New Housing Structure for Deep Sea Equipment

Final Report
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Team 21

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Abstract

The Florida State University's Earth, Ocean, and Atmospheric Science group is looking to update the frame for their aquatic tether operated vehicle. Their current frame is too heavy, too tall, has too much empty space, does not tow straight, and is difficult to transport for their cruises. This document contains a detailed description of the updated frame project along with current status and future work. The first portion of the report encompasses background research conducted on other universities' tether operated vehicles 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 and how they are going to be analyzed. The results obtained will be used to aid in the design of models and the testing of moments and forces on the models. Once a design is chosen, it will be built and tested on a cruise at the end of spring semester.

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 aquatic tethered operated vehicle (TOV) to a smaller, lighter, more modular, levelly oriented, and easily portable design. A TOV, in this case, is an underwater submersible that it attached via a cable (otherwise known as the tether) and is dragged behind a self-propelling vehicle. The design currently is a 3 feet by 3 feet by 6 feet rectangular prism with 17 pieces of equipment attached to collect data and house necessary electronics. It cruises at approximately 2,000 m below the sea level. This TOV needs to be able to withstand pressures of 2,900 psi and be impact resistant in case of collisions with 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.

1.2 Background Research

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 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 Fig. 1[4]. They have 17 different pieces of equipment that they attach to the frame when the TOV is taken out for cruises. Also attached to the frame is plastic surfaces, which creates a drag force perpendicular to the flow, promoting a straighter tow. This TOV is towed behind a boat and it cruises at about 5 miles per hour, 2,000 meters below the surface.

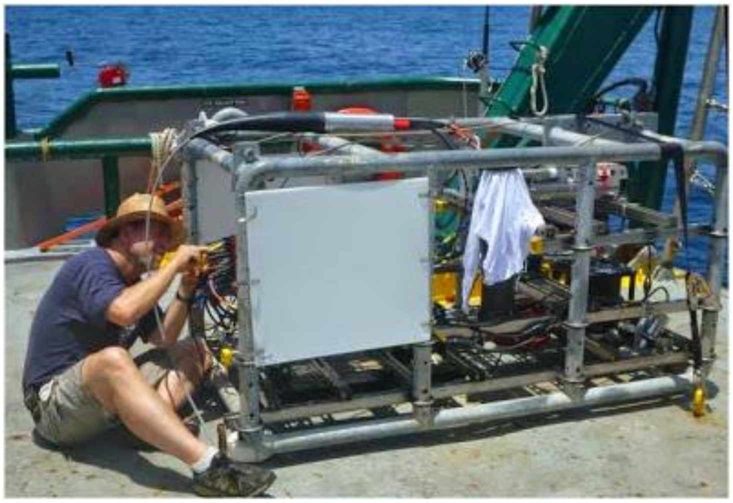


Figure 1: FSU previous TOV design

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

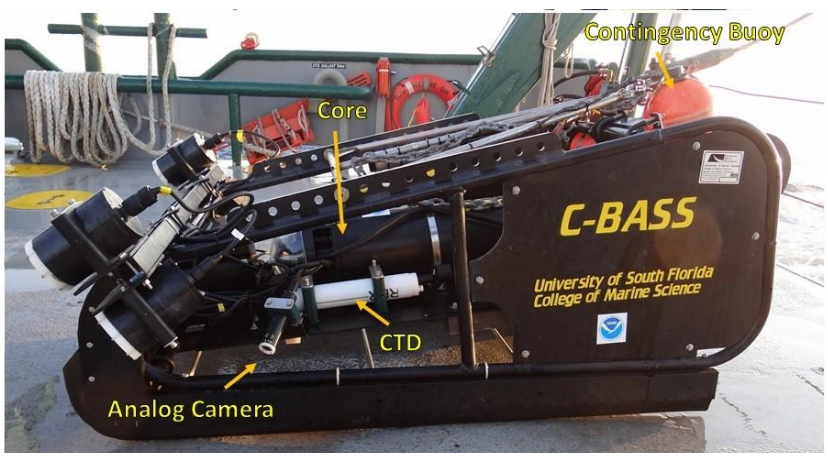


Figure 2: USF design

UM on the other hand has a cylindrical design, figure 3[6], 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

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 (MILET-2) project is the 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 does not tow straight.

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 does not tow straight. In order to fix these issues, an analysis in cost, geometry, and materials will need to be completed and implemented. Conclusively, the design will be an improved TOV frame that is smaller, lighter, more modular, and has maintains a level towing angle**.**

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
- Tow straight while underwater

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, located on 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, balanced moments, 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, balanced moments and size, are associated with the structural design. The HOQ ranked the most important engineering characteristics as size, followed by weight, cost, machinability, strength, and balanced moments. Since two customer requirements were to decrease weight and maximize the footprint area while reducing the volume, it makes sense that size and weight were ranked as the top two engineering characteristics.

Table 1: House of Quality Diagram for MILET-2

		Engineering Characteristics					
		Cost	Weight	Strength	Balanced Moments	Size	Machinability
Customer Requirements	Importance to Customer						
Smaller than current TOV	10	6	4			10	
Lighter than current TOV	10	6	10	3		6	
Longevity	7	5		10			5
Low Cost	8	10	5	3		4	6
Ease of Movement	8		8			7	
Modularity	10					3	8
Level Towing Angle	10				10		
Score (CI x EC)		235	244	124	100	278	163
Relative Weight (Score/Sum)		20.541958	21.3286713	10.8391608	8.74125874	24.3006993	14.2482517
Rank		3	2	5	6	1	4

Once the HOQ was finished, extensive background research was 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.

It was decided that a strictly experimental method of analysis would be used. This is because after trying to perform a computer simulation, it was unknown what magnitude and direction of forces that the towing cable will create, since 2000 meters down the cable has its own dynamics. After receiving advice from multiple professors, they agreed that experimental analysis would be the best option

After background research was finished, some analysis was done to come up with new geometries for the new frame. This analysis took into account the volume, footprint area, frontal area, geometry of piping, and weight distribution effect. A material analysis was also done to determine the optimal material to use on the full scale model. After the sponsors approved these new designs and problems that arose were fixed, a smaller scale model was built to test how the shape will behave while being towed in large depths, simulated using a testing flume in the Florida State physics department. These experiments have not yet been performed. Again, any issues that arise will be fixed. Once the models are tested and the best geometry is chosen, a final design will then be built and tested in St. Petersburg.

2.2 Design Concepts

2.2.1 Selected Design Concepts

As can be seen in figure 4 below, this design's structure decreases in height towards the front, the center of body is moved back. This is one way that the group hopes to fix the unlevel towing problem that FSU's EOAS group currently has. As previously used in the FSU TOV design, adding surfaces on either side of the structure created drag force perpendicular to the flow which allows the system to tow more straight. The geometry may make it difficult to evenly distribute the component's weight about the structure and may cause unbalanced moments.

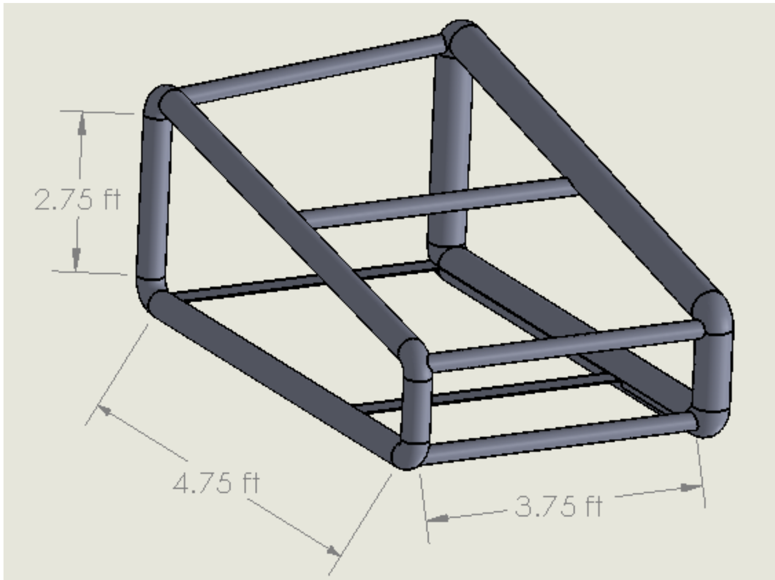


Figure 4: Full Scale Triangular Design

The square design, seen below in figure 5, uses a square for the footprint area, as this maximizes the area. As previously mentioned, adding surfaces on either side of the structure creates equal drag forces perpendicular to the flow which allows the system to tow straighter. While this design does have a smaller volume than the FSU's current frame, it has a larger volume than the triangular design. This might provide FSU's EOAS group with the opportunity to add additional pieces of equipment when and if it is necessary. The design would also more easily distribute the weight of the components as it has constant dimensions unlike the triangular design. There is no support added on the bottom surface to maximize the footprint area and ensure that there is nothing to interfere with the components function.

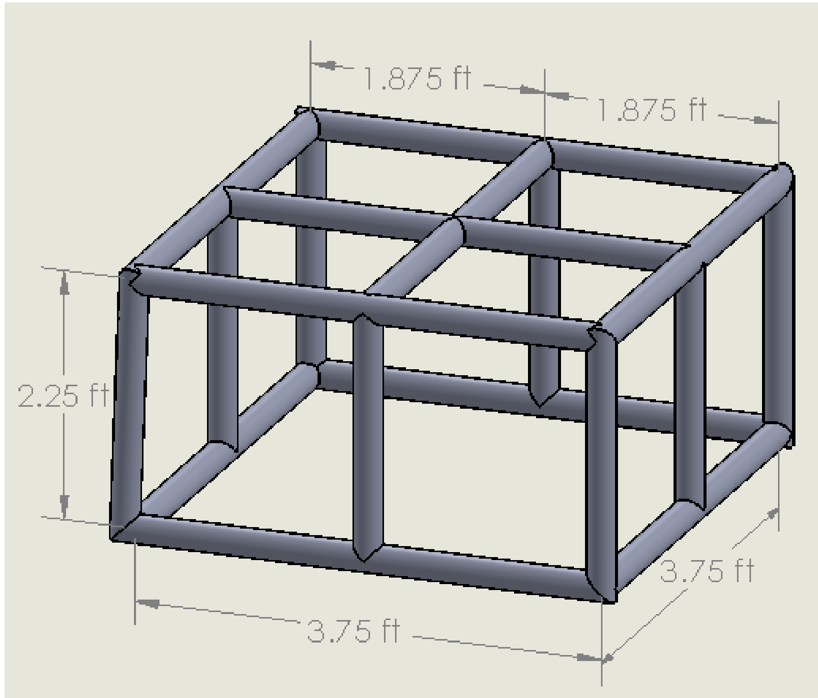


Figure 5: Full Scale Square Design

2.2.2 Eliminated Design Concepts

The cylindrical design, seen below in figure 6, was eliminated for many reasons. The first is that it would only allow for cable attachment points at the top of the structure. This is unfavorable because only this could cause the structure to be susceptible to roll. Also, this design as a small footprint area, no matter which way it is oriented during towing. Finally, this design has a large height. Height is something the design group is looking to minimize because it makes it easier for the sponsor to deploy and retrieve the vehicle. Because of these reasons, this design does not meet most of the customer requirements and was eliminated.

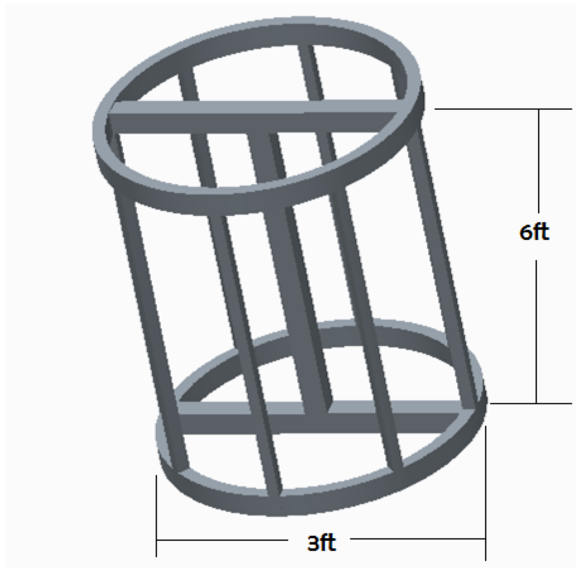


Figure 6: Cylindrical Design

The design below, seen in figure 7, decreases in dimension towards the front and the side. This would move the center of mass backwards, which could solve the problem of the TOV towing with the front closer to the ocean floor, a problem FSU's EOAS currently has. Because of this though, it may be difficult to distribute the components so that the weight is evenly distributed about the structure. In addition to this, previous structures took advantage of side surfaces to promote straight towing. The taper in this design would make side surfaces create a drag force since a portion of the side surface would be normal to the flow direction. This design also does not meet all customer requirements, so it has also been eliminated.

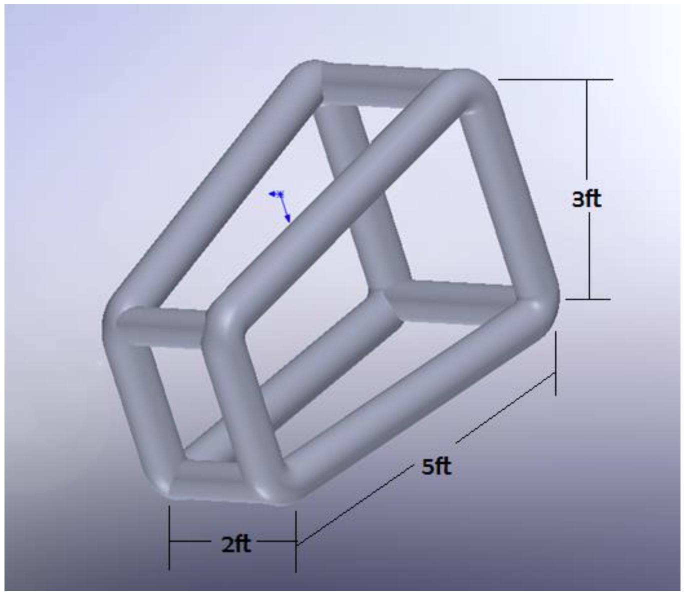


Figure 7: Tapered Triangular Design

2.3 Experimental Analysis

There are multiple ways to approach this analysis through both computer simulation and experimental testing. Basic computer simulation using MATLAB to understand the buoyancy of a piece of equipment was done. This was completed for every piece of equipment to determine the tendency of all the equipment to sink or float. Although this did aid in the fundamental understanding of the project, further computer simulation to determine how the vehicle will behave could not be done due to the fact that the magnitude and direction of the tether forces acting on the vehicle were unknown. This made it difficult to design the vehicle to be in equilibrium. To further develop a computer simulation of the system, a thorough knowledge of the fluid mechanics must be known and the ability to transfer this into something the programs syntax can interpret would be time consuming. After consulting professors in the field of fluid dynamics computation, it was recommended that an experimental approach be utilized. Therefore it was decided, due to time constraints, that the most appropriate method of analysis would be testing miniature, scaled models to determine how the geometry and various cable attachment points would affect the behavior and tow angle of the vehicle.

2.3.1 Unbalanced Moment Solutions

Since the current vehicle is maxed out on power, no active actuators can be added to control the angle that the vehicle is towed. While the group considered adding fins, which would be passive, this would add a large drag force while dropping the vehicle 2000 meters into the water. The EOAS group does not want to wait the extra time it would take to drop the vehicle with the fins added. The group decided that the best method of controlling the angle of tow would be to find the optimal cable attachment points that would create balanced moments about the vehicle, causing it to be towed levelly. To do this, various holes were added to the miniature models which will be used as different cable attachment points. During the experiment, the cable attachment location will be changed to find the best positions that create the most level tow.

2.3.2 Experimental Evaluation

To perform an experimental analysis, models had to be created. To ease in machining, a simple method was utilized to create these models. Two profiles for each model was created in addition to various connector pieces. These pieces were press fitted together and the drawings can seen below in figures 8 and 9. Various holes were drilled in uniform increments across the models. These holes are for testing various cable attachment points and the effect this has on the vehicle's orientation. The completed models can be seen below in figure 10. These models were scaled down using a feet to inches scale.

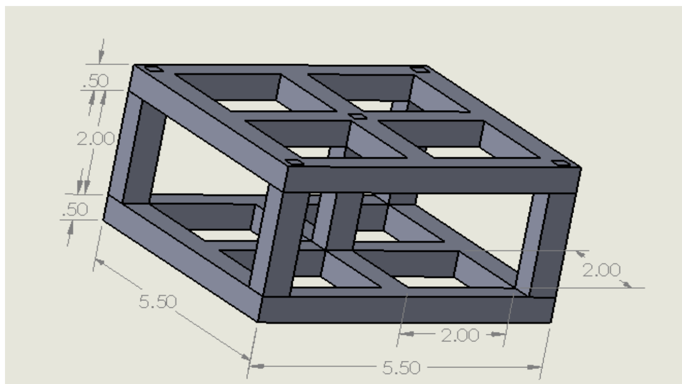


Figure 8: Scaled Square Model, Dimensions in inches

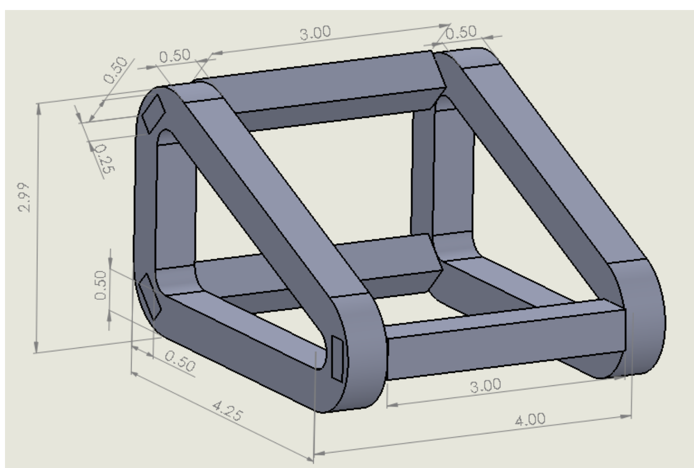


Figure 9: Scaled Triangle Model, Dimensions in inches

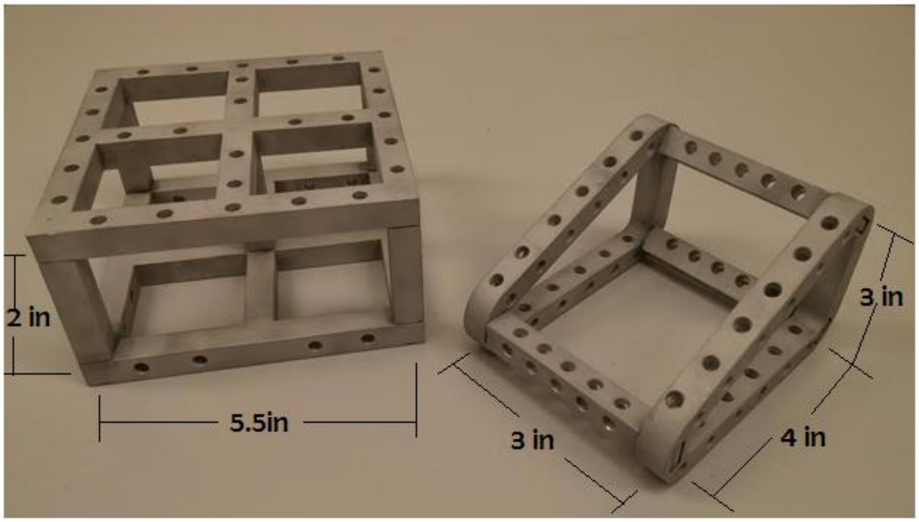


Figure 10: Completed Scaled Models

We will be utilizing these models in FSU physics department's flow flume. An image of this flume can be seen below in figure 11. This system works by either passing water by the test subject at a specified speed, or it also has a gantry system located at the top of the flume which can be utilized to pull the test subject through the fluid at a specified speed.

The models in the flume will be tested for the system stability; this includes the roll, pitch, and yaw of the structure. We are aiming to have the model's bottom area parallel to the bottom of the flume. This will be done by testing the structure's behavior with various different attachment points of the cable and also various different weight distributions. The various different weight distributions will represent the heavier and lighter pieces of equipment placed around the structure. This will be simulated by connecting heavier objects, such as lead, and lighter objects, such as small pieces of styrofoam, to the structure. We will be observing the significant rotational tendencies caused by these different variables.


Figure 11: Florida State University Physics Department's Flow Flume

2.4 Material Analysis

The objective of redesigning the housing structure is to minimize mass and minimize cost. The component that was analyzed is the longest member of the unit structure and was chosen because it is the weakest member. All design processes should design for the weakest portion. A process using the function of the component, constraints on physical dimensions and properties, objectives for the design, and free variables were used to organize and evaluate the design. This will make up the FCOFV which stands for Function, Constraints, Objectives and Free Variables. This component is to be a light, stiff, strong and inexpensive beam. These were chosen due to the fact that it must be more portable than the previous design (light), stiff to prevent buckling upon impact with some massive underwater object, strong to withstand the forces acting on the member and inexpensive due to the budget. The component is constrained by its length, outer radius as well as the forces acting on the member. Additionally, the material must be nonferrous. This is to ensure minimal interference with the electrical components on board. For this component, the free variables were the wall thickness and material choice. Once the FCOFV was created, pertinent equations were found to optimize the objectives. Equations for mass, thickness and cost were derived and a full step by step derivation is included in the appendix. This led to determining material indices to be used as a metric for the selection of materials. The material chosen for this design was Al6061. This material was chosen due to the fact that it optimized both objectives for each material index.

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 and able to moved about the structure
- 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.

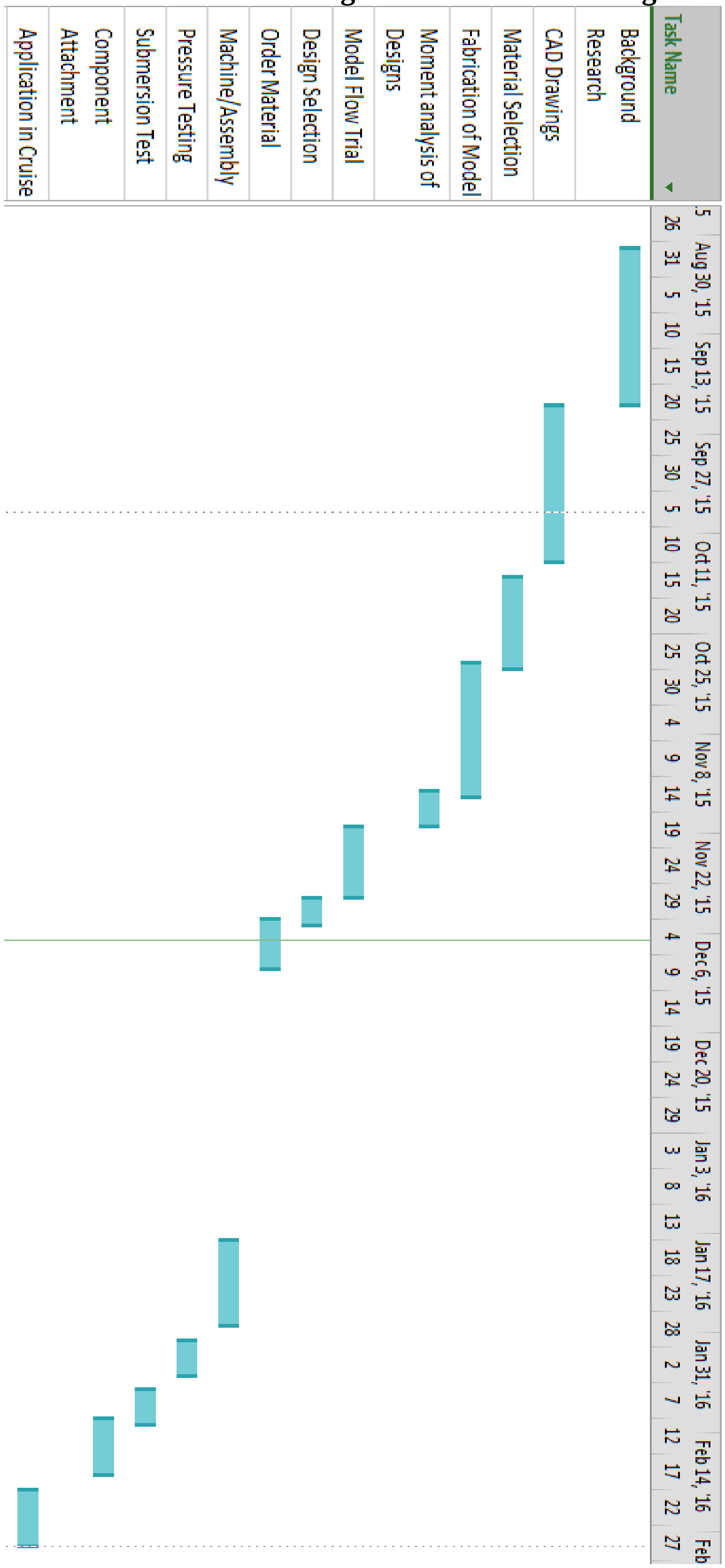
3 Scheduling and Resource Allocation

3.1 Gantt Chart

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.

As the semester comes to an end, mostly all long term plans have become short term. The Gantt chart was updated because the group is slightly behind schedule. Within the next couple of weeks the group must finalize testing, choose a geometry based off of this testing, order the material necessary to create a full scale version, and have the full scale structure machined and assembled. After it is assembled, it will be tested under high pressures in the civil department's hydrostatic pressure unit. There will also be a in water submersion test after the components have been attached to the frame. If all of the testing goes well, the structure should be ready for the cruise that the EOAS group has planned at the end of Spring semester.

Table 2: Gantt Chart Outlining Future Work for Design 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 had been broken up between the members below:

- William: Material analysis for various materials on the weakest member of the frame. Also performing cost analysis on these materials.
- Kasey: Created the drawings for the miniature models that were submitted to the machine shop for fabrication and assembly.
- Chelsea: Created the drawings for the full size models that will be utilized once a decision has been made on the best geometry.

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.

Two of the designs, the cylindrical design and the tapered triangular design, as can be seen in figures 6 and 7 in section 2.2.2, have been eliminated due to the fact that they do not meet most of the customer requirement

The triangular design has a smaller volume than the FSU’s current TOV design and would be lighter when made with aluminum. Surfaces on the sides of this design will be added to create balancing drag forces on either side, causing the vehicle to tow in a straight line. It also has a footprint area that is equally as big as FSU’s current TOV. This may pose a problem as one of the project objectives is to increase footprint area. This could easily be fixed by increasing the dimensions to make the footprint bigger, while also keeping it smaller that the current TOV. The variable distribution of the volume may cause an uneven weight distribution, which may be avoided by strategically placing the elements on the frame, and may even aid in correcting the orientation issue that FSU’s EOAS group currently faces.

The square design will also 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 and retrieval. The surfaces on the sides of the design will, just like the previous design, create balancing drag forces which will cause the vehicle to tow in a straight line. Being a square, this design maximizes the footprint area. It also has constant dimensions will create an equally distributed volume which will easy in equally distributing the weight.

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.

4.2 Environmental Analysis

One of the TOV's main purposes is to help the environment. It does this by surveying the ocean floor looking for possible situations that could be harmful to the water and wildlife, such as gas leaks. Since this vehicle will be utilized in the ocean, there are many aspects of the project that could harm the environment instead of helping it.

One main source of concern is the wildlife that will encounter the vehicle. One concern that the group voiced to the sponsor after being introduced to the project is the affect it had on the animals and plants it encounters on the ocean floor. The sponsor for this project informed the group that the area where the TOV surveys and collects data has very little wildlife and a mostly muddy ocean floor. Therefore, though the vehicle is designed to operate 2 meters above the ocean floor, if the vehicle does hit the ocean floor, there are little to no coral or oyster beds that could be destroyed. The vehicle also has an open design, so if fish were to swim close to the vehicle, it could easily swim through it without being harmed.

Another consequence that a vehicle might have on the environment is introducing foreign waste. This could include various pieces of plastic or metallic dust that was created during machining. This will be minimized by thoroughly cleaning the vehicle after attaching the components and before introducing the new frame to the ocean.

The electronics on the TOV could additionally be a source of danger to the wildlife in the ocean. Electronics utilized in water creates a possibility of electrocution. To minimize the risk of this, the electronic components have been sealed and water-proofed to avoid introducing water to any of the electrical components.

Finally, waste created during machining and construction may pose a threat to the environment. FSU/FAMU's College of Engineering machine shop aims to minimize this waste by saving and reusing material that is not utilized during any project. The miniature models were created using leftover material from a different project. To the group's knowledge, the machine shop also properly disposes of or recycles the unusable product created during the machining process.

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, easily moveable design, with a level towing angle. It was decided that an experimental analysis would be performed rather than a computer simulation. This was decided after consulting with various professors and receiving input that an experimental approach would be more appropriate for this application.

After narrowing the four design concepts down to two, miniature models were created. These models are scaled down from the full scale models using a foot to inch conversion. Various holes were places around the miniature models so that side surfaces can be added and the cable attachment points could be varied. These models will be tested in FSU’s physics department’s flow flume which will simulate similar conditions that the full scale model will experience, such as towing speed. After this experiment, the full sized frame will begin machining and assembly. Using the results from the experiment, the optimal geometry and cable attachment points will be implemented into the full scale production.

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.

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