefits from light weighting, aerodynamics, and optimization	Remove all internal materials in the hardtop to make it lighter	Eliminate motors to save fuel while implementing a pedal system to propel boat using human power	Use lightweight thermoplastics instead of fiberglass
Use glue instead of resin	Lightweight hardtop with less dense materials and with aerodynamic changes	Use less resin and fiberglass to reduce weight	Make a hardtop hologram, thus eliminating the hardtop whilst still having one	Have passengers use oars to increase overall power of the boat and increase performance
Mount with glue instead of bolts to save weight	Lightweight hardtop with less dense materials and less material usage due to optimization	Make the hardtop from a thin single sheet of steel	Use a sail instead of a hardtop that can double as a sail and hardtop and rigidly hold some electronics	Make it out of lightweight nickel phosphorous

Put holes in hardtop to make lighter	Active aerodynamics in the hardtop supports to alter orientation of hardtop depending on boat orientation and speed	Make the hardtop out of low-density polyethylene	Make hardtop out of solar cells and use the solar energy to sustainably power the motors, saving fuel	Integrate the mounts into the hardtop design to reduce mounting hardware weight
Install active aero to change aerodynamics during operation	Greatly increase coefficient of lift by changing hardtop profile, ignore drag coefficient	Greatly increase coefficient of drag by changing hardtop profile, ignore lift coefficient	Fill the hull with helium to help lift boat out of water, decreasing drag	Like a prop plane, use prop engines and mount them to hardtop, removing outboard motors for fuel efficiency
Change hardtop to soft top to make lighter	Exchange hardtop for hot air balloon to create lift	Make hardtop out of laminated paper	Wear a hat while boating so no need for a hardtop	Attach turbine engines to hardtop to increase lift and forward thrust, increasing performance
Thin out hardtop and instruct service person to avoid standing on it	Equip boat with large fuel tanks in place of water and waste tanks for longer motor usage and farther boat range	Use hellcat engines instead, they are abundant and relatively cheap and produce a lot of power for making things go faster	Use an electrochromic glass roof to allow for shade to be provided when needed and being lighter than fiberglass	Use less paint on the boat to make it lighter
Use another boat	Rid the hardtop of all inside supports for extreme light weighting	Buy more engines	Reduce amount of fiberglass used in hardtop	Reduce amount of resin used in hardtop
Make hardtop out of glue	Make hardtop heavy to weigh the boat down forcing it to reach plane speed earlier and stay planted in the water	Install jets under the boat acting normal to water line to increase lift on boat	Reduce amount of foam core used in hardtop	Reduce amount of gelcoat used in hardtop

Implement helium into layers of hard top. Will act as a buoyant force.	Use the hardtop as a wing like TIE fighters do from Star Wars except oriented perpendicularly to the TIE fighter's wings	Make smaller volume hardtop	"You can have any color you'd like so long as it's black"- except we use white	Attach sails on top of the hardtop
Attach actuated microjets to ensure decreased drag and flow separation	Replace foam support for a 3d printed accordion structure	Attach necessary equipment on places other than the hardtop	Make the supports and the hardtop a single piece, reducing weight from fasteners	Project the hardtop as a hologram for aesthetics to reduce weight
Change the hardtop for an airfoil	Use biomimetic design to copy aerodynamics of stingray	Make the hardtop out of 3D graphene	Make the hardtop out of aero graphite	Make hardtop out of metallic micro lattice
Use S-2glass as the primary material instead of E-glass	Biomimetic design against aerodynamics of flounder	Make hardtop out of thin PLA plastic 3D printed	Reduce gravity	Use biomimetic design to copy aerodynamics of a hawk and incorporate those aerodynamics into the design of the hardtop
Use a circular hardtop instead of a rectangular to save material	Reduce EPA regulations on the engines of the boat to increase performance	Make sides of hardtop curved like an airplane wing to increase lift	Attach airfoil flaps to the hardtop and use an Arduino and a stepper motor to control the flaps to get the best lift.	Make the hardtop out of lithium
Make the hardtop smaller in area	Integrate hardtop to front of the boat to create a closed environment in the cockpit and thus rid the boat of potential air vacuum under hardtop	Using a less dense core to reduce weight	Make servo actuated mounts to allow the hardtops angle of attack be adjusted during operation	Use a rocket engine when extra speed is needed
3D print the whole hardtop with lighter material, saving	Like the lids of a dumpster, use hard plastic that can support heavier loads and	Make hard top out of cardboard and make it water proof	Increase down force so the boat becomes a submarine	Change the hardtop for an improvised tent

money in assembly	deform but not break (cheap too)			
Have a maximum capacity of 2 persons on the boat	Make engines more efficient to increase boat performance	Make the hardtop out of a thin layer titanium	Change the hardtop for a folding one that can be folded backwards when not needed and opened when needed (convertible)	Soak the boat’s hull in oil to reduce friction since oil is less dense than water.

Appendix G: Analytical Hierarchy Process

AHP Rating Values

Rating Value	Relative weighting importance	Explanation of weighting
1	A and B have equal importance.	A and B both contribute equally to product success.
3	A is slightly more important than B.	A contributes slightly more to product success than B.
5	A is strongly more important than B.	A contributes strongly more than B to product success.
7	A is thought to be so very much more important than B.	A is very much more important to product success than B.
9	A is clearly demonstrated to be more important than B.	A is demonstrated with evidence to be more detrimental to product success than B.

Table A-2: AHP Rating Explanations

Analytical Hierarchy Process (AHP)

Criteria Comparison Matrix [C]

Criteria Comparison Matrix [C]							
	LBC	Strain	Deflection	Weight	L-D Ratio	Cost	Mfg. Cost
Load Bearing Capacity	1	1	1	0.33	0.33	1	0.33
Strain	1	1	1	1	0.2	0.2	1
Deflection	1	1	1	1	1	0.33	1
Hardtop Weight	3	1	1	1	0.33	1	0.33
Lift-to-Drag Ratio	3	5	1	3	1	1	1
Implementation Cost	1	5	3	1	1	1	1
Manufacturability	3	1	1	3	1	1	1
Sum	13	15	9	10.33	4.867	5.53	5.67

Table A-3: Comparison Matrix of Engineering Characteristics

Normalized Criteria Comparison Matrix [NormC]

	LBC	Strain	Deflection	Weight	L-D Ratio	Cost	Mfg. Cost	Criteria Weights {W}
Load Bearing Capacity								
Strain								
Deflection								
Hardtop Weight								
Lift-to-Drag Ratio								
Implementation Cost								
Manufacturability								
Sum	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Table A-4: Normalized Comparison Matrix of Engineering Characteristics

Normalized Criteria Comparison Matrix [NormC]								
	LBC	Strain	Deflection	Weight	L-D Ratio	Cost	Mfg. Cost	Criteria Weights {W}
LBC	0.07692308	0.06666667	0.11111111	0.03225806	0.06849315	0.18072289	0.05882353	0.08499978
Strain	0.07692308	0.06666667	0.11111111	0.09677419	0.04109589	0.03614458	0.17647059	0.08645516
Deflection	0.07692308	0.06666667	0.11111111	0.09677419	0.20547945	0.06024096	0.17647059	0.11338086
Hardtop Weight	0.23076923	0.06666667	0.11111111	0.09677419	0.06849315	0.18072289	0.05882353	0.1161944
L-D Ratio	0.23076923	0.33333333	0.11111111	0.29032258	0.20547945	0.18072289	0.17647059	0.2183156
Cost	0.07692308	0.33333333	0.33333333	0.09677419	0.20547945	0.18072289	0.17647059	0.20043384
Manufacturability	0.23076923	0.06666667	0.11111111	0.29032258	0.20547945	0.18072289	0.17647059	0.18022036
Sum:	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Consistency Check		
Weighted Sum Vector	Criteria Weights {W}	Consistency Vector
1.048121	0.1056	9.925
2.691252	0.2544	10.579
2.224183	0.2193	10.142
1.520471	0.1137	13.372

1.250903	0.1151	10.868
0.579788	0.0543	10.677
1.706916	0.1671	10.215

Table A-5: Consistency Check Table for Engineering Characteristics

Average Consistency	7.78266
Consistency Index	0.13044
Consistency Ratio (<0.10)	0.09662

Table A-6: Consistency Calculations for Engineering Characteristics

Load Bearing Capacity Comparison			
	Lightweight Hardtop	Aerodynamic Hardtop	Optimal Hardtop
Lightweight Hardtop	1	0.33	1
Aerodynamic Hardtop	3	1	3
Optimal Hardtop	1	0.33	1
Sum	5	1.66	5

Table A-7: Comparison Matrix Representative of All High Fidelity Designs

Normalized Load Bearing Capacity Comparison				
	Lightweight Hardtop	Aerodynamic Hardtop	Optimal Hardtop	Design Alternative Priorities {Pi}
Lightweight Hardtop	0.2000	0.1988	0.2000	0.1996
Aerodynamic Hardtop	0.6000	0.6024	0.6000	0.6008
Optimal Hardtop	0.2000	0.1988	0.2000	0.1996
Sum	1.000	1.000	1.000	1.000

Table A-8: Normalized Comparison Matrix Representative for All High Fidelity Designs

Load Bearing Capacity Consistency Check		
Weighted Sum Vector	Criteria Weights {W}	Consistency Vector
0.5975	0.1996	2.9933
1.7984	0.6008	2.9933
0.5975	0.1996	2.9933

Table A-9: Consistency Check Representative for All High Fidelity Designs

Consistency Ratio	<0.10
1- LBC	0
2- Strain	0

3- Deflection	0
4- Hardtop Weight	0
5- L-D Ratio	0
6- Implementation Cost	0
7- Manufacturability	0

Table A-10: Consistency Ratios of All High Fidelity Designs

Hardtop Weight AHP

Hardtop Weight Comparison			
	Lightweight Hardtop	Aerodynamic Hardtop	Optimal Hardtop
Lightweight Hardtop	1	0.20	1
Aerodynamic Hardtop	5	1	5
Optimal Hardtop	1	0.20	1
Sum	7	1.4	7

Table A-7: Comparison Matrix Representative of All High Fidelity Designs

Normalized Hardtop Weight Comparison				
	Lightweight Hardtop	Aerodynamic Hardtop	Optimal Hardtop	Design Alternative Priorities {Pi}
Lightweight Hardtop	0.1429	0.1429	0.1429	0.1429
Aerodynamic Hardtop	0.7143	0.7143	0.7143	0.7143
Optimal Hardtop	0.1429	0.1429	0.7143	0.1429
Sum	1.000	1.000	1.000	1.000

Table A-8: Normalized Comparison Matrix Representative for All High Fidelity Designs

Hardtop Weight Consistency Check		
Weighted Sum Vector	Criteria Weights {W}	Consistency Vector
0.42857	0.1429	2,9991
1.7984	0.7143	2.9991
0.5975	0.1429	2.9991

Table A-9: Consistency Check Representative for All High Fidelity Designs

L-D Ratio AHP

L-D Ratio Comparison			
	Lightweight Hardtop	Aerodynamic Hardtop	Optimal Hardtop
Lightweight Hardtop	1	5	5
Aerodynamic Hardtop	0.20	1	1

Optimal Hardtop	0.20	1	1
Sum	1.4	7	7

Table A-7: Comparison Matrix Representative of All High Fidelity Designs

Normalized L-D Ratio Comparison				
	Lightweight Hardtop	Aerodynamic Hardtop	Optimal Hardtop	Design Alternative Priorities {Pi}
Lightweight Hardtop	0.7143	0.7143	0.7143	0.7143
Aerodynamic Hardtop	0.1429	0.1429	0.1429	0.1429
Optimal Hardtop	0.1429	0.1429	0.1429	0.1429
Sum	1.000	1.000	1.000	1.000

Table A-8: Normalized Comparison Matrix Representative for All High Fidelity Designs

L-D Ratio Consistency Check		
Weighted Sum Vector	Criteria Weights {W}	Consistency Vector
2.14287	0.7143	2.99996
0.42857	0.1429	2.9991
0.42857	0.1429	2.9991

Table A-9: Consistency Check Representative for All High Fidelity Designs

Implementation Cost AHP

Implementation Cost Comparison			
	Lightweight Hardtop	Aerodynamic Hardtop	Optimal Hardtop
Lightweight Hardtop	1	0.20	0.20
Aerodynamic Hardtop	5	1	1
Optimal Hardtop	5	1	1
Sum	11	2.4	2.4

Table A-7: Comparison Matrix Representative of All High Fidelity Designs

Normalized Implementation Cost Comparison				
	Lightweight Hardtop	Aerodynamic Hardtop	Optimal Hardtop	Design Alternative Priorities {Pi}
Lightweight Hardtop	0.0909	0.0833	0.0833	0.08585
Aerodynamic Hardtop	0.4545	0.4167	0.4167	0.42929
Optimal Hardtop	0.4545	0.4167	0.4167	0.42929

Sum	1.000	1.000	1.000	1.000

Table A-8: Normalized Comparison Matrix Representative for All High Fidelity Designs

Implementation Consistency Check		
Weighted Sum Vector	Criteria Weights {W}	Consistency Vector
0.257575	0.08585	3.000
1.287878	0.42929	3.000
1.287878	0.42929	3.000

Table A-9: Consistency Check Representative for All High Fidelity Designs

Criteria Comparison Matrix [C]

	Colum	Colum	Colum	Colum	Colum	Colum	Colum
	1	1	1	0.333333	0.333333	1	0.333333
	1	1	1	1	0.2	0.2	1
	1	1	1	1	1	0.333333	1
	3	1	1	1	0.333333	1	0.333333
	3	5	1	3	1	1	1
	1	5	3	1	1	1	1
	3	1	1	3	1	1	1
Sum	13	15	9	10.333	4.8667	5.5333	5.6667

Consitency Check

WSM	{W}	Cons Vec
WSM	{W}	Cons V
0.656846	0.085	7.727625
0.665	0.086455	7.691854
0.866377	0.113381	7.641302
0.904309	0.116194	7.782724
1.748209	0.218316	8.007715
1.572582	0.200434	7.845893
1.402388	0.18022	7.78152

Consistency Calculations

Colum	Colum
Avg. Cons	7.782662

Colum	Colum
Cons Index	0.130444

Normalized Comparison Matrix [NormC]

Colum	Colum	Colum	Colum	Colum	Colum	Colum	{W}
0.076923	0.066667	0.111111	0.032258	0.068493	0.180723	0.058824	0.085
0.076923	0.066667	0.111111	0.096774	0.041096	0.036145	0.176471	0.086455
0.076923	0.066667	0.111111	0.096774	0.205479	0.060241	0.176471	0.113381
0.230769	0.066667	0.111111	0.096774	0.068493	0.180723	0.058824	0.116194
0.230769	0.333333	0.111111	0.290323	0.205479	0.180723	0.176471	0.218316
0.076923	0.333333	0.333333	0.096774	0.205479	0.180723	0.176471	0.200434
0.230769	0.066667	0.111111	0.290323	0.205479	0.180723	0.176471	0.18022
1	1	1	1	1	1	1	1

Calculations

Colum
7.782662

Colum
0.130444

Colum	Colum
# elements	7

Colum	Colum
AHP for # e	1.35

Column	Colum
Cons Ratio	0.096625

PART 2

Final Rating Matrix

Colum	Colum	Colum
0.1996	0.6008	0.1996
0.1996	0.6008	0.1996
0.1996	0.6008	0.1996
0.1429	0.7143	0.1429
0.7143	0.1429	0.1429
0.0858	0.42929	0.42929
0.1429	0.1429	0.7143

Transpose Final Rating Matrix

0.1996	0.1996	0.1996	0.1429	0.7143	0.0858	0.1429
0.6008	0.6008	0.6008	0.7143	0.1429	0.42929	0.1429
0.1996	0.1996	0.1996	0.1429	0.1429	0.42929	0.7143

Alternative Value

Colum	Colum
Lightweigh	0.272351
Aero	0.397122
Optimal	0.31943

Table A-10: Excel Sheet Used for AHP Calculations of Engineering Requirements Against Designs

Appendix H: Operations Manual

1. Scope

1.1 Motivation

As technology improves, several industries have been constantly seeking improvements and the marine industry is not an exception. With the introduction of fiberglass, the overall weight of boats has decreased substantially. The competition among the marine industry has increased with advanced technology and an improvement in any area is desired, such as light weighting. Lightweight a boat in any way improves the overall fuel efficiency along with the top speed of the boat. These characteristics can make a difference in the marine industry.

1.2 Purpose

The purpose and benefits of designing a standard for center console hardtop design and material selections are to:

1. Allow boat designers to use a standard across the industry for material selection in terms of both fiberglass and foam cores while taking into consideration cost vs. Weight.
2. Introduce a way of defining benefits gained from the thickness of the hardtop, the leading edge and trailing edge shape.
3. Reduce the effort required to select hardtop design parameters.

2. Definitions

2.1 Hardtop

A rigid form of a roof on an automobile or vessel; in this application, the roof of the boat over the console used to control the vessel while providing shade.

2.2 Leading Edge

The outside front surface of an object, in this case the area of the hardtop facing the front of the boat, heading into the wind when the boat is going forward.

2.3 Trailing Edge

The outside rear surface of an object, in this case the area of the hardtop facing the rear of the boat.

2.4 Coefficient of Lift

The lift coefficient is a dimensionless coefficient that relates the lift generated by a lifting body to the fluid density around the body, the fluid velocity, and an associated reference area.

2.5 Coefficient of Drag

The drag coefficient is a dimensionless quantity that is used to quantify the drag or resistance of an object in a fluid environment, such as air or water.

2.6 Thickness

The distance between two opposing sides. In this case, the distance between the top layer and bottom layer of the hardtop.

2.7 Wetted Surface

The surface area of a boat’s hull in the water; directly proportional to the amount of drag caused by water.

2.8 Gelcoat
A liquid that hardens to form a thick protective layer over a fiberglass surface. It helps with provide a clean finish and provide water proofing.
2.9 Fiberglass
Fiberglass is a type of fiber-reinforced plastic using glass fiber. The fibers may be randomly arranged, flattened into a sheet, or woven into a fabric.
2.10 Chopped Strand Mat (CSM)
CSM is a random array of fibers in a mat that provides equal strength in all directions and is used in a variety of hand lay-up and open-mold applications.
2.11 Core
The middle portion of the hardtop. Made up of a structural foam that provides rigidity and thickness.
2.12 Resin
A solid or highly viscous substance of plant or synthetic origin that is typically convertible into polymers. Resin is cured and bonded to the fiberglass.
2.13 Catalyst
A substance that increases the rate of a chemical reaction without itself undergoing any permanent chemical change. Used to help cure the resin in this application.

3. General Model Structure

3.1 Overview of Parameters
There are a fixed number of parameters on the hardtop that, when changed, impact the performance of the boat. Changes to the overall geometry of the hardtop, to the leading edge, trailing edge, and thickness can impact boat performance. Changes to the materials and molding process can also impact the performance of the boat. This set of guidelines focuses on materials, overall geometry, thickness, and leading and trailing edge changes to the hardtop and how they impact the boat.

4. Design Considerations

4.1 Material Selection
One must first understand the tolerances characteristics desired in order to select the right materials. Depending on desired properties, desired cost, molding procedure, and lamination schedule, one may have to select a gelcoat, chopped strand mat, composite fibers, core, resin, and catalyst.
4.1.1 Gelcoat
Gelcoat is the top surface finishing coat that can be seen on the finished surface of the part. This generally weighs the same regardless of what brand or kind of gelcoat, so the selection of this material is up to the manufacturer.
4.1.2 Chopped Strand Mat
Chopped Strand Mat adds to mold security and waterproofness and is generally a necessary material for hand-laid molds and open molds. CSM provides equal strength in all directions, and this material is important for surface finish. Regardless of brand or kind of CSM the outcome is generally the same, and this material selection can be left up to the preference of the manufacturer.

4.1.3 Composite Fibers

Designers will see the biggest fluctuation in design tolerance here with the selection of glass to use. Depending on cost, quality, quantity, or desired characteristics, one of the following may be beneficial to use over the other.

4.1.3.1 E-Glass

This is a common fiberglass with good strength and other engineering characteristics. Compared to the other glass selections provided in this set of guidelines, it is the least costly yet still provides desirable characteristics. This material is suitable for use in hardtops. Reference [5.2.1] for complete information in this material.

4.1.3.2 S-Glass

S-Glass is very desirable due to its high strength-to-weight ratio and its small thickness. Thinner than E-Glass with a lower density, this material is ideal for use in hardtops, but commonly finds use in military and aerospace applications due to its other characteristics such as a low dielectric constant allowing for transparency and radio frequency transmissions to pass through the material. This material also is completely flame resistant and will not catch fire. S-Glass also retains its strength at high and low temperatures, which is why it is used in aerospace applications. Though a hardtop does not encounter large temperature differentials, it may get extremely hot if kept outside when global irradiance is at a maximum. This extra strength is desirable as the hardtop will last longer over time. S-Glass also has high impact resistance and retains strength after local fibers are damaged or orientation is changed due to impacts, making it suitable for military applications. This material is suitable for hardtop usage due to the many desirable engineering characteristics. S-Glass is middle range in the area of cost, making it more expensive that E-Glass but less expensive to materials such as carbon fiber and aramid. Reference [5.2.2] for complete information in this material.

4.1.3.3 Carbon Fiber

Carbon fiber could be considered an “exotic” material because of its outstanding mechanical properties when compared to any fiberglass material. Along with these mechanical properties, the weight of carbon fiber is less than most materials while having the same or even greater mechanical properties. Carbon fiber is an ideal material for light-weighting and high strength applications, but it is also costly. Usage depends on the desired goal. Carbon fiber is much less dense than traditional E-Glass and S-Glass however, it is more expensive. The thickness is comparable to S-Glass and Aramid. Reference [5.2.3] for complete information in this material.

4.1.3.4 Aramid

Aramid is a synthetic fabric known for being strong and heat-resistant used on military purposes along with aerospace and marine industries [5.2.5]. While having similar mechanical properties than fiberglass, Aramid's energy absorption if substantially greater but when compared to carbon fiber, aramid’s compressive strength is lower. Reference [5.2.4] for complete information in this material.

4.1.4 Core

Designers can also make a large improvement in weight savings depending on the core material chosen. Core is important for structural rigidity of parts as well as the addition of thickness. Different sizes of core are available to achieve rigidity at different designed thicknesses.

Different cores have different resin absorption rates and therefore gain different weights when infused with resin. For hardtop design, if lesser weight is desired, designers may want to examine Divinycell cores.

4.1.4.1 Divinycell Core

Divinycell cores are one of the lightest cores available on the market for marine applications. Divinycell is affordable and the perforated cores available for selection allow for the transmission of resin from one side to the other. With lesser density core prior to infusion, using Divinycell can save weight. If Divinycell is used in a hardtop, this core will provide desired rigidity at a lesser weight.

4.1.5 Resin

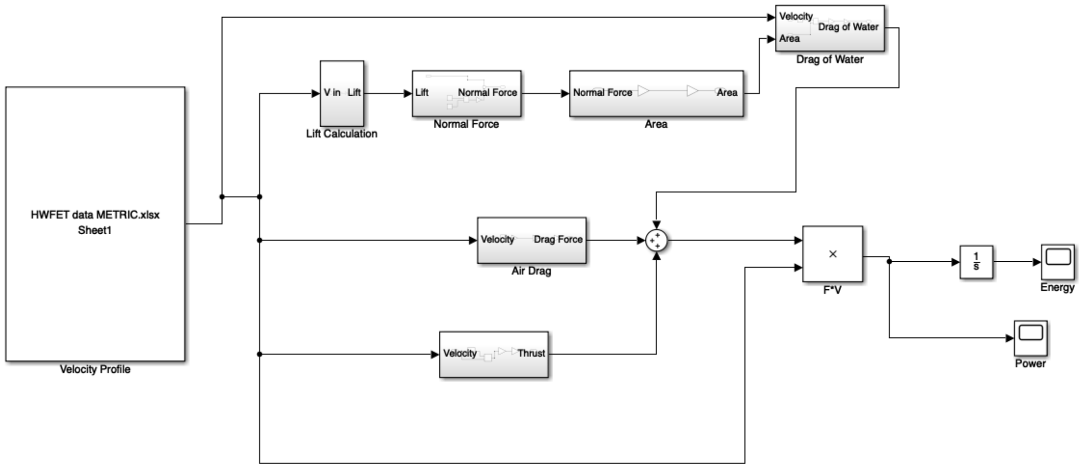
Resin must be chosen with compatibility to other materials used in the hardtop. The resin chosen must be compatible with the chosen cores and composite fibers as well as the chopped strand mat. Failure to match compatibility will result in failure of the hardtop and a compromised mold that will not achieve structural integrity and very well may not even completely infuse.

4.1.6 Catalyst

Catalyst must be compatible with resin and other materials. Catalyst makes virtually no difference in the weight of the completed hardtop. This is just used for infusion and to cause the resin to set. Designers may choose this according to resin and other material choices for the hardtop.

4.2 Overall Geometry

The overall geometry was considered when making improvements to the hardtop. When the geometry of the hardtop was changed to a variety of airfoils, the coefficient of lift was increased, and coefficient of drag was decreased. The increase in lift and decrease in drag provided an overall benefit to performance and fuel efficiency. The airfoils tested were the NACA 2412 [5.3.1] and the NACA 6409 [5.3.2]. However, when the size of the airfoil shaped hardtops was considered, the added weight made it an unrealistic design approach. When the thickness of the airfoils was reduced, this lost most of the benefits of the new overall geometry. A Simulink system (Shown below) was developed to help validate the changes in hardtop weight, coefficient of lift and coefficient of drag and how this changes effect power and energy of the boat using a velocity profile taken from the EPA [5.3.3].

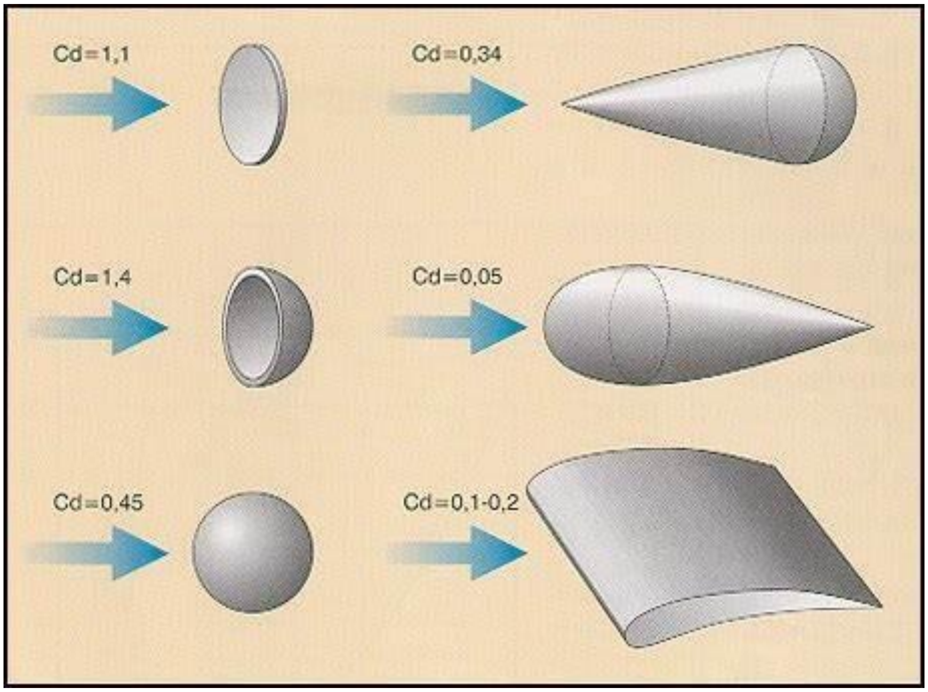


Simulink Model of boat with hardtop; hardtop parameters are adjusted for comparison of results.

It should be decided to move forward with leading and trailing edge shape changes for improving the aerodynamics of the hardtop.

4.3 Coefficient of Drag Exploration

When figuring out the relationship between hardtop frontal area, shape and drag. It is important to reduce the coefficient of drag, Cd, as much as possible. Using the table below it is clear that an airfoil or teardrop shape is the most effective way to reduce coefficient of drag on a 3D shape. The lowest drag value is for an airfoil shape, further validating that importance of mirroring airfoil edges for hardtop improvements.



4.4 Leading Edge

Through analysis it is found that moving forward with overall geometry changes were not beneficial to the hardtop but shaping the leading edge to mirror an airfoil (we used NACA airfoils) provided a decrease in overall drag without sacrificing any light weighting done through material changes.

Leading edges create the least disturbance in airflow when they occupy the least amount of cross-sectional area parallel to the direction of airflow. Curvature should be kept to a minimum, as too much curvature will create flow separation on the top or bottom surfaces depending on the direction of curvature (up or down). This flow separation negatively affects the boat because it adds unnecessary drag. To avoid this, the leading edge geometry must follow the curve or general trendline of the rest of the hardtop design. When the boat is in plane, the hardtop should be oriented close to zero degrees for its angle of attack, meaning that the leading edge should be parallel with incoming flow. This will result in the least amount of drag generated by the leading edge, which is the most beneficial to the boat performance.

4.5 Trailing Edge

Through analysis it is found that moving forward with overall geometry changes were not beneficial to the hardtop but shaping the trailing edge to mirror an airfoil (we used NACA airfoils) provided an increase in overall lift without sacrificing any light weighting done through material changes.

It was determined that the trailing edge geometry can play the largest role in increasing lift without significant changes to current hardtop design and increase in overall thickness. There is a tradeoff between a trailing edge creating increased lift and flow separation. Current hardtop design provides little lift benefits while still allowing flow separation. Modeling the trailing edge to mirror the airfoils listed allowed for increased lift coefficient without substantially increasing drag.

5. References for Operations Manual

5.1 Applicable Documents

Typical marine standards such as NMMA and other conferences apply to boat building and security. Whichever code of standards the designer company follows, reference such standards for specific compliance accordingly.

5.2 Materials References

5.2.1 E-Glass

The online Materials information resource. (n.d.). Retrieved March 17, 2021, from http://www.matweb.com/search/DataSheet.aspx?MatGUID=d9c18047c49147a2a7c0b0bb1743e812&ckck=1

5.2.2 S-Glass

S2-glass.com. 2004. S-2 Glass Fiber. [online] Available at: <http://s2-glass.com/wp-content/uploads/2016/04/Advanced_Materials_Brochure-Technical.pdf> [Accessed 10 March 2021].

5.2.3 Carbon Fiber

Johnson, Todd. "A Beginner's Guide to the Lightweight Composite Material Carbon Fiber." *ThoughtCo*. Web. 16 Mar. 2021.

5.2.4 Aramid

"Introduction to Aramid Fiber." Aramid Fiber. Web. 16 Mar. 2021.

5.2.5 Aramid

Yang, Hung M. "Aramid Fiber." Web. 16 Mar. 2021.

5.3 Geometry

5.3.1 NACA 2412

NACA 2412 (naca2412-Il), airfoiltools.com/airfoil/details?airfoil=naca2412-il.

5.3.2 NACA 6409

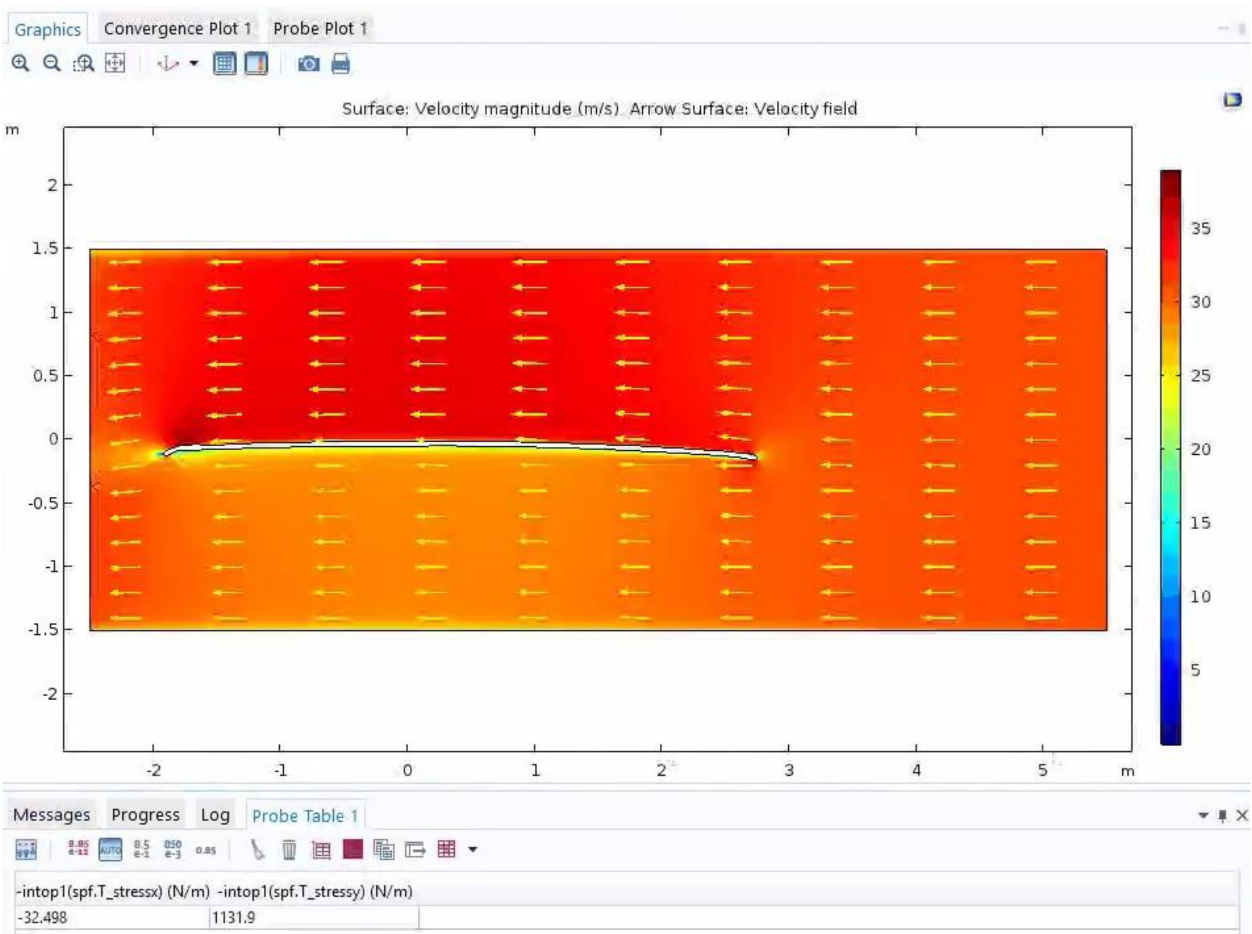
NACA6409 9% (n6409-Il), airfoiltools.com/airfoil/details?airfoil=n6409-il.

5.3.3 EPA

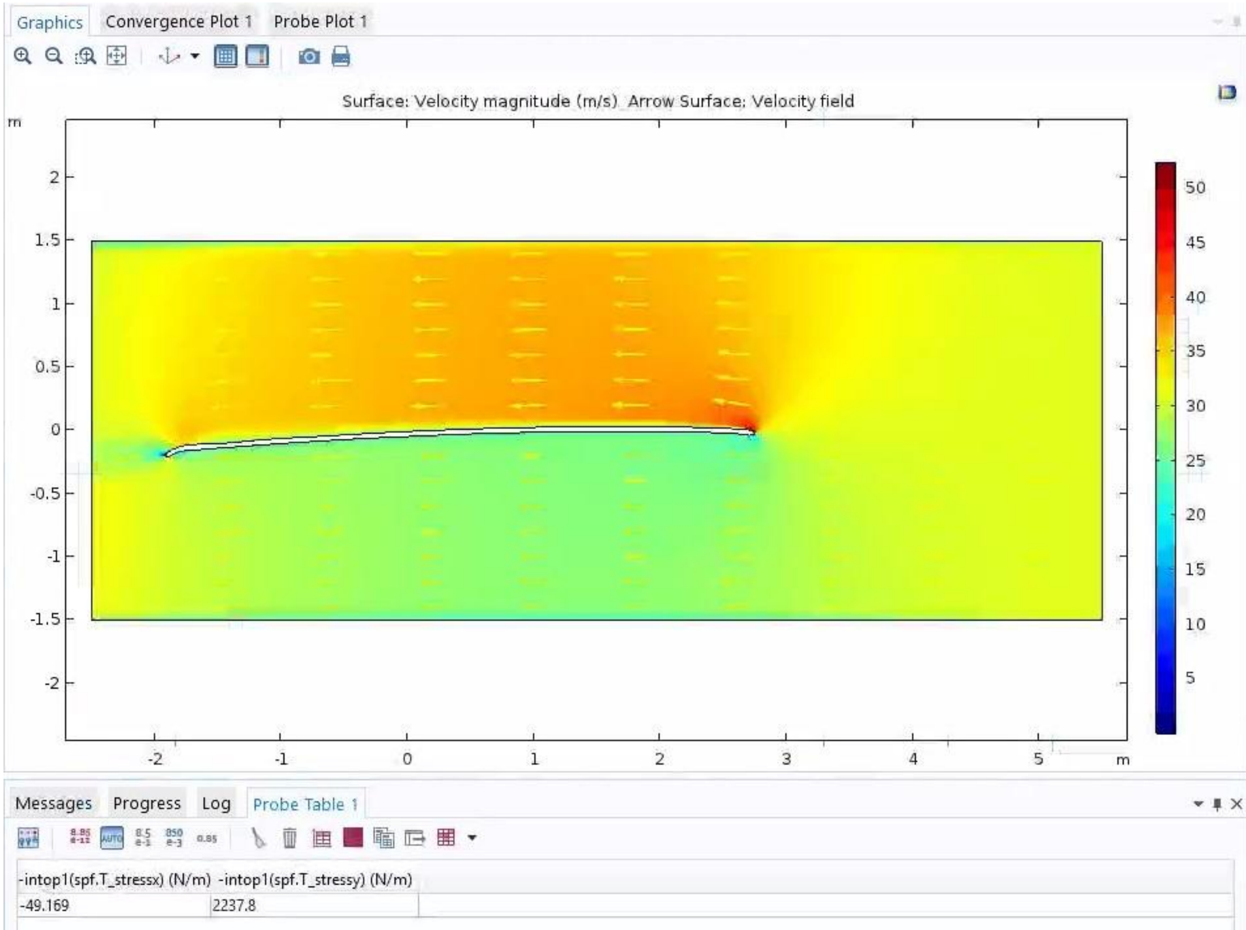
"Dynamometer Drive Schedules." *EPA*, Environmental Protection Agency, 1 Feb. 2021, www.epa.gov/vehicle-and-fuel-emissions-testing/dynamometer-drive-schedules.

Appendix I: Engineering Drawings

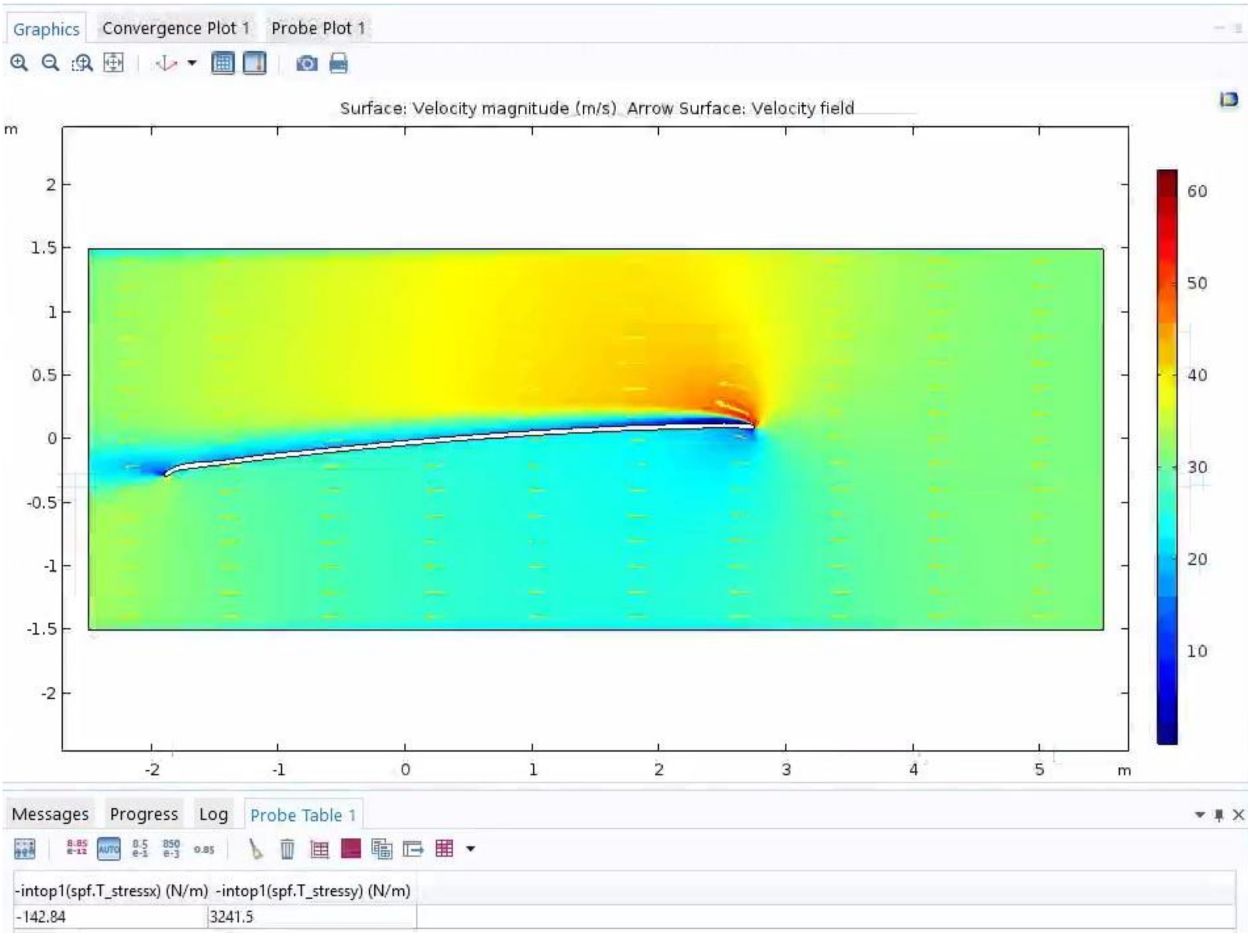
We did not create any engineering drawings during this project as our end goal was to recommend a course of action to Intrepid on how to improve their hardtop or future hardtops. We also did not create any physical prototypes, so no CAD work was performed to aid in the building of a prototype. Below, we show some COMSOL tested FEA figures that act as our "engineering drawings" for this design project.



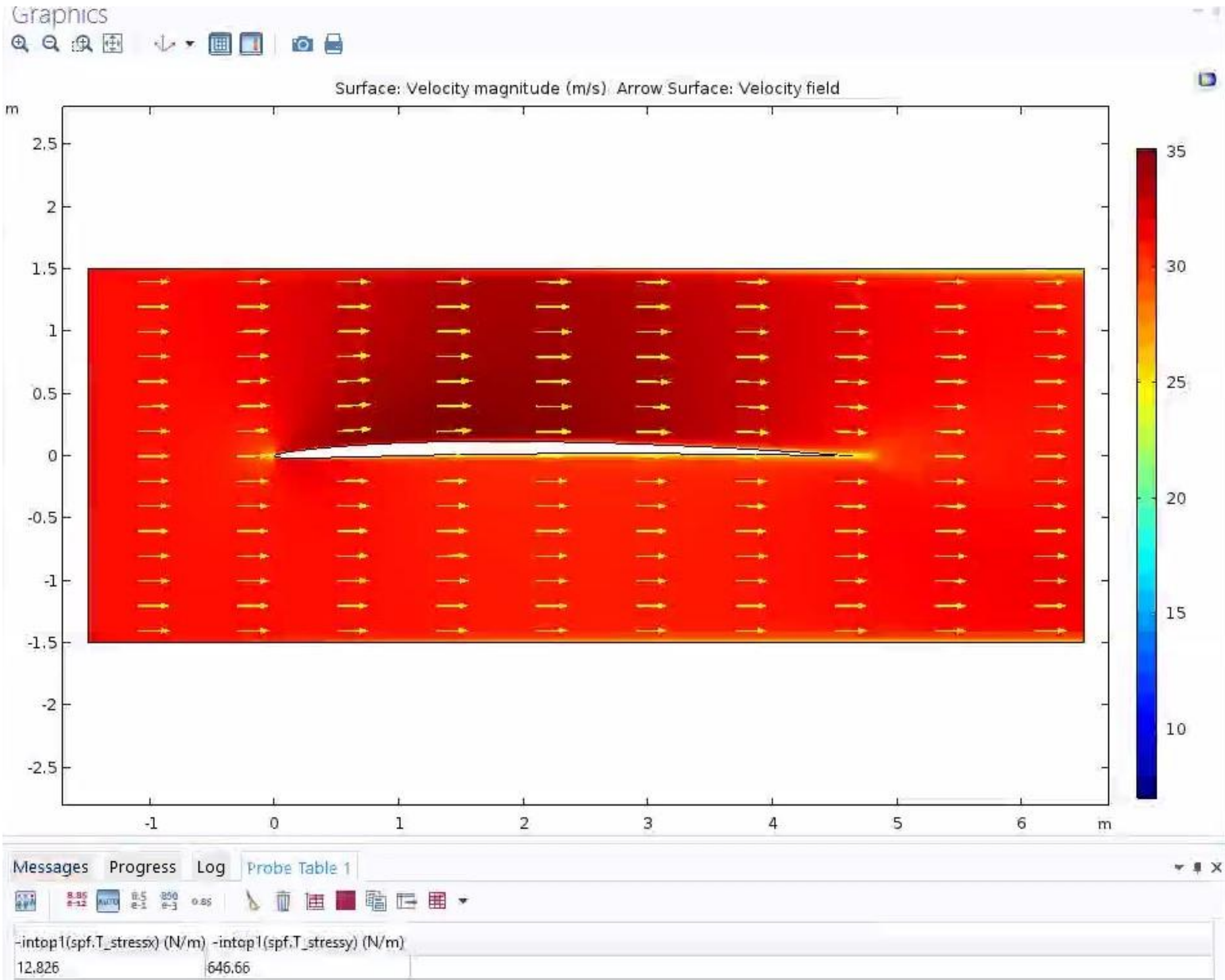
Current Intrepid 409 Valor Hardtop at 0 degrees angle of attack to calculate the coefficient of lift and drag and compare it to similar airfoil geometries inspected for improvement.



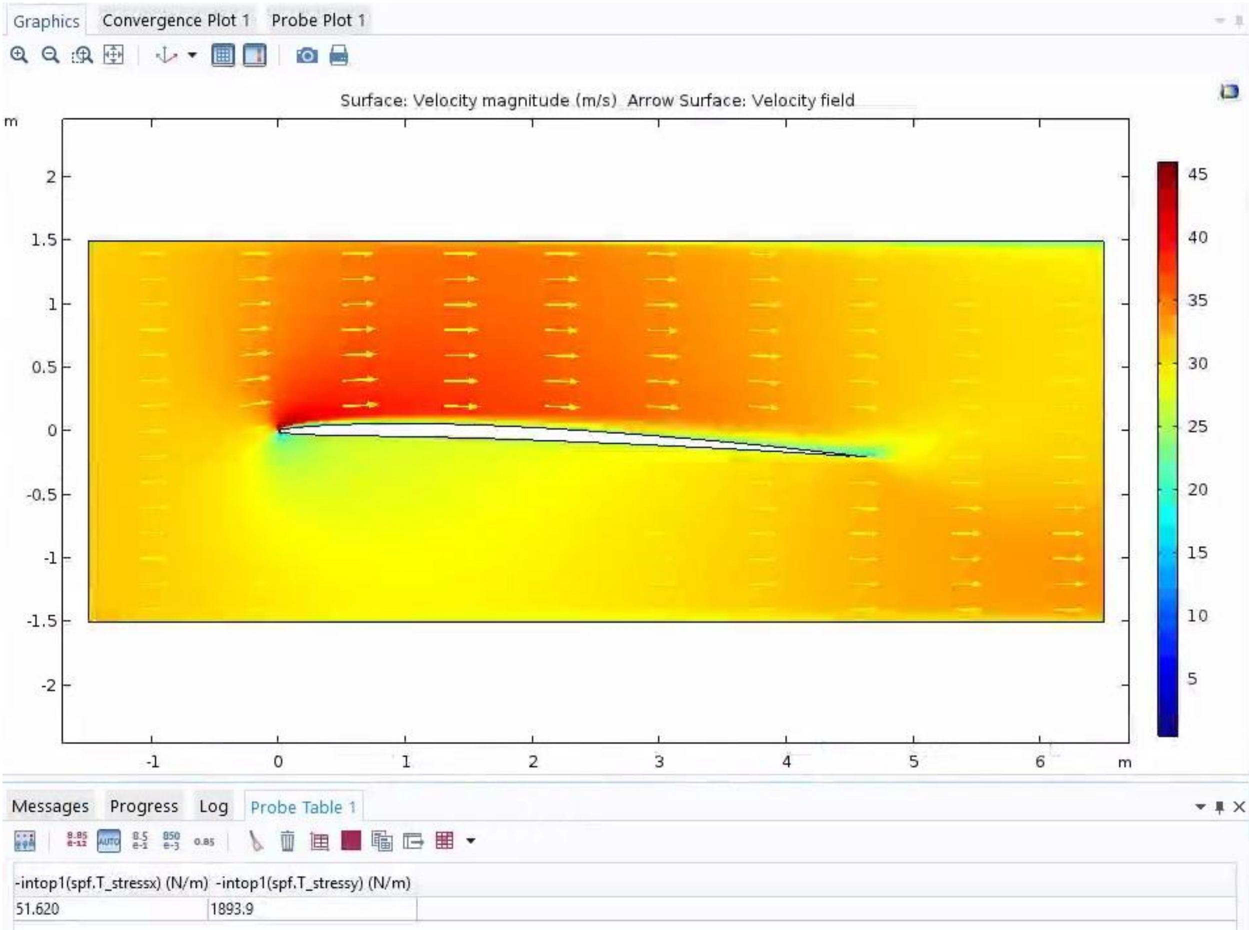
Current Intrepid 409 Valor Hardtop at 2.5 degrees angle of attack to calculate the coefficient of lift and drag and compare it to similar airfoil geometries inspected for improvement.



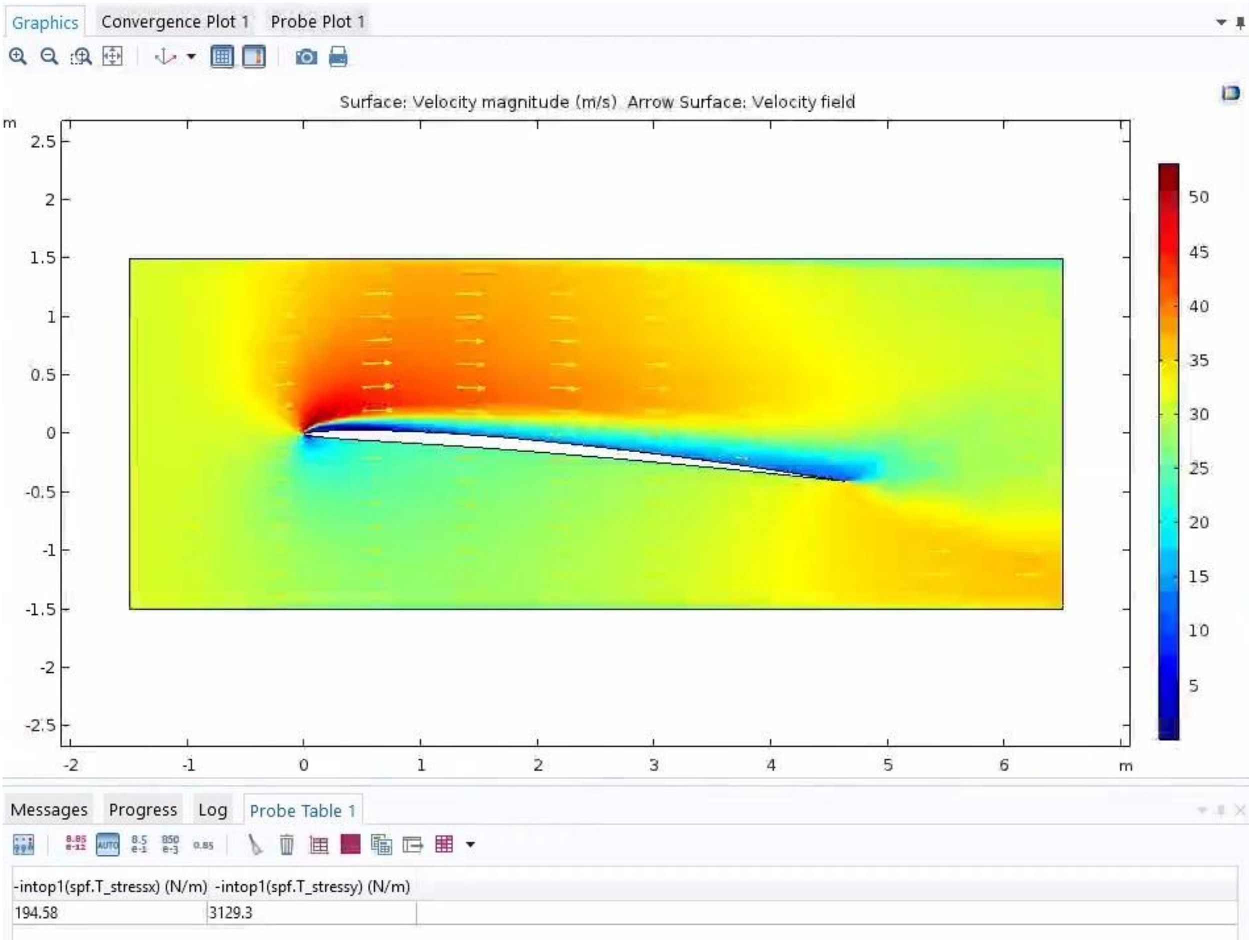
Current Intrepid 409 Valor Hardtop at 5 degrees angle of attack to calculate the coefficient of lift and drag and compare it to similar airfoil geometries inspected for improvement.



NACA 6409 25% Thickness studied at 0 degrees angle of attack to calculate the coefficient of lift and drag and compare to current Intrepid 409 Valor hardtop cross section inspected for improvement.



NACA 6409 25% Thickness studied at 2.5 degrees angle of attack to calculate the coefficient of lift and drag and compare to current Intrepid 409 Valor hardtop cross section inspected for improvement.



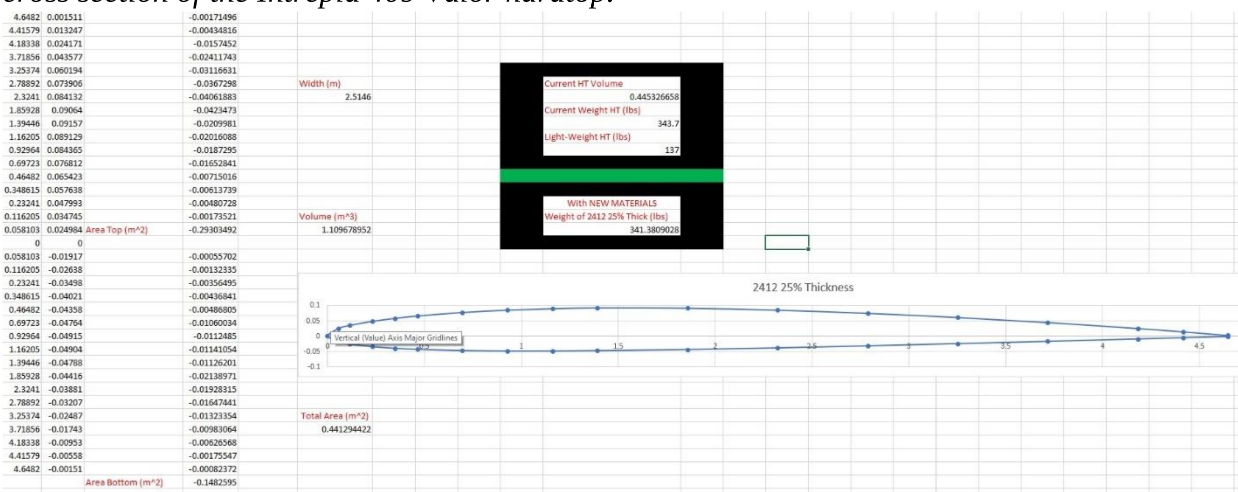
NACA 6409 25% Thickness studied at 5 degrees angle of attack to calculate the coefficient of lift and drag and compare to current Intrepid 409 Valor hardtop cross section inspected for improvement.

Appendix J: Calculations

Current 409 Valor Hardtop Cross-section			
Cross-section tested at 70 mph (31.2928 m/s) in COMSOL at three different angles of attack.			
Angle of Attack, α (degrees)	0°	2.5°	5°
Lift (N/m)	1131.9	2237.8	3241.5
Drag (N/m)	32.498	49.169	142.84

NACA 6409 Airfoil, 25% thickness cross-section			
Cross-section tested at 70 mph (31.2928 m/s) in COMSOL at three different angles of attack.			
Angle of Attack, α (degrees)	0°	2.5°	5°
Lift (N/m)	646.66	1893.9	3129.3
Drag (N/m)	12.826	51.620	194.58

Table J1: COMSOL calculations of lift and drag at varying angles of attack for the Intrepid 409 Valor hardtop as well as the NACA 6409 airfoil at 25% Thickness validating beneficial current cross section of the Intrepid 409 Valor hardtop.

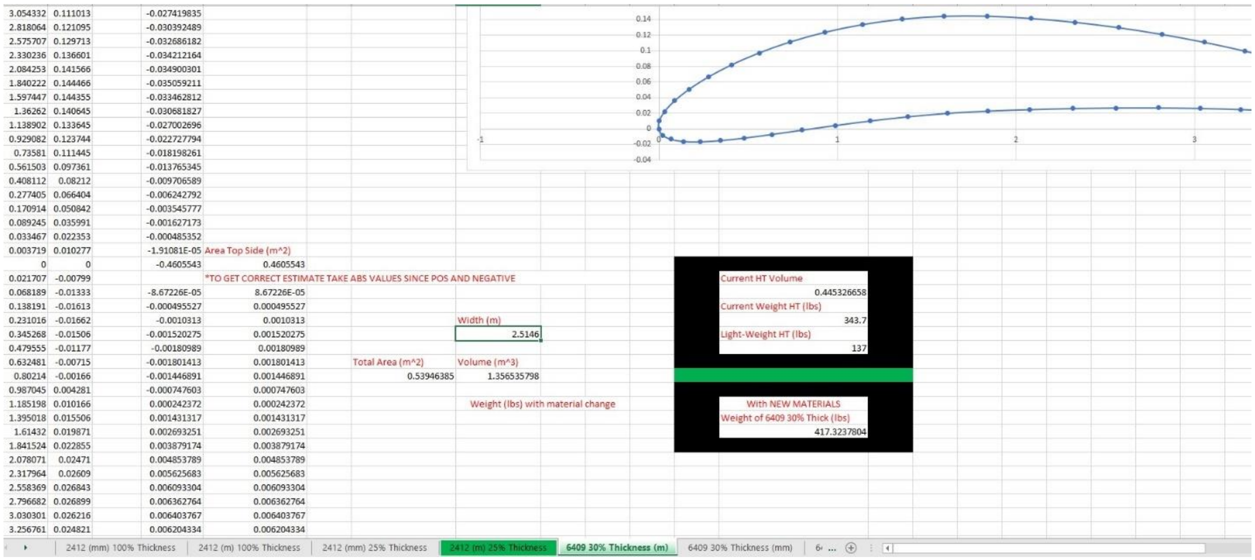


4.6482	0.001511		-0.00171496
4.41579	0.013247		-0.00434816
4.18338	0.024171		-0.0157452
3.71856	0.043577		-0.02411743
3.25374	0.060194		-0.03116631
2.78892	0.073906		-0.0367298
2.3241	0.084132		-0.04061883
1.85928	0.09064		-0.0423473
1.39446	0.09157		-0.0209981
1.16205	0.089129		-0.02016088
0.92964	0.084365		-0.0187295
0.69723	0.076812		-0.01652841
0.46482	0.065423		-0.00715016
0.348615	0.057638		-0.00613739
0.23241	0.047993		-0.00480728
0.116205	0.034745		-0.00173521
0.058103	0.024984	Area Top (m^2)	-0.29303492
0	0		
0.058103	-0.01917		-0.00055702
0.116205	-0.02638		-0.00132335
0.23241	-0.03498		-0.00356495
0.348615	-0.04021		-0.00436841
0.46482	-0.04358		-0.00486805
0.69723	-0.04764		-0.01060034
0.92964	-0.04915		-0.0112485
1.16205	-0.04904		-0.01141054
1.39446	-0.04788		-0.01126201
1.85928	-0.04416		-0.02138971
2.3241	-0.03881		-0.01928315
2.78892	-0.03207		-0.01647441
3.25374	-0.02487		-0.01323354
3.71856	-0.01743		-0.00983064
4.18338	-0.00953		-0.00626568
4.41579	-0.00558		-0.00175547
4.6482	-0.00151		-0.00082372
		Area Bottom (m^2)	-0.1482595

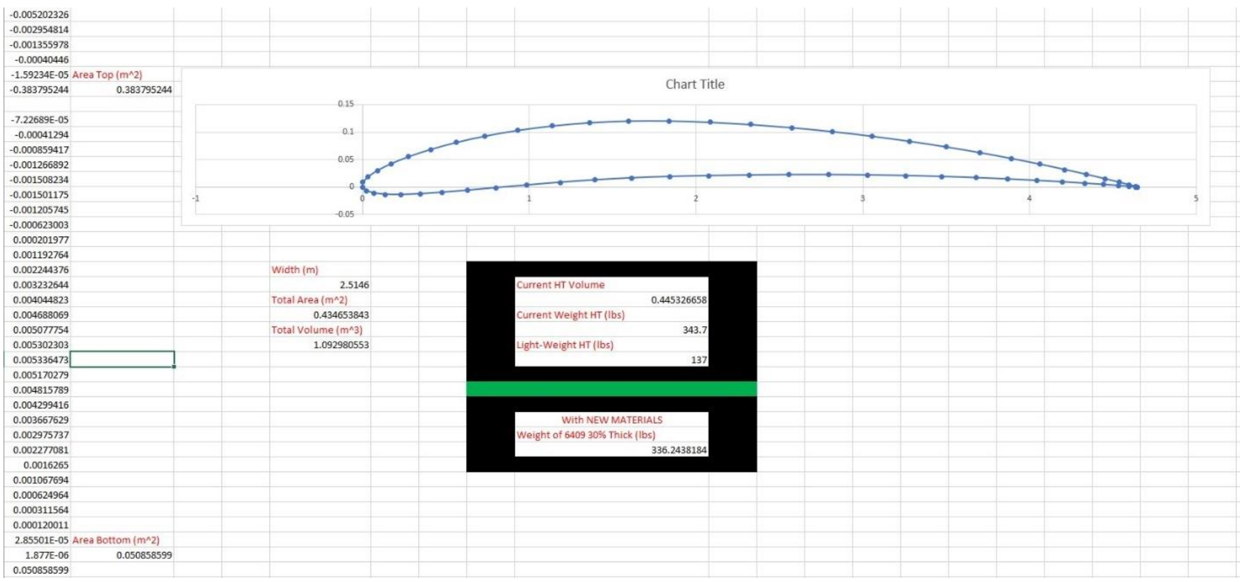
Width (m) 2.5146
Volume (m^3) 1.109678952
Total Area (m^2) 0.441294422

Current HT Volume 0.445326658
Current Weight HT (lbs) 343.7
Light-Weight HT (lbs) 137
With NEW MATERIALS
Weight of 2412 25% Thick (lbs) 341.3809028

Respective weight analysis for airfoils at different thicknesses to compare total weight to the current hardtop geometry after material switches were induced. Validated current geometry because respective airfoil geometries were far too heavy.



Respective weight analysis for airfoils at different thicknesses to compare total weight to the current hardtop geometry after material switches were induced. Validated current geometry because respective airfoil geometries were far too heavy.



Respective weight analysis for airfoils at different thicknesses to compare total weight to the current hardtop geometry after material switches were induced. Validated current geometry because respective airfoil geometries were far too heavy.

INPUT

This spreadsheet was written by Dingo Tweedie, October 2004.
Dit rekenblad werd deur Dingo Tweedie, oktober 2004, geschreven.
Versie 1.2.1

Hull

Length of Waterline	L_{WL}	40.00	feet	=	12.192	metres	
Beam	B	11.08	feet	=	3.378	metres	
VCG	VCG	4.00	feet	=	1.219	metres	
Displacement	Δ	20,000	lbf	=	9,072	kg	
Deadrise @ Transom	β_T	10.00	°				
Deadrise @ Amidships	$\beta_{)0(}$	10.00	°				
Distance to Amidships	$L_{)0(}$	20.000	feet	=	6.096	metres	
	θ	0.000	°				
Angle of Thrust Line	ε	0.00	°				
	f	0.00	feet	=	0.000	metres	
Minimum Speed	V_{min}	6.7	kn	=	11.3	feet/s	This is the minimum speed valid for this analysis
Maximum Speed	V_{max}	145.4	kn	=	245.5	feet/s	This is the maximum speed valid for this analysis

S/Str.

Length Overall	LOA	40.00	feet	=	12.192	metres
Maximum Beam	B_{max}	11.08	feet	=	3.378	metres
Moulded Depth of Hull	Z	11.67	feet	=	3.556	metres
Height of House	H_{SS}	0.00	feet	=	0.000	metres
Breadth of House	B_{SS}	0.00	feet	=	0.000	metres
Frontal Area of House	A_{SS}	0.00	$feet^2$	=	0.000	m^2

Number

Number of Propellers	N	3

Trim Tab

Chord	c_F	1	feet	=	0.305	metres
Span Ratio	σ	0.333	(<= 1)			
Deflection Angle	δ	2	°			

Rudder

Chord	c_{rudder}	0.00	feet	=	0.000	metres	
Thickness	t	0.00	feet	=	0.000	metres	
Area	A_{rudder}	0.00	$feet^2$	=	0.000	m^2	
Centrepoint	x_c	0.00	feet from transom	=	0.000	metres	(+ve fwd)
	y_c	0.00	feet from baseline	=	0.000	metres	(+ve up)

Shaft

Diameter of Shaft	Φ_{shaft}	0.00	feet	=	0.000	metres	
Length of Shaft & Hub	l	0.00	feet	=	0.000	metres	
Centrepoint	x_c	0.00	feet from transom	=	0.000	metres	(+ve fwd)
	y_c	0.00	feet from baseline	=	0.000	metres	(+ve up)

Strut

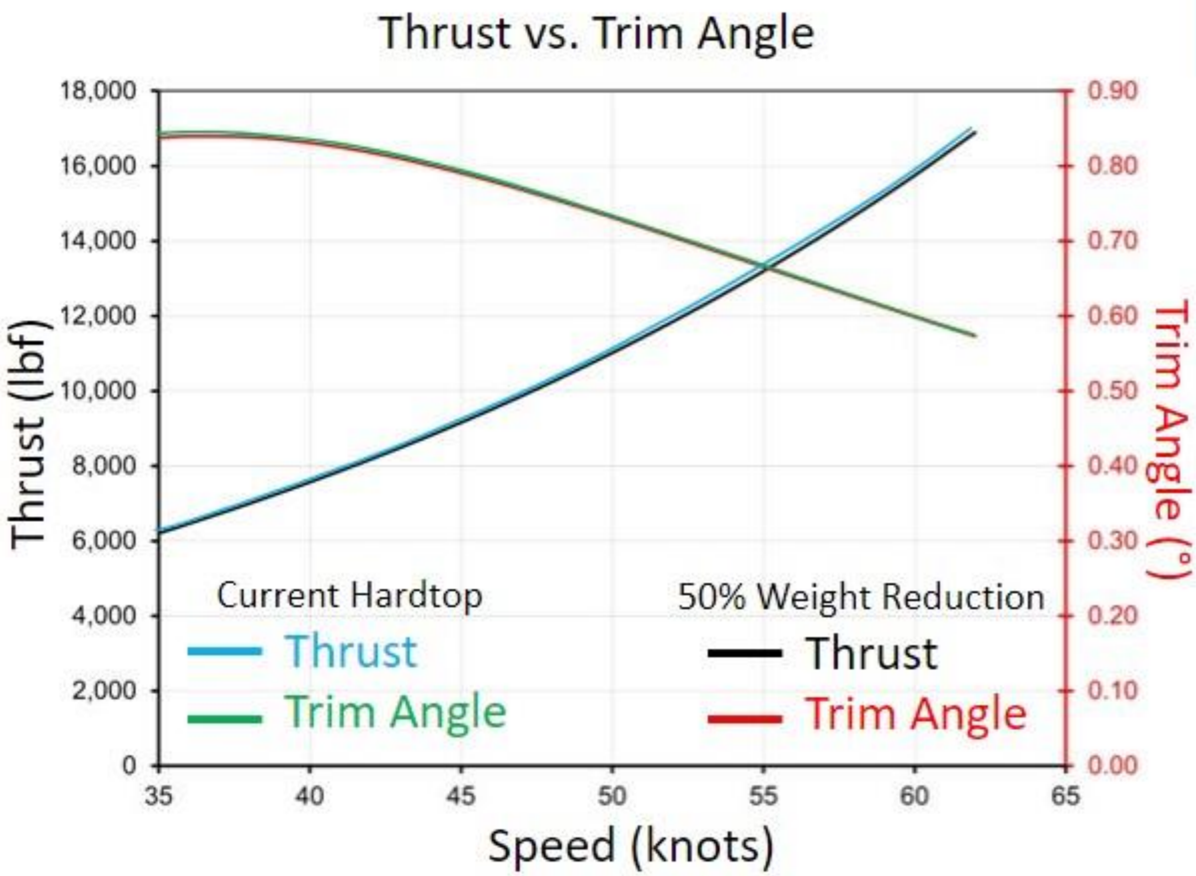
Chord	c_{strut}	0.00	feet	=	0.000	metres	
Thickness	t	0.00	feet	=	0.000	metres	
Area	A_{strut}	0.00	$feet^2$	=	0.000	m^2	****
Centrepoint	x_c	0.00	feet from transom	=	0.000	metres	(+ve fwd)
	y_c	0.00	feet from baseline	=	0.000	metres	(+ve up)

OUTPUT

Go

V	LCG		τ	D		T		$P_{effective}$		h		τ_{cr}		Comments	λ
[kn]	[ft]	[metres]	[°]	[lbf]	[kN]	[lbf]	[kN]	[ehp]	[ekW]	[ft]	[metres]	Lew.[°]	Angeli [°]		
35	29	8.839	0.84	6,201	27.6	6,202	27.6	666	497	1.19	0.363	3.23	2.12	Note: not planing	5.6630
36	29	8.839	0.84	6,459	28.7	6,459	28.7	714	533	1.19	0.363	3.08	2.04	Note: not planing	5.5945
38	29	8.839	0.84	6,996	31.1	6,997	31.1	816	609	1.16	0.354	2.83	1.90	Note: not planing	5.4736
40	29	8.839	0.83	7,566	33.7	7,567	33.7	929	693	1.14	0.347	2.60	1.77	Note: not planing	5.3743
42	29	8.839	0.82	8,172	36.4	8,173	36.4	1,053	786	1.12	0.341	2.41	1.66	Note: not planing	5.2951
44	29	8.839	0.80	8,818	39.2	8,818	39.2	1,191	889	1.09	0.332	2.24	1.56	Note: not planing	5.2351
46	29	8.839	0.78	9,505	42.3	9,506	42.3	1,342	1,001	1.06	0.323	2.09	1.47	Note: not planing	5.1925
48	29	8.839	0.76	10,237	45.6	10,238	45.6	1,508	1,125	1.03	0.314	1.95	1.39	Note: not planing	5.1658
50	29	8.839	0.73	11,017	49.0	11,017	49.0	1,691	1,262	1.01	0.308	1.83	1.32	Note: not planing	5.1537
52	29	8.839	0.71	11,847	52.7	11,848	52.7	1,891	1,411	0.98	0.299	1.72	1.25	Note: not planing	5.1552
54	29	8.839	0.68	12,732	56.7	12,733	56.7	2,110	1,575	0.96	0.293	1.62	1.19	Note: not planing	5.1689
56	29	8.839	0.65	13,675	60.9	13,676	60.9	2,350	1,754	0.93	0.283	1.53	1.14	Note: not planing	5.1946
58	29	8.839	0.63	14,679	65.3	14,680	65.3	2,613	1,950	0.91	0.277	1.45	1.09	Note: not planing	5.2312
60	29	8.839	0.60	15,750	70.1	15,750	70.1	2,900	2,164	0.89	0.271	1.38	1.04	Note: not planing	5.2792
62	29	8.839	0.57	16,894	75.2	16,895	75.2	3,215	2,399	0.87	0.265	1.31	1.00	Note: not planing	5.3390

Respective thrust analysis performed to study reduction in thrust at lower hardtop weights as a result of a marginally lower center of gravity of the vessel after weight reduction.



Respective thrust vs. speed plot at full hardtop weight and 50% reduction in hardtop weight showing marginal decrease in thrust throughout the powerband translating to an ultimate reduction in fuel consumption resulting from lessening the hardtop weight.

SD2

cost analysis

Aircell T-100 — \$4.59/ft²

1" → \$577.47

3/4" → \$577.47

CORE

Total: \$1154.96

Area 125.8125 ft²

Divinycell H-35: Non-perforated \$245.39 → 4' x 8' sheet → 3.932 sheets for 2 HT

1" → \$964.79

3/4" → \$964.79

Perforated H-35 (\$104.99)(3.932)(2) \$825.641 → \$329.32 decrease

CORE

Total: \$1929.57 → \$774.61 increase

Current weight 327.1125 lbs

Gelcoat: \$78.98/gallon → 9 lbs. per gallon

Hardtop takes 16.364 lbs gelcoat

\$143.61 per side of mold

Total: \$287.21

Divinycell core switch 187.461 lbs → 42.7% weight reduction from core alone

↳ Resin weight 75.4875 lbs

Cost →

1oz CSM:

WEIGHT ANALYSIS FIBERGLASS

E-BXM 1208: A = 125.8125 ft²

lb/ft² = 0.324 → 2 sheets ∴

= (0.324 lb/ft²)(125.8125 ft²)(2 sheets)

Total weight = 81.5265 lbs

18.3% reduction in weight from fiberglass alone

S-2 Glass:

2.1 – 9 oz/yd² → 0.05625 + 0.0295762 (resin absorbtion)

Resin content 52.58 %vol ∴ resin absorbtion

(0.05625)(0.5258) = 0.02957625 lb/ft²

↳ = (0.08582625)(2)(125.8125)

Total weight = 21.596 lbs

Weight reduction: (81.5625 lbs) (1208) – (21.596 lbs) (S-2 Glass)

Weight reduction = 59.93 lbs

199.582 lbs. reduction

327.1125 lbs ↓ 127.5305 lbs. → 61.01% reduction in weight

Total Weight Reduction

187.461 – 59.93 lbs

→ = 127.5305 lbs

WEIGHT NEW HT

SD2

Total cost

Current HT

Resin → $\frac{75.4875 \text{ lbs}}{9.2 \frac{lb}{gal}}$ = (8.205 gallons)($54.99/gal)

| Resin $451.20 |

Gelcoat
($1079.47)(2)
$2158.9425

1208
$221.43

CSM
$289.37

Aircell T-100
$1154.96

Total → $4275.90 → current cost

Fiberglass & Core Change

1208 → (S-2)
→ $1.56/ft²

S-2
($196.2675)(2)
$392.535

3.84767172
3.8% cost INCREASE
If only switching fiberglass

Divinycell
$825.64

→ cost of hardtop mat.
$4117.69 → $158.21 SAVED
↓
Total cost DECREASE = 3.7%

If only switching core
7.70% cost DECREASE

Appendix K: Risk Assessment

Project Hazard Control- For Projects with Medium and Higher Risks

Name of Project: 511: Intrepid		**Date of submission:** 12/04/2020
Team member	**Phone number**	**e-mail**
Erika Craft	561-727-9849	epc16@my.fsu.edu
John Karamitsanis	813-992-0152	jhk16c@my.fsu.edu
Cory Stanley	850-566-4472	cps18u@my.fsu.edu
Juan Tapia	850-273-3139	jdt16b@my.fsu.edu
Faculty mentor	**Phone number**	**e-mail**
Dr. William Oates	850-645-0139	woates@eng.famu.fsu.edu
Dr. Shayne McConomy	850-410-6624	smcconomy@eng.famu.fsu.edu

Rewrite the project steps to include all safety measures taken for each step or combination of steps. Be specific (don't just state "be careful").

1. **Simulink/Coding, CAD Modeling, FEA for Aerodynamic Analysis**

Before turning on computer, one must check the connections of all wires. Be sure to take note of all connections an ensure that no metal is exposed at any connection point. Full connection of wires is required for complete safety. Wires must stay clear of areas where they could potentially be unplugged such as at the user's foot space, near the mouse pad or keyboard, or on walls where they can be brushed against and accessed too easily to prevent from connection disruptions. Electrocution can result in very serious injuries, so care must be taken. Reference **OSHA 3075** guidelines for further information on electrical wire safety. When leaving the workstation, connections should again be checked to make sure no wires shifted or no connections were disrupted during computer usage. If shifting occurred, the wires must be replaced, and connections must be restored to avoid future accidents.

2. **Handwritten Calculations/Deskwork**

Follow best practices as laid out by the **OSHA Computer Workstations** guidelines for avoiding eye strain and overuse of hands and wrist. These guidelines include setting your workstation in an ergonomic manner to avoid unneeded strain, making sure correct seating posture is used to reduce stress on the body, taking breaks as required and

wearing optional blue light glasses to avoid eye strain while looking at computer screens for extended periods of time.			
Thinking about the accidents that have occurred or that you have identified as a risk, describe emergency response procedures to use.			
Be sure to take note of all connections an ensure that no metal is exposed. Our risks are low in nature so the emergency response would include reaching out to our PI and seeking medical attention at our earliest convenience. In the event a team member is seriously electrocuted and needs medical attention, 911 may be called to immediately address the accident and injuries and after the fact the PI will be notified and an incident report will be filled out identifying the particulars of the situation. This is not likely; however, it must still be considered.			
List emergency response contact information:			
• Call 911 for injuries, fires or other emergency situations • Call your department representative to report a facility concern			
Team Member Name	Phone number	Faculty or other COE emergency contact	Phone number
Erika Craft	(561) 727-9849	**Dorr Campbell**	(850) 410-6610
John Karamitsanis	(813) 992-0152	**Mohd Ali**	(850) 410-6588
Cory Stanley	(850) 566-4472	**Kourosh Shoele**	(850) 645-0143
Juan Tapia	(850) 273-3139	**Eric Hellstrom**	(850) 645-7489
Non-team Member Name	Phone number		
Ethan Hale	(904) 860-4712		
Connor Chuppe	(561) 306-3836		
Safety review signatures			
Team member	Date	Faculty mentor	Date
Erika Craft	**12/3/20**	**Shayne McConomy**	**12/3/20**
John Karamitsanis	**12/3/20**	**William Oates**	**12/3/20**
Cory Stanley	**12/3/20**		
Juan Tapia	**12/3/20**		
Non-team member			
Ethan Hale	**12/3/20**		
Connor Chuppe	**12/3/20**		

Report all accidents and near misses to the faculty mentor.

FAMU-FSU College of Engineering
Project Hazard Assessment Policy and Procedures

INTRODUCTION

University laboratories are not without safety hazards. Those circumstances or conditions that might go wrong must be predicted and reasonable control methods must be determined to prevent incident and injury. The FAMU-FSU College of Engineering is committed to achieving and maintaining safety in all levels of work activities.

PROJECT HAZARD ASSESSMENT POLICY

Principal investigator (PI)/instructor are responsible and accountable for safety in the research and teaching laboratory. Prior to starting an experiment, laboratory workers must conduct a project hazard assessment (PHA) to identify health, environmental and property hazards and the proper control methods to eliminate, reduce or control those hazards. PI/instructor must review, approve, and sign the written PHA and provide the identified hazard control measures. PI/instructor continually monitor projects to ensure proper controls and safety measures are available, implemented, and followed. PI/instructor are required to reevaluate a project anytime there is a change in scope or scale of a project and at least annually after the initial review.

PROJECT HAZARD ASSESSMENT PROCEDURES

It is FAMU-FSU College of Engineering policy to implement followings:

1. Laboratory workers (i.e. graduate students, undergraduate students, postdoctoral, volunteers, etc.) performing a research in FAMU-FSU College of Engineering are required to conduct PHA prior to commencement of an experiment or any project change in order to identify existing or potential hazards and to determine proper measures to control those hazards.
2. PI/instructor must review, approve and sign the written PHA.
3. PI/instructor must ensure all the control methods identified in PHA are available and implemented in the laboratory.
4. In the event laboratory personnel are not following the safety precautions, PI/instructor must take firm actions (e.g. stop the work, set a meeting to discuss potential hazards and consequences, ask personnel to review the safety rules, etc.) to clarify the safety expectations.
5. PI/instructor must document all the incidents/accidents happened in the laboratory along with the PHA document to ensure that PHA is reviewed/modified to prevent reoccurrence. In the event of PHA modification a revision number should be given to the PHA, so project members know the latest PHA revision they should follow.
6. PI/instructor must ensure that those findings in PHA are communicated with other students working in the same laboratory (affected users).
7. PI/instructor must ensure that approved methods and precautions are being followed by :
    a. Performing periodic laboratory visits to prevent the development of unsafe practice.
    b. Quick reviewing of the safety rules and precautions in the laboratory members meetings.
    c. Assigning a safety representative to assist in implementing the expectations.

d. Etc.

8. A copy of this PHA must be kept in a binder inside the laboratory or PI/instructor's office (if experiment steps are confidential).

Project Hazard Assessment Worksheet				
PI/instructor: Shayne McConomy	Phone #:(850) 410-6624	Dept.: Mech Eng.	Start Date: 01/06/2021	Revision number: 0
Project: Intrepid Hardtop – Team 511			Location(s): FAMU-FSU College of Engineering, ME SD Lab	
Team member(s): Erika Craft, John Karamitsanis, Cory Stanley, Juan Tapia			Phone #: (850) 410-6624	Email: smcconomy@eng.famu.fsu.edu

Experiment Steps	**Location**	**Person assigned**	**Identify hazards or potential failure points**	**Control method**	**PPE**	**List proper method of hazardous waste disposal, if any.**	**Residual Risk**	**Specific rules based on the residual risk**
Simulink, Coding	FAMU-FSU CoE	Cory	Loose Electrical Wires, Stress, Back Pain, Headaches Errors in code, miscalculations	Check with preliminary hand calculations or theoretical values	Blue Light Glasses (optional)	N/A	HAZARD: 1 CONSEQ: Electrocution Residual: Med	Be careful when plugging computers in or messing with wires
CAD Modeling	FAMU-FSU CoE	Entire Team	Loose Electrical Wires, Stress, Back Pain, Headaches	Ensure only necessary constraints are added	Blue Light Glasses (optional)	N/A	HAZARD: 1 CONSEQ:	Take breaks when modeling for long

			Over constrained models				Eye Strain Residual: Low	periods of time
FEA for Aerodynamic Analysis	FAMU-FSU CoE	John	Loose Electrical Wires, Stress, Back Pain, Headaches Weak form incorrectly input into FEA solver (COMSOL), incorrect boundary conditions or geometry	Check against theoretical values, models, and hand calculations (if any). Validate by convergence.	Blue Light Glasses (optional)	N/A	HAZARD: 1 CONSEQ: Eye Strain Residual: Low	Take breaks when performing simulations for long periods of time
Handwritten Calculations	FAMU-FSU CoE	Entire Team	Stress, Back Pain, Headaches, Poor Posture, Tendon Damage Miscalculations, Human errors	Verify with known values and calculations	Wrist wrap	N/A	HAZARD: 1 CONSEQ: Carpal Tunnel Residual: Low	Wrist mobility exercises and stretching, break in between long periods of writing

Principal investigator(s)/ instructor PHA: I have reviewed and approved the PHA worksheet.

Name	Signature	Date	Name	Signature	Date
___Shayne McConomy___	__________________	___________	___William Oates___	__________________	__________

Team members: I certify that I have reviewed the PHA worksheet, am aware of the hazards, and will ensure the control measures are followed.

Name	Signature	Date	Name	Signature	Date
____Erika Craft____	Erika Craft	__12-3-20__	___Cory Stanley___	Cory Stanley	__12-3-20__
____John Karamitsanis____	J. Karamitsanis	__12-3-20__	___Juan Tapia___	Juan Tapia	__12-3-20__

DEFINITIONS:

Hazard: Any situation, object, or behavior that exists, or that can potentially cause ill health, injury, loss or property damage e.g. electricity, chemicals, biohazard materials, sharp objects, noise, wet floor, etc. OSHA defines hazards as "*any source of potential damage, harm or adverse health effects on something or someone".* A list of hazard types and examples are provided in appendix A.

Hazard control: Hazard control refers to workplace measures to eliminate/minimize adverse health effects, injury, loss, and property damage. Hazard control practices are often categorized into following three groups (priority as listed):

1. **Engineering control:** physical modifications to a process, equipment, or installation of a barrier into a system to minimize worker exposure to a hazard. Examples are ventilation (fume hood, biological safety cabinet), containment (glove box, sealed containers, barriers), substitution/elimination (consider less hazardous alternative materials), process controls (safety valves, gauges, temperature sensor, regulators, alarms, monitors, electrical grounding and bonding), etc.
2. **Administrative control:** changes in work procedures to reduce exposure and mitigate hazards. Examples are reducing scale of process (micro-scale experiments), reducing time of personal exposure to process, providing training on proper techniques, writing safety policies, supervision, requesting experts to perform the task, etc.
3. **Personal protective equipment (PPE):** equipment worn to minimize exposure to hazards. Examples are gloves, safety glasses, goggles, steel toe shoes, earplugs or muffs, hard hats, respirators, vests, full body suits, laboratory coats, etc.

Team member(s): Everyone who works on the project (i.e. grads, undergrads, postdocs, etc.). The primary contact must be listed first and provide phone number and email for contact.

Safety representative: Each laboratory is encouraged to have a safety representative, preferably a graduate student, in order to facilitate the implementation of the safety expectations in the laboratory. Duties include (but are not limited to):

- Act as a point of contact between the laboratory members and the college safety committee members.
- Ensure laboratory members are following the safety rules.
- Conduct periodic safety inspection of the laboratory.
- Schedule laboratory clean up dates with the laboratory members.
- Request for hazardous waste pick up.

Residual risk: Residual Risk Assessment Matrix are used to determine project's risk level. The hazard assessment matrix (table 1) and the residual risk assessment matrix (table2) are used to identify the residual risk category.

The instructions to use hazard assessment matrix (table 1) are listed below:

1. Define the workers familiarity level to perform the task and the complexity of the task.

2. Find the value associated with familiarity/complexity (1 – 5) and enter value next to: HAZARD on the PHA worksheet.

Table 1. Hazard assessment matrix.

		Complexity		
		Simple	Moderate	Difficult
Familiarity Level	Very Familiar	1	2	3
	Somewhat Familiar	2	3	4
	Unfamiliar	3	4	5

The instructions to use residual risk assessment matrix (table 2) are listed below:

1. Identify the row associated with the familiarity/complexity value (1 – 5).
2. Identify the consequences and enter value next to: CONSEQ on the PHA worksheet. Consequences are determined by defining what would happen in a worst case scenario if controls fail.
    a. Negligible: minor injury resulting in basic first aid treatment that can be provided on site.
    b. Minor: minor injury resulting in advanced first aid treatment administered by a physician.
    c. Moderate: injuries that require treatment above first aid but do not require hospitalization.
    d. Significant: severe injuries requiring hospitalization.
    e. Severe: death or permanent disability.
3. Find the residual risk value associated with assessed hazard/consequences: Low –Low Med – Med– Med High – High.
4. Enter value next to: RESIDUAL on the PHA worksheet.

Table 2. Residual risk assessment matrix.

Assessed Hazard Level	**Consequences**				
	Negligible	Minor	Moderate	Significant	Severe
5	Low Med	Medium	Med High	High	High
4	Low	Low Med	Medium	Med High	High
3	Low	Low Med	Medium	Med High	Med High
2	Low	Low Med	Low Med	Medium	Medium
1	Low	Low	Low Med	Low Med	Medium

Specific rules for each category of the residual risk:

Low:

- Safety controls are planned by both the worker and supervisor.
- Proceed with supervisor authorization.

Low Med:

- Safety controls are planned by both the worker and supervisor.
- A second worker must be in place before work can proceed (buddy system).
- Proceed with supervisor authorization.

Med:

- After approval by the PI, a copy must be sent to the Safety Committee.
- A written Project Hazard Control is required and must be approved by the PI before proceeding. A copy must be sent to the Safety Committee.
- A second worker must be in place before work can proceed (buddy system).
- Limit the number of authorized workers in the hazard area.

Med High:

- After approval by the PI, the Safety Committee and/or EHS must review and approve the completed PHA.
- A written Project Hazard Control is required and must be approved by the PI and the Safety Committee before proceeding.
- Two qualified workers must be in place before work can proceed.
- Limit the number of authorized workers in the hazard area.

High:

- The activity will not be performed. The activity must be redesigned to fall in a lower hazard category.

Appendix A: Hazard types and examples

Types of Hazard	**Example**
Physical hazards	Wet floors, loose electrical cables objects protruding in walkways or doorways
Ergonomic hazards	Lifting heavy objects Stretching the body Twisting the body Poor desk seating
Psychological hazards	Heights, loud sounds, tunnels, bright lights
Environmental hazards	Room temperature, ventilation contaminated air, photocopiers, some office plants acids
Hazardous substances	Alkalis solvents
Biological hazards	Hepatitis B, new strain influenza
Radiation hazards	Electric welding flashes Sunburn
Chemical hazards	Effects on central nervous system, lungs, digestive system, circulatory system, skin, reproductive system. Short term (acute) effects such as burns, rashes, irritation, feeling unwell, coma and death. Long term (chronic) effects such as mutagenic (affects cell structure), carcinogenic (cancer), teratogenic (reproductive effect), dermatitis of the skin, and occupational asthma and lung damage.

Noise	High levels of industrial noise will cause irritation in the short term, and industrial deafness in the long term.
Temperature	Personal comfort is best between temperatures of 16°C and 30°C, better between 21°C and 26°C. Working outside these temperature ranges: may lead to becoming chilled, even hypothermia (deep body cooling) in the colder temperatures, and may lead to dehydration, cramps, heat exhaustion, and hyperthermia (heat stroke) in the warmer temperatures.
Being struck by	This hazard could be a projectile, moving object or material. The health effect could be lacerations, bruising, breaks, eye injuries, and possibly death.
Crushed by	A typical example of this hazard is tractor rollover. Death is usually the result
Entangled by	Becoming entangled in machinery. Effects could be crushing, lacerations, bruising, breaks amputation and death.
High energy sources	Explosions, high pressure gases, liquids and dusts, fires, electricity and sources such as lasers can all have serious effects on the body, even death.
Vibration	Vibration can affect the human body in the hand arm with `white-finger' or Raynaud's Syndrome, and the whole body with motion sickness, giddiness, damage to bones and audits, blood pressure and nervous system problems.
Slips, trips and falls	A very common workplace hazard from tripping on floors, falling off structures or down stairs, and slipping on spills.
Radiation	Radiation can have serious health effects. Skin cancer, other cancers, sterility, birth deformities, blood changes, skin burns and eye damage are examples.
Physical	Excessive effort, poor posture and repetition can all lead to muscular pain, tendon damage and deterioration to bones and related structures
Psychological	Stress, anxiety, tiredness, poor concentration, headaches, back pain and heart disease can be the health effects
Biological	More common in the health, food and agricultural industries. Effects such as infectious disease, rashes and allergic response.