New Housing Structure for Deep Sea Equipment

Midterm Report 1

Team 21

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Abstract

This document contains a detailed description of our project along with current status and future work. The first portion of the report encompasses background research conducted in order to direct and aid our design process. Also included is the problem statement, project scope, our goals and objectives including our project constraints. Design concepts with preliminary analysis is included with a comparison of the designs in a Pugh matrix and a short discussion of these results. The results obtained will be used to aid in the design of models and the testing of moments and forces on the models.

1. Problem Statement and Project Scope

1.1 Introduction

The Earth, Ocean, and Atmospheric Science (EOAS) group at Florida State University is interested in updating their current tethered underwater vehicle to a smaller, lighter, more modular, able to orient itself, and easily moveable design. The design currently is a large rectangular prism which contains 15 pieces of equipment to collect data and house needed electronics. This TOV needs to be able to withstand pressures of 2000 meters deep and be impact resistant to possible rocks on the ocean floor. In order to do this, research must be done on previous TOVs and the best aspects from each - i.e: shape, inside design, material - can be implemented into our design. To determine an optimal volume and equipment set up within the housing, there must be standardization when analyzing the potential designs.

1.2 Background

To create a TOV, it is necessary to determine the optimal design for underwater use. Florida State University (FSU), University of South Florida (USF), University of Mississippi (UM), and other non-university companies have designed TOV's to best suit their needs. After gathering information from non-university companies, it was clear that their budget was larger and therefore, had more access to resources. However, most on-university companies seemed to have an outer casing housing the electronics with a long horizontal section which could possibly lend to a longer design in the future but is also much more expensive.

FSU, USF, and UM have all made previous TOV's. FSU currently has a TOV which is made of galvanized steel piping. The rectangular prism shape has dimensions of 3 feet by 6 feet by 3 feet and can be seen in figure 1. They have approximately 15 different pieces of equipment that they attach to the frame when the TOV is taken out for cruises. Also attached to the frame is white plastic surfaces, which force the water through the center of the structure; this maximizes the structures ability tow straight. This TOV is towed behind a boat and it cruises at about 2000 meters below the surface.

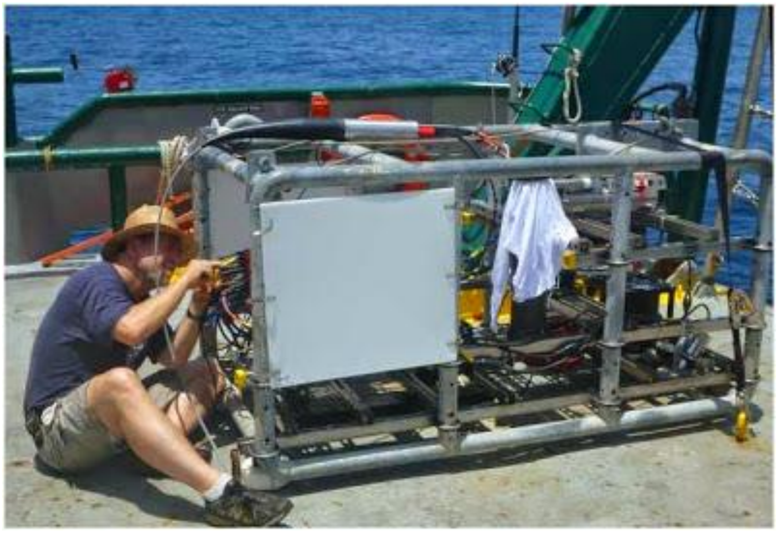


Figure 1: FSU previous TOV design[1]

USF has a small TOV called the C-BASS (The Camera-Based Assessment Survey System) which can be seen in figure 2. This smaller vehicle may require fewer parts which would make the vehicle lighter and easier to handle. Its shape and added surfaces may make a more hydrodynamic shape and aid in keeping the vehicle level while underwater. This vehicle is designed to withstand up to 250 meters of water, but with modifications can be used much deeper.

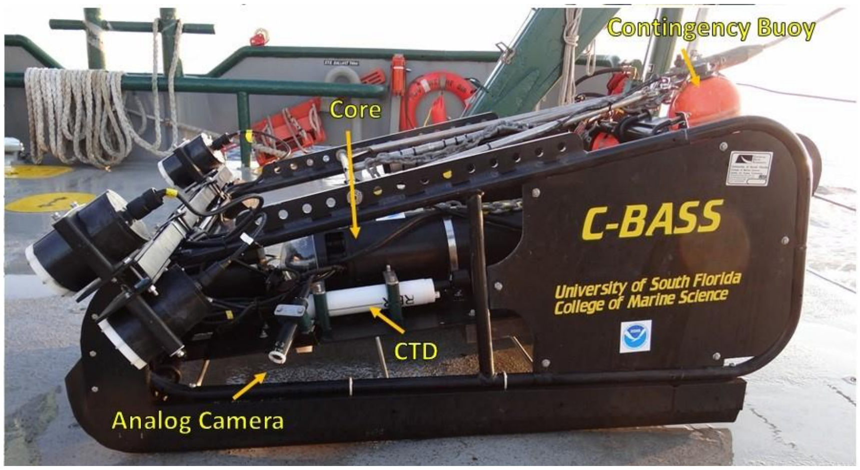


Figure 2: USF design[2]

UM on the other hand has a cylindrical design, Figure 3, the first of its kind. Although this is a very different shape from those previously seen, its analysis could give insight on better potential options for the inside modeling of the equipment. The UM team also had more necessary data collecting equipment than the USF team, about the same number of pieces of equipment that the FSU group needs, from physical observations.

Figure 3: UM design[6]

Although many designs do seem similar to the aforementioned non-university companies, there has been research on underwater simulations for these designs. Updating it for what is necessary for FSU's TOV could potentially help better understand underwater conditions. On top of this, the oceanography lab has an available underwater environment which allows test models of designs to be tested.

1.3 Problem Statement

The sponsor for this Modular Instrument Lander and Equipment Toolsled v2.0 (MILET2) project is the Earth, Ocean, and Atmospheric Science (EOAS) group at Florida State University. Currently, they have a tether operated vehicle (TOV). Their TOV is 6 feet long, 3 feet wide, and 3 feet tall and is made of galvanized steel piping. Many sensors, cameras, lights, and lasers have the ability to attach to the TOV. The TOV is currently able to be pulled behind a boat via a tether and collects data at a depth of about 2000 meters under water. The current TOV has too much empty space, is too heavy, is difficult to move around, and cannot be oriented once submerged.

1.4 Project Scope/Goal

As aforementioned, the problems with the current TOV is that it has too much empty space, is too heavy, is difficult to move around, and cannot be oriented once submerged. In order to fix these issues, an analysis in cost, optimal shape, and materials will need to be completed and implemented. Computer simulations in MatLab will not only help with determining the best shape, but will also help with plotting the changing underwater forces acting on the system. Conclusively, the design will be an improved TOV frame that is smaller, lighter, more modular, and has the ability to be oriented underwater.

1.5 Project Objectives

The main project objectives:
- Reduce the weight and size of the new frame
- Design a modular frame
- Must be easier to transport and manipulate
- Have an orientation system

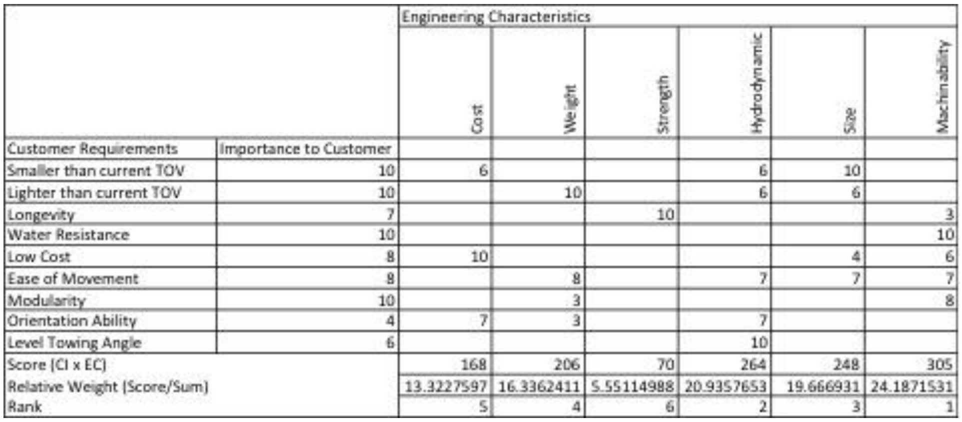
1.6 Project Constraints

Constraints:
- The total cost may not exceed $2,000 (additional funding available if proven necessary)
- Must be modular in the sense that components may move about the frame
- Made of corrosion resistant materials
- Ability to hold all necessary equipment
- The frame must be pressure resistant (minimum of 2000 meters)

2. Design and Analysis

2.1 Methodology

Initially the most important aspect of the project is to get an in depth understanding of what is needed. This includes gathering information on equipment such as weight and dimensions. A house of quality (HOQ) diagram, table 1 on the following page, was created to determine the most important engineering characteristics to keep in mind during the design and analysis of the project: cost, weight, strength, hydrodynamic, size, and machinability. Because this project is redesigning the housing structure, cost, weight, strength, and machinability can be considered as individual components of a materials property to help in determining the best material. The other two components, hydrodynamic (including both shape and passive actuators) and size, are associated with the structural design. Because the modularity and how the system moves underwater was originally thought to be the most important aspects of this project, it came to no surprise when machinability (important aspect of modularity) and hydrodynamic (underwater movement) ranked as the top two most important. Finally, the HOQ ranked the most important engineering characteristics as machinability, followed by hydrodynamic, size, weight, cost, and strength.



		Engineering Characteristics					
		Cost	Weight	Strength	Hydrodynamic	Size	Machinability
Customer Requirements	Importance to Customer						
Smaller than current TOV	10	6			6	10	
Lighter than current TOV	10		10		6	6	
Longevity	7			10			3
Water Resistance	10						10
Low Cost	8	10				4	6
Ease of Movement	8		8		7	7	7
Modularity	10		3				8
Orientation Ability	4	7	3		7		
Level Towing Angle	6				10		
Score (CI x EC)		168	206	70	264	248	305
Relative Weight (Score/Sum)		13.3227597	16.3362411	5.55114988	20.9357653	19.666931	24.1871531
Rank		5	4	6	2	3	1

Table 1: House of Quality Diagram for MILET-2

Once the HOQ was finished, extensive background research needs to be done to understand previous designs and how these designs performed underwater using moment, drag, and centroidal analysis. When the best aspects of each design are determined, they will be integrated with personal deigns to determine the best design possible for this project.

After background research is finished, new designs need to be drawn and have its own analysis done similar to the previously mentioned analysis in the *Project Scope/Goal* section. After the sponsors approve these new designs and problems that arise are fixed, a smaller scale model will be built to test how the shape will behave while being towed in large depths in a tank in the lab. Again, any issues that arise will be fixed. Once the models are tested and the best geometry is chosen, an optimal material will be chosen for the vehicle's purpose. A final design will then be built and tested in St. Petersburg.

2.2 Design Concepts

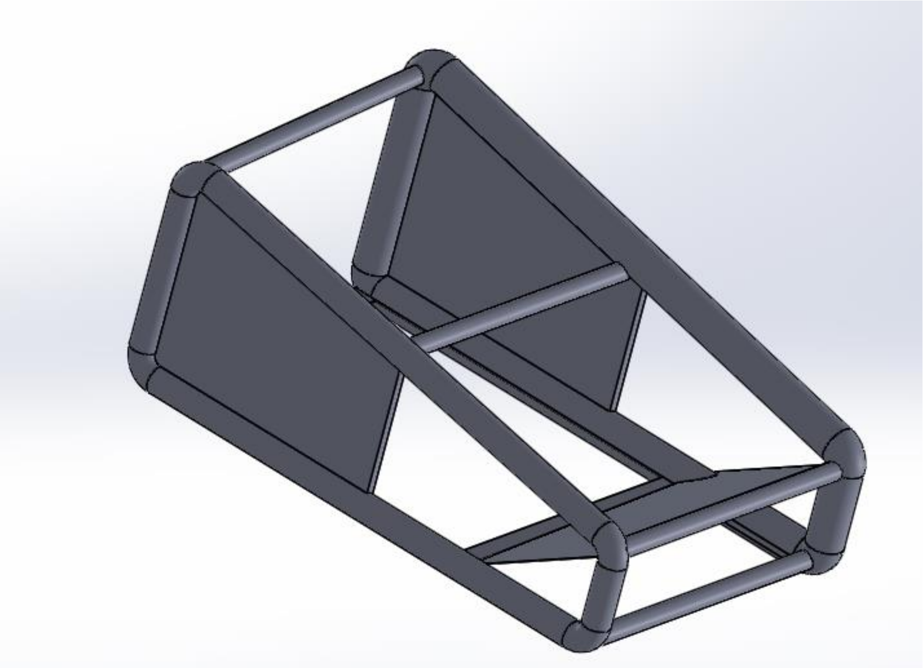


Figure 4: "nose up" design, design concept 1

This design was inspired by the USF design in that it is small in size and easy to transport. As the structure decreases in height towards the front, the center of body is moved back which promotes a more bottom leveled view throughout towing. As previously used in the FSU TOV design, adding surfaces on either side of the structure created drag force acting on each side which allows the system to tow straighter. Although this was a great feature on for the current FSU TOV, there was still an issue of the front side of the structure dipping forward relative to the back of the TOV. To fix this, an angled surface with a "nose up" design, similar to a plane, was added to create an upward lift force, helping to keep the system more leveled.

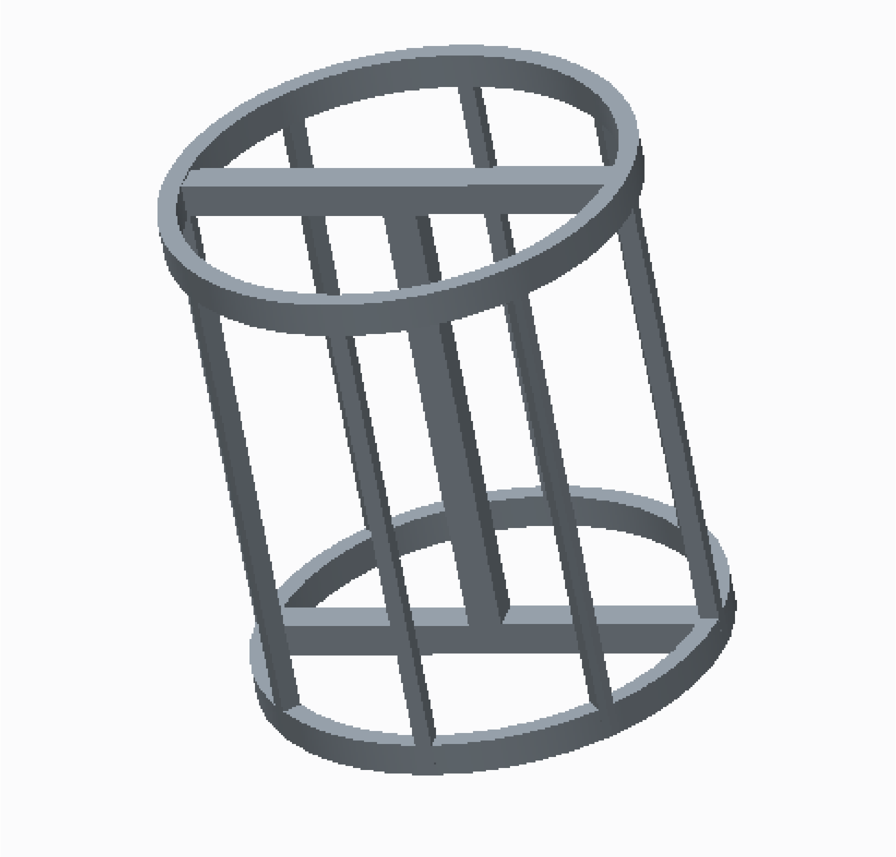


Figure 5: Cylindrical support design, design concept 2

Inspiration from the University of Mississippi created this multifaceted support rooted system. With 8 bars around the perimeter, a center bar, and bars at the top and bottom of the structure, this system optimizes inner space and support locations allowing for variability of inside equipment locations. Although appealing at first, this structure has a couple downsides: one being issues with consistency in orientation. Naturally, the system will want to spin because the connection points to the main tether will be equidistant apart creating a rotation about the center bar out of water, which would be highly dangerous, and possibly in water as well. The relatively large height would negatively affect the bottom surface's ability to remain oriented parallel to the ocean floor, creating a moment about the center of mass which would leave the system similarly oriented as seen in the picture above: with the back/bottom surface not parallel to the ocean floor. It would also have a relatively small footprint compared to the other designs and compared to the old frame; therefore this design does not meet the customer requirements for this project.

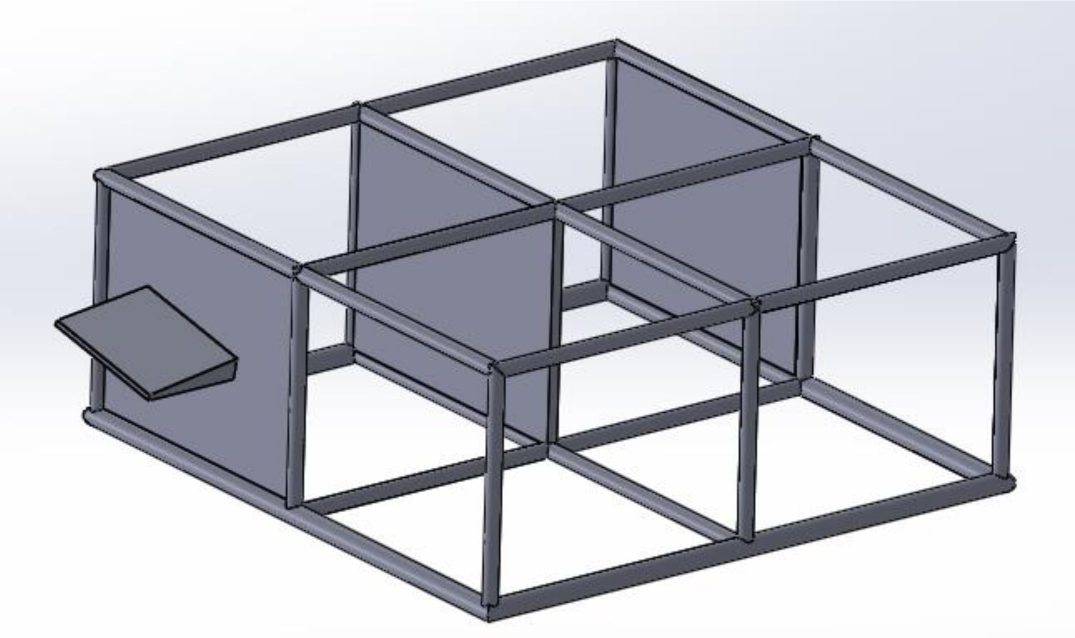


Figure 6: Maximum footprint design, design concept 3

One of the sponsors for this project recommended a square surface area for the bottom of the structure to get the maximum amount of space to have electronic components pointed towards the ocean floor. Taking into account his suggestion and the need to decrease the structures overall volume, a rectangular prism was designed where the height will be less than the bottom lengths of the square. As previously mentioned, adding surfaces on either side of the structure creates equal drag forces on each side which allows the system to tow straighter. Unlike the previous structure which has a surface with a “nose up” design towards the front of the structure, this design would use fins in the back with a downward slope towards the front to force the back of the system down and therefore, the bottom surface area more in line with the ocean floor. This design might be better than the USF inspired design because it would be easier to evenly distribute the weight of the components since the volume is evenly distributed.

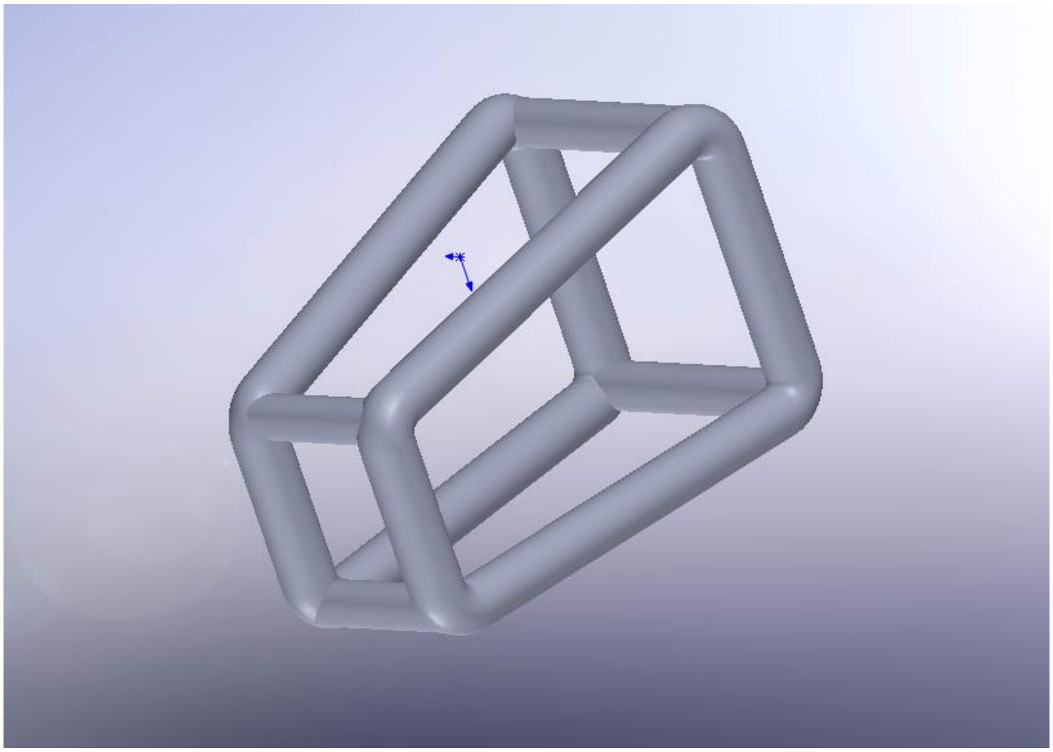
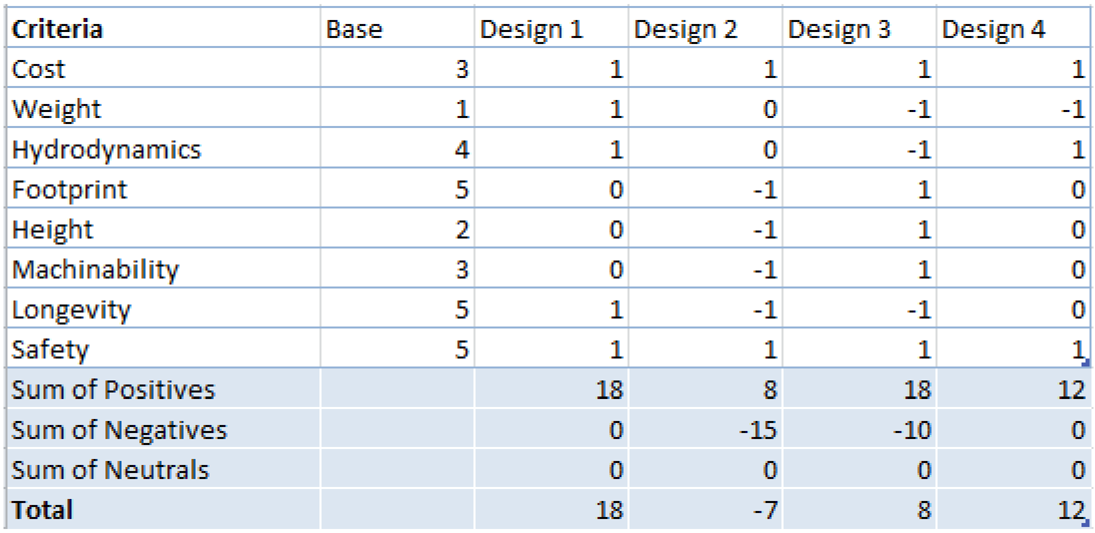


Figure 7: Trapezoidal design, design concept 4

Finally this design was suggested to us by the other of our two sponsors. Similar to the USF inspired design, the structure decreases in height towards the front. This would, as aforementioned, move the center of mass backwards helping the system stabilize itself with a clear view of the ocean floor relative to the structures bottom surface. However, the system tapers in towards the front as well. This creates added moments about the structures center of mass making it more complicated when determining the placements of inside equipment. In addition to this, previous structures took advantage of side surfaces to promote straight towing. The taper in this design would have side surfaces increase drag since a portion of the surface would be directly in line with incoming water relative to the structure.

2.3 Decision Matrix

A decision matrix for the analysis done has been created. Although this is not the final decision matrix, it was deemed important in order to determine where following stages of the project will lead. This will be discussed further in the final section of this report.



Criteria	Base	Design 1	Design 2	Design 3	Design 4
Cost	3	1	1	1	1
Weight	1	1	0	-1	-1
Hydrodynamics	4	1	0	-1	1
Footprint	5	0	-1	1	0
Height	2	0	-1	1	0
Machinability	3	0	-1	1	0
Longevity	5	1	-1	-1	0
Safety	5	1	1	1	1
Sum of Positives		18	8	18	12
Sum of Negatives		0	-15	-10	0
Sum of Neutrals		0	0	0	0
Total		18	-7	8	12

Table 2: Pugh Matrix deciding best design concept with current analysis

2.4 Force Analysis: Possible moment fixing options

To analyze how the vehicle will behave underwater, it will be necessary to determine what forces are acting on the body and what kind of moments those forces and the towing cable will create around the body's center of mass. The relevant forces in this analysis would be drag force, force of the tether, force of gravity, buoyant force, and lift force, if the particular design has upward facing fins. An analysis was done on each of the components to determine the forces that will act on each of them. A further analysis will be done on the frame of the body to determine the total forces acting on the entire vehicle.

The drag force will act on the frontal area as the vehicle is being towed. The equation for drag force is shown below in equation 1, where C is the drag coefficient, rho is the density of the fluid that the component is in, A is the frontal area, and V is the velocity of the object. The components are assumed to be cylindrical or rectangular. Sandrey M, in her paper *Drag Force and Drag Coefficient*, approximated the drag coefficient for these shapes to be 1.2 and 2.2, respectively.[5]

$$F_{drag} = \frac{1}{2} C\rho A V^2 \qquad 1$$

The gravity force will act downwards at each component's center of mass. The equation for the force of gravity is shown below in equation 2, where m is the mass of the object, and g is the gravity constant.

$$F_{gravity} = mg \qquad 2$$

The buoyancy force will act upwards at each component's center of mass. The equation for the buoyant force is shown in equation 3, where V is the velocity of the component, g is the gravity constant, and rho is the density of the fluid that the component is in.

$$F_{buoyancy} = Vg\rho \tag{3}$$

The lift force will act upwards at each upward facing fin. The equation for lift force is shown below in equation 4, where C_L is the lift coefficient, rho is the density of the fluid that the fin is in, A is the fin area, and V is the velocity of the component.

$$F_{lift} = \frac{1}{2} C_L \rho A V^2 \tag{4}$$

Since the vehicle should be in equilibrium and towed at a constant speed, the tether force should be equal to the unbalanced forces on the body. Appropriate tether locations for the cable will have to be determined using a moment balance analysis.

2.5 Product Specifications

2.5.1 Design Specifications

- Geometric dimensions and tolerances: In order to accurately determine the best dimensions, a simulation to optimize the volume with the necessary equipment will be written using MatLab. Tolerances will be later determined using error techniques and added into the simulation.
- Static: A material stress analysis for the structure will be done based on the equipment placement within it and pressure forces that will act on the structure. Dynamic: A structural analysis based on how underwater forces affect the structure in a material deformation aspect as well as how the structure will behave underwater will be done. This can be done through simulation in order to continuously change design conditions.
- Weight: Since this system will be both underwater and above water, a weight calculation needs to be done for both mediums. This can be done by adding systems components together when they’re underwater and when they’re above water.
- Equipment Integration within the design system: Depending on the centroidal analysis, the components will be put in to keep the system the most stable.

2.5.2 Performance Specifications

- Water Resistant: The structure will be utilized at great ocean depths so its material must be resistant to rust and wear from the salt water.
- Level towing angle: Must cruise at a constant level angle so that the bottom of the frame is parallel to the bottom of the ocean floor.
- Modular: Data collecting equipment must be removable from the frame in addition to the frame having the ability to break down into components.
- Easy to transport: The new frame must be easier to transport long distances than the original frame. This includes the ability to be broken down into smaller components and being generally smaller and lighter than the original vehicle.

- Resistant to pressures occurring at 2000+ meters: The vehicle's operating depth is approximately 2000 meters so the new frame must be able to resist the large forces that occur due to the water pressure.
- Holds all data collecting equipment: The new frame must have a large enough volume and footprint to hold all data collecting equipment and a large enough footprint to allow the necessary pieces of equipment to have a clear view of the ocean floor.
- Power Consumption: All actuators added to the new frame must not consume any more power than the original frame.

3. Scheduling and Resource Allocation

3.1 Gantt

Illustrated below is Team 21's Gantt chart. This provides the breakdown as a timeline with specific tasks that are to be conducted throughout this semester. The lengths of the bars are indicative of the duration of each task.

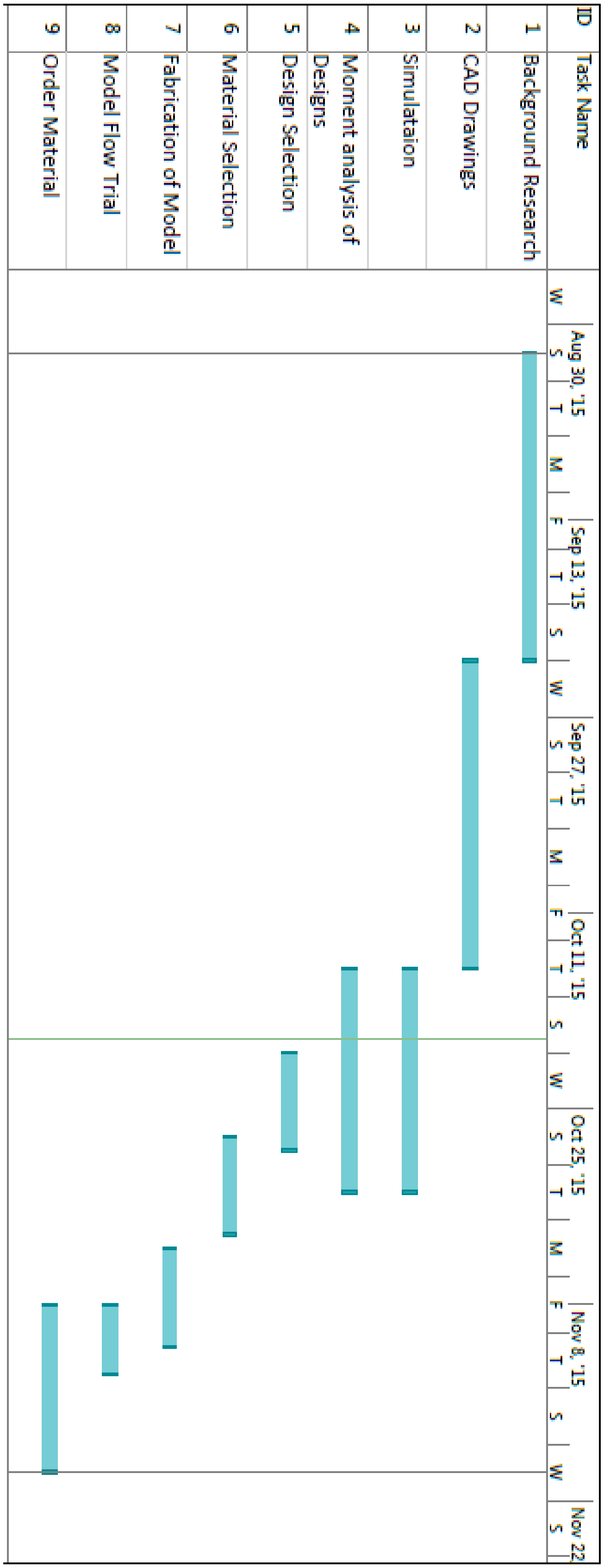


Table 3: Gantt chart outlining future plans for the project

3.2 Resource Allocation

Because this team only has 3 members, it was decided as a team to do most of the work together, though some of the conceptual design tasks have been broken up between the members below:

- William: Material analysis for various materials on the weakest member on the frame. Also performing cost analysis on these materials.
- Kasey: Centroidal and force analysis on the body. Determination of all forces acting on the frame and on each component to find the total forces acting on the entire vehicle.
- Chelsea: Simulation and force distribution on the cable. Deciding optimal placement for cable connection points to the frame.

4. Results

Though the team has not yet completed the experimental analysis that has been planned, some preliminary analysis has caused the team to rule out some of the designs and favor a few designs over the rest.

The first design, which was inspired by USF's TOV, is a favored design over the rest of the designs. It has a smaller volume than the current design and would be lighter when made with aluminum. The surfaces on the sides of this design will create balancing drag forces on either side, causing the vehicle to tow in a straight line. It also has a footprint area that is larger than the design three and four. The angled surface on the front of the design is utilized to create an upward lift force to fix the problem of the body being towed at an angle. The only concern that the team has is that the variable distribution of the volume will cause a uneven weight distribution, which may be avoided by strategically placing the elements on the frame.

It was decided that the second design will not be ideal for this application because a cylindrical design will have difficulty maintaining a constant orientation, does not have a large footprint, and therefore does not well meet the sponsor requirements.

The third design is also one that is favored by the team. The general rectangular prism shape was suggested by one of the sponsors. It will have a smaller volume than FSU's current TOV and it will have a smaller height, which is something that the sponsor is looking to get out of the new frame for ease of deployment. The surfaces on the sides of the design will create balancing drag forces, similar to the first design, which will cause the vehicle to tow in a straight line. It has the largest footprint out of all of the designs. It also has angled fins that, similar to the angled surface in the first design, will add an upward lift force and fix the angled towing problem.

It was also decided that the fourth design which tapers towards the middle axis and towards the front could be a poor design for this application because the side panels that are utilized to keep the vehicle towing straight will no longer be parallel to the flow, which will cause a greater drag force than all of the other designs.

4.1 Risk and safety Analysis

The risk and safety analysis document is attached with this document. It articulates the various risks that are associated with this project found in various steps. After addressing the risk source, it discusses how to avoid or mitigate the risks associated with that aspect of the project. For instance, in the document, it states the risk involved in deployment and retrieval of the vehicle. While the vehicle is hoisted in the air, it has free range of motion to sway and rotate because it is only attached by a single tether. It is of the utmost importance that the individual controlling the winch holding the vehicle and any team members are aware of everyone's position relative to the hanging body. It also goes into discusses the risk of instability in the ocean. The document offers that each individual on the boat must maintain a minimum of three points of contact at all times while moving about the ship. Lastly, the machining and assembly of the vehicle are discussed in the analysis. It states that appropriate attire be worn and that supervision by a peer or lab technician is required at all times while working in the shop.

5. Conclusion

The Earth, Ocean, and Atmospheric Science (EOAS) group at Florida State University is interested in updating their current tethered underwater vehicle to a smaller, lighter, more modular, able to orient itself, and easily moveable design. Background research in previous designs exemplifies that side surfaces, as used in both the USF design and the previous FSU design, promote a straighter tow. This is why both design one and three take advantage of this. Design two and four however, do not use this because of space restraints and added drag it would cause on the system respectively.

In order to orient the system to have a more direct sight to the ocean floor, multiple options can be taken: adjustment of tethered locations, the addition of fins, or the addition of a surface with an upward slope could be added. This will be further analyzed in the upcoming weeks through structure modeling and computer simulation using Adams. After building models in the machine shop, different attachment locations for the tether will be experimented with, as well as possible surface and fin options to determine the optimal passive orientation control.

6. Biographies

6.1 Team Lead: William R. Hodges

I am a senior in the department of mechanical engineering. I will graduate with a bachelor's degree in the field with a specialization in material science. I currently do research at the High Performance Materials Institute. Here I investigate ceramic colloidal processing and apply the knowledge to create tougher ceramic plates to be used for ballistics. I aspire to use the skills I've gained in the program and through research to obtain a materials oriented career.

6.2 Lead Mechanical Engineer: Chelsea Dodge

I am a mechanical engineering senior with a mixed focus in Dynamics and Thermal Fluids. This past summer, I worked on developing lab equipment for Mechanical Systems 1. Upon graduation, I plan to pursue an engineering career in the private sector.

6.3 Financial Advisor: Kasey Raymo

I'm Kasey Raymo and I'm graduating in May 2016 with a bachelor’s degree in mechanical engineering. I was born in Chicago and raised in Satellite Beach, Florida. I'm an animal lover. I hope to someday use my degree to work with developing sustainable energy solutions.

7. Acknowledgements

We would like to thank the sponsors, Dr. Ian Macdonald and Eric Howarth, for giving this team the opportunity to help them with their project and providing the necessary guidance along the way. We would also like to thank Dr. Nikhil Gupta and Dr. Chiang Shih for making the time to meet with us at least twice a month and helping us on deciding on proper analysis techniques. Additionally, we would like to thank our advisor, Dr. Camilo Ordoñez, for also providing advice on proper analysis techniques and suggesting software for flow dynamic simulation. Finally, we would like to thank the professors that the team have gone to for guidance. They include Dr. Patrick Hollis, Dr. Kunihiko Taira, Dr. Carl Moore, Dr. Simone Hruda.

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