Final Spring Report

Group 21

New Housing Structure for Deep Sea Equipment

Earth, Ocean and Atmospheric Science

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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, has too much empty space, does not tow parallel to the ocean floor, and is difficult to transport for their cruises. The weight was reduced by changing the metal from steel to aluminum. The geometry was changed so that the footprint was increased while the volume was decreased. The average height was decreased as to ease in deployment and retrieval. Feet and wheels were added to the design to ease in transportation. Side panels were added and the bridle cable lengths were augmented to create a parallel tow. This document contains a detailed description of the design process for the updated frame, the final design, along with current status of its machining. 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 are the problem statement, project scope, objectives, and constraints. After conceptual design, the team built models of the design concepts and tested them. The results from these tests and other details about the selected design are included.

1 Problem Statement and Project Scope

1.1 Introduction

A tether-operated vehicle (TOV) is a body that is towed behind a self-propelled vehicle by means of a tether or cable. It is usually utilized in water and its purpose is for surveying and exploring the ocean by means of data collecting equipment. Its altitude in the water is controlled by a winch and pulley system. The Earth, Ocean, and Atmospheric Science (EOAS) group at Florida State University currently has an aquatic TOV. It currently is an open 3-foot by 3-foot by 6-foot galvanized steel rectangular prism frame made of piping. It operates by cruising very slowly with the boat at about 5 knots, 2,000 meters under the water. It weighs approximately 900 pounds with all the equipment attached. It can be seen below in Fig. 1.

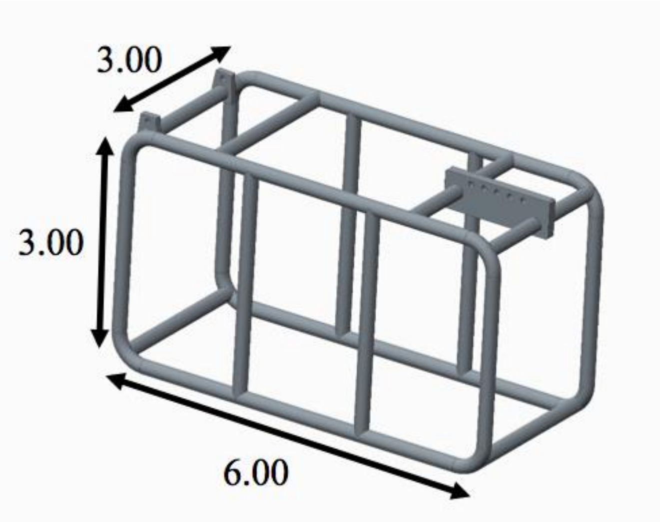


Figure 1: *Florida State University's current frame for their TOV, units in feet.*

FSU utilizes 17 pieces of equipment to collect data. These include cameras, light, lasers, surveying equipment, and various electronic housings. A majority of them are cylindrical in shape and their weight ranges from 1.7 to 80 pounds. The largest component has a diameter of 10.5 inches and a length of 30 inches. The total weight of all the components is 485 pounds. Figures of 2 of the components can be seen in Fig. 2 and Fig. 3 below. These figures show the general size and shape of the components and also how they attach to the unistrut bars, which attach to the frame.

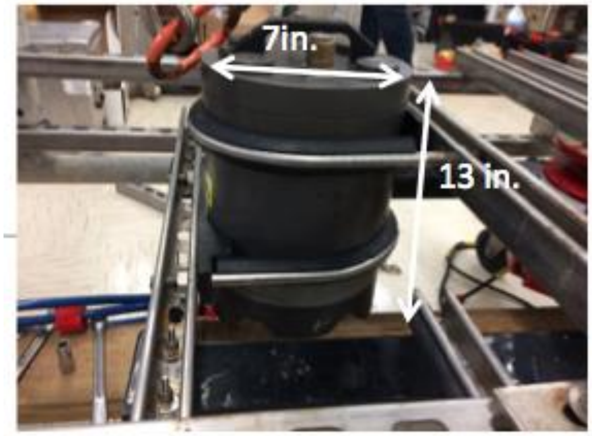


Figure 2: *Still camera utilized on FSU 's TOV. Attached to frame via U-bolts and unistrut.*

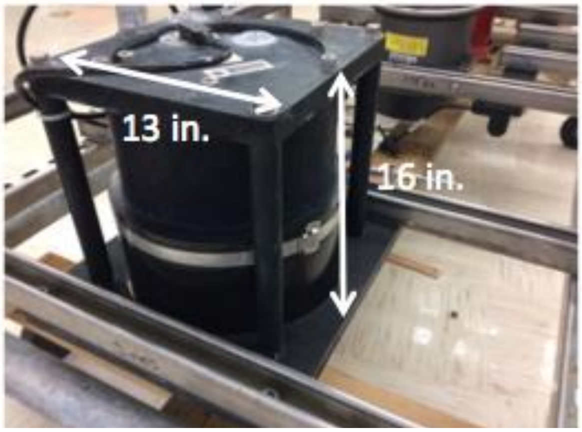


Figure 3*: Sub-bottom profiler transmitter utilized on FSU's TOV. Attached to frame via unistrut.*

FSU's current TOV has too much empty space, is too heavy, is difficult to move around and transport, and does not tow parallel to the ocean floor. For these reasons, the oceanography group at Florida State is interested in updating the frame for their TOV to address these issues.

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, they had more access to resources. For this reason, background research was done on other universities' TOVs that had similar applications.

FSU, USF, and UM have all made previous TOV's. FSU currently has a TOV called the Modular Instrument Lander and Equipment Toolseld (MILET). It is made of galvanized steel piping. The rectangular prism shape has dimensions of 3 feet by 3 feet by 6 feet and can be seen in Fig. 4[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 are plastic surfaces, which create a drag force perpendicular to the flow, promoting a straighter tow.

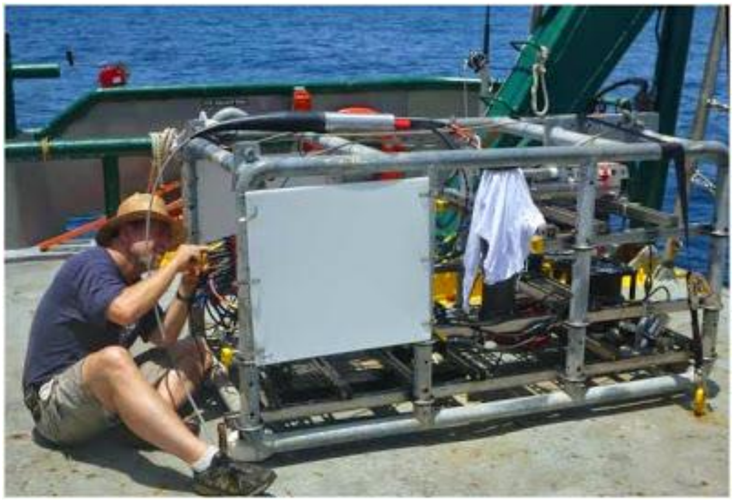


Figure 4: *FSU's previous tether-operated vehicle, the MILET.*

USF has a TOV called the C-BASS (The Camera-Based Assessment Survey System), which can be seen below in Fig. 5[2]. Its dimensions are unavailable, but its scale in the picture looks slightly smaller than FSU's TOV. This smaller vehicle may require fewer parts, which would make the vehicle lighter and easier to handle. Its added surfaces may promote a level-towing angle while underwater as FSU's TOV attempts to do. This vehicle is designed to withstand "up to 250 meters of water, but with modifications can be used much deeper."

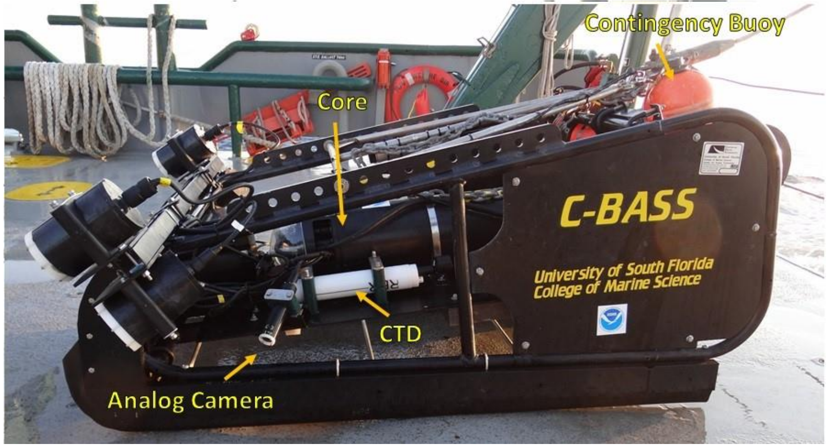


Figure 5: *USF's tether-operated vehicle, the C-BASS.*

UM on the other hand has a cylindrical design called the I-Spider, which can be seen in Fig. 6[6]. It is the first of its kind. They also use their TOV at depths of around 2000 meters under the water. This design is similar in that the vehicle maintains a fiber optic link between it and the cruise ship, though it is different in that it has a device that is released from the cage to collect the data. For this reason, it does not need the constant orientation that FSU's TOV requires, making it significantly different.

Figure 6: *UM's tether-operated vehicle, the I-Spider.*

While these designs have similar applications to FSU's TOV, neither of them have the same application. USF's C-BASS performs the same duties of surveying and exploring of the ocean floor, but does it in much shallower waters. UM's I-Spider also performs similar duties of surveying and exploring the ocean floor while remaining fiber optically connected to the ship, but it does this by means of a station service device which leaves the frame to collect information and then returns. For these reasons, different design components of each of the school's TOVs are considered during the conceptual design process.

1.3 Problem Statement

The sponsor for this Modular Instrument Lander and Equipment Toolsled v2.0 (MILET-2) 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 surveying devices, 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 transport, and does not tow parallel to the ocean floor.

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 transport, and does not tow parallel to the ocean floor. In order to address these issues, a new frame is to be designed that is smaller, lighter, more modular (in that the components may be moved about the frame), and maintains a level towing angle, passively**.**

1.5 Project Objectives

The main project objectives for the new frame:

- Increase the footprint area (area with direct line of sight to ocean floor)
- Reduce the weight
- Reduce the height
- Increase modularity (components may be moved about frame)
- Increase mobility
- Maintain a level towing angle, passively

1.6 Project Constraints

Constraints for the design of the new frame are as follows:

- The total cost may not exceed $2,000 (additional funding available if proven necessary)
- Made of corrosion resistant materials
- Ability to hold all weight and volume of necessary equipment
- No extra power consumption
- Impact resistant

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 the data collecting equipment such as weight and dimensions. A house of quality (HOQ) diagram, located on Table 1 was created to prioritize the engineering characteristics 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 material’s property to help in determining the best material. The other two engineering characteristics, 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 the design of the TOV updated frame.*

		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

It was decided that a strictly experimental method of analysis would be used. This is because after trying to perform a force and momentum balance, 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. This conceptual design phase resulted in two possible designs. A material analysis was also done to determine the optimal material to use on the full-scale model. A stress analysis was performed after the material and design concepts were selected. After the sponsors approved these new designs and problems that arose were fixed, smaller scale models were built to test how the shape and connection location affects orientation of the vehicle while being towed at slow speeds. These experiments resulted in the selection of one design, which is currently being machined.

2.2 Design Concepts

The team started the design process with 4 design concepts. After some preliminary analysis, two of the design concepts were eliminated. In this section, the eliminated design concepts are shown and reasoning is given behind that elimination process. In addition, the selected design concepts can be seen along with an explanation as to why they were chosen and some advantages they have over the previous frame.

2.2.1 Eliminated Design Concepts

The cylindrical design, seen below in Fig. 7, was eliminated for many reasons. The first was that it would only allow for cable attachment points at the top of the structure. This would be unfavorable because this could cause the structure to be susceptible to roll. This design was also unfavorable because it had a smaller footprint area compared to the original TOV, no matter which way it is oriented during towing. It did not utilize piping as the other designs do. Piping is more hydrodynamic than a square cross sectional support would be. This design did not decrease the height compared to FSU's current TOV. It did not have points that would ease in attaching and detaching wheels. It may have been more difficult to attach the equipment since the volume is doughnut shaped. Finally, there would have been no easy way to attach side surfaces to control the yaw or translation motion of the frame. For these many reasons, this design was seen as an unfit upgrade compared to the current TOV frame, and was eliminated.

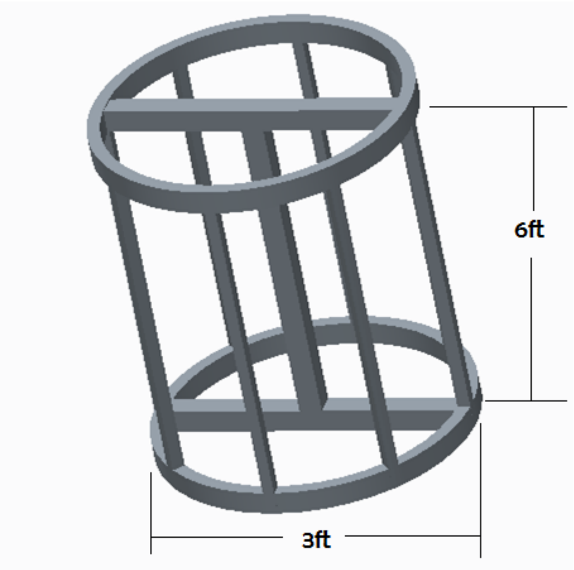


Figure 7: *Cylindrical design concept which had been eliminated from consideration.*

The next design, seen in Fig. 8, decreased in dimension along two axes, the front and the side. Due to this taper, it would have been significantly more difficult to add surfaces parallel to the flow, is what minimizes the yaw and the translational motion of the structure. Panels could have been added on its sides, but that would create an additional, unnecessary drag component since a portion of the side surface would be normal to the flow. The taper that occurs towards the sides also would cause an unnecessary decrease in footprint area. This design also did not meet many of the customer requirements, so it was also eliminated.

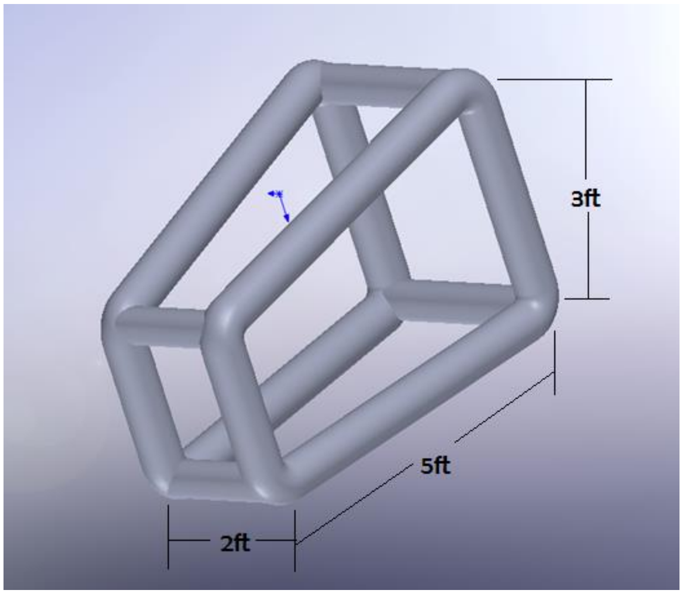


Figure 8*: Two-axes tapered design concept which had been eliminated from consideration*

2.2.2 Selected Design Concepts

As can be seen in Fig. 9, this design's structure decreased in height towards the front. This uneven distribution of volume would most likely lead to an uneven distribution in weight, as more components would fit in the back than in the front. This would move the center of gravity back, and hopefully would create a correcting moment if the design experienced the same angle of tilt that the original frame was experiencing. As previously used in the FSU TOV design, adding surfaces on either side of the structure created drag force perpendicular to the flow which allowed the system to maintain a constant yaw. These surfaces also prevented the body from experiencing translational motion to either side. This design would make it simple to attach these surfaces. This geometry would decrease the average height, reduce the weight due to the reduction in material, would provide one possible solution to correcting the orientation, and would increase the footprint area. For these reasons, this design was selected to move forward with experimental testing.

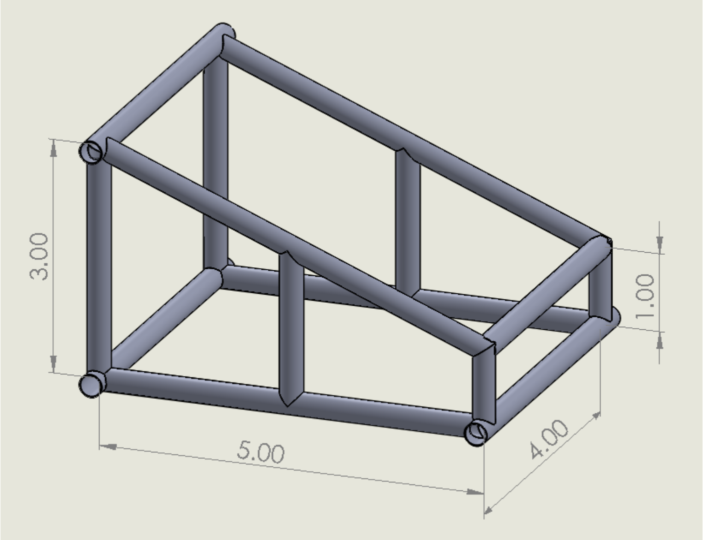


Figure 9*: One axes tapered trapezoidal design concept, which had been selected to move forward with experimental testing.*

The square design, seen in Fig. 8, utilized a square for the footprint area, as this maximized the area. As previously mentioned, surfaces on either side of the structure would be utilized to create equal drag forces perpendicular to the flow, allowing the system to minimize yaw rotation and translational motion. This design also would simplify adding these surfaces because it already has sides parallel to the flow. This design had a smaller volume than FSU's current frame, and a larger volume than the trapezoidal 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 trapezoidal 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. This geometry would decrease the average height and would increase the footprint area. For these reasons, this design was selected to move forward with experimental testing.

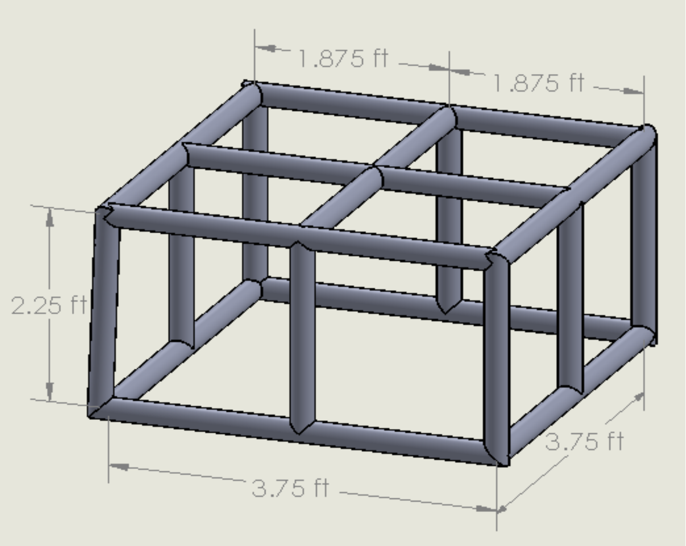


Figure 10*: Square footprint design concept, which had been selected to move forward with experimental testing.*

2.3 Experimental Analysis

The team decided to use experimental testing to determine the best model. The purpose of these tests were to determine how the geometry, tether locations, bridle tether lengths, and various drag surfaces affected the system stability, including the pitch, yaw, and roll of the structure.

2.3.1 Initial Models

During the first semester, the funds to be utilized had not yet been made available to the team. The full-scale measurements were scaled down by 12 for these models. Due to this, the team utilized available material in the machine shop. A 0.5 inch thick aluminum plate was used to water jet two profiles for each model. In addition, 4 connector pieces were water jetted out of the same plate. These pieces were press fitted and welded together. The CAD drawings for these models can be seen in Fig. 11 and 12. Various holes were drilled in uniform increments across the beams in order to test various tether locations and the effect they had on the system's orientation. The complete machined models can be seen in Fig 13. Various side surfaces were laser cut out of Acrylonitrile-Butadiene-Styrene (ABS) plastic and attached to the models using zip ties.

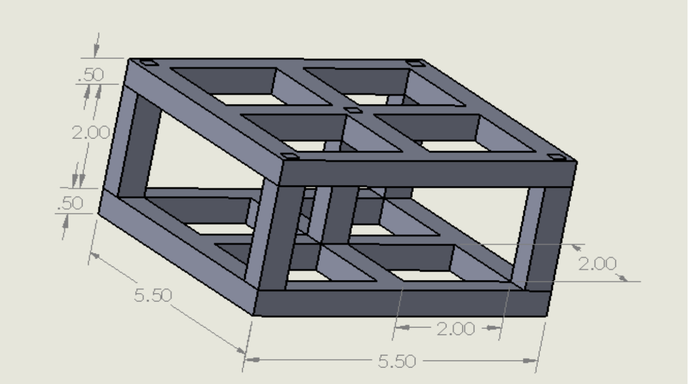


Figure 11*: Scaled square model utilized in first round of testing, dimensions are in inches.*

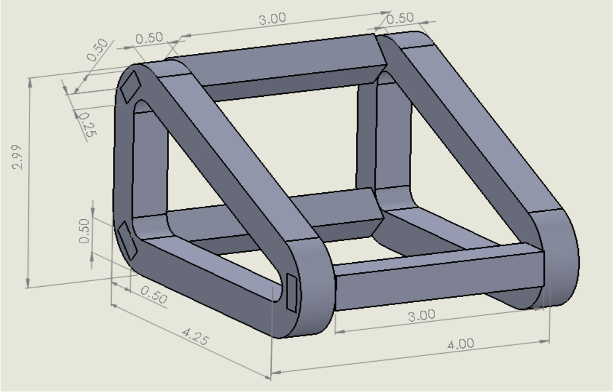


Figure 12*: Scaled trapezoidal model utilized in first round of testing, dimensions are in inches.*

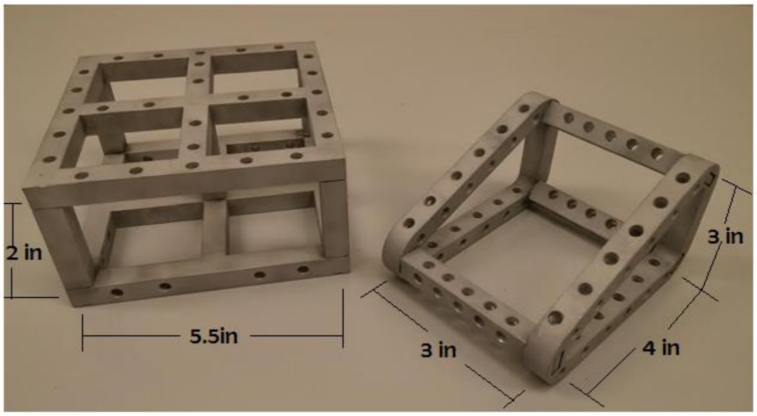


Figure 13: *Square cross section scaled trapezoidal and square models utilized in first round of testing.*

A 3 connection point bridle was simulated using fluorocarbon line. The fluorocarbon line was attached to the model at 3 points and met at a point, depending upon the lengths of the bridle cables. This connection of the 3 tethers of the bridle was then attached to a steel braided cable. The steel braided cable was what was used to drag the models through the testing site. The models were tested in an 8 foot deep pool. The models were dragged slowly through the pool. A camera held at the same height of the models captured the behavior of the systems.

2.3.2 Initial Models Testing Results

A gridded backdrop was not utilized in this round of testing so it was difficult to thoroughly analyze the results. Instead, visual observation showed how parallel the models towed compared to the horizontal black tile line. Pictures of the testing of these models can be seen in Figs. 14 and 15 below. In addition to not being able to quantify the data collected, these tests cannot be considered entirely accurate. These models have a solid square cross section for their beams, whereas the final design will have a hollow circular cross section. Because of this, the results from these tests cannot be extrapolated to the large scale, and more models needed to be made and tested.

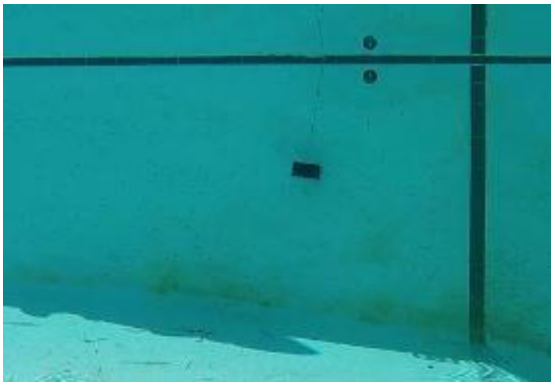


Figure 14: *Snap shot of the video of the first round of testing. Shows square model being pulled through pool. Does not give much information due to lack of references.*

2.3.3 Final Models

At the beginning of the second semester, designs were made for new hollow circular cross section models. The funds were made available soon after. At this point, the material for the new models was ordered and the drawings and material were submitted to the machine shop. The full-scale measurements were scaled down by 5.5 for these models. Steel piping with a 0.5 inch outer diameter and 0.065 inch thickness was utilized due to its higher melting temperature in order to make the machining process easier for the machinists. The CAD drawings for these models can be seen in Figs. 15 and 16. Hose clamps were utilized as the connection sites in order to ease in moving the connections sites and transferring them from one model to the other. The complete machined models can be seen in Fig. 17. New side surfaces were laser cut out of ABS plastic and attached to the models using zip ties. In addition to the side surfaces, another surface was laser cut in order to see how a frontal drag surface affected the system.

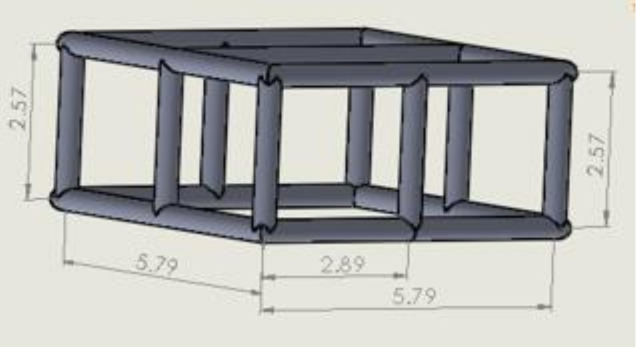


Figure 15*: Final pipe square model*

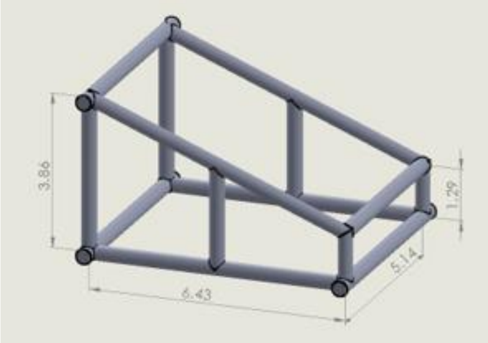


Figure 16*: Final pipe trapezoidal model*

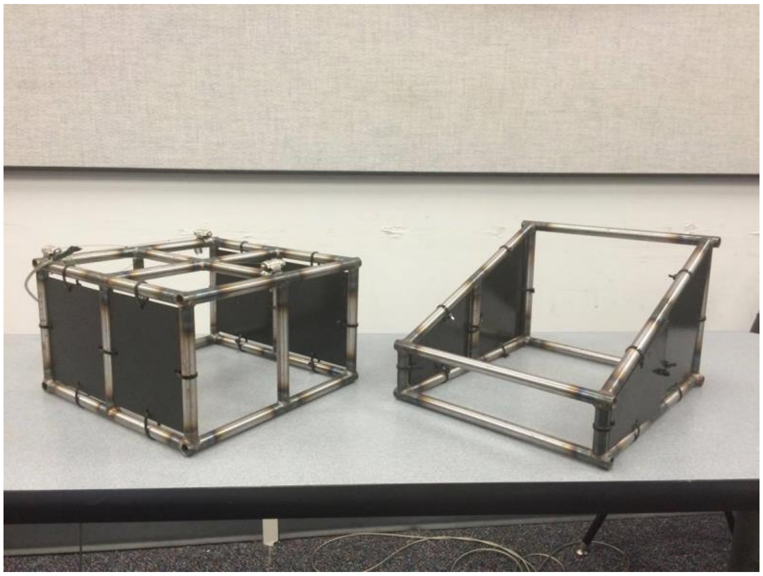


Figure 17: *Circular hollow cross section scaled trapezoidal and square models utilized in second round of testing.*

A 3 connection point bridle was again simulated using fluorocarbon line. The line was attached to the hose clamps which were attached to the models at 3 points. From the hose clamps attached to the model, the three lines met at a single point above the model that was then attached to a steel braided cable. The steel braided cable was what was used to drag the models through the testing site. Testing was completed in an eight foot deep pool. The models were dragged slowly through the pool while a camera held at the same height of the models captured the behavior of the systems.

2.3.4 Final Model Testing Results

A gridded backdrop was utilized in this round of testing in order to obtain quantifiable data. Pictures of the testing of these models can be seen in the Figs. below. Fig. 18 shows the base trapezoidal model test. Fig. 19 shows the trapezoidal model test with a frontal drag surface attached. It was thought that this surface would create drag and therefore tension in the steel cable, negating the parabolic shape of the cable that occurs 2000 meters under the water. While this did create tension in the cable, it also dramatically increased the angle that the model was being towed at. This is something the group is trying to minimize, so the top surface was ruled out. Fig. 20 shows the trapezoidal model test after the frontal bridle cable was shortened. As can be seen, the model tows closely parallel to the horizontal. Finally, Fig. 21 shows the square model test. This image shows that it tows at an angle. In addition to towing at an angle, the yaw of the structure was unstable compared to the trapezoidal model, forcing the system to spin towards the wall. No matter how the connection lengths or locations were varied, it was difficult to create a level tow and minimize the yaw of the structure. For these reasons, the trapezoidal model was determined to be the best geometry and the lengths of the bridle cables utilized in Fig. 20 were recorded in order to scale them up for the final model.

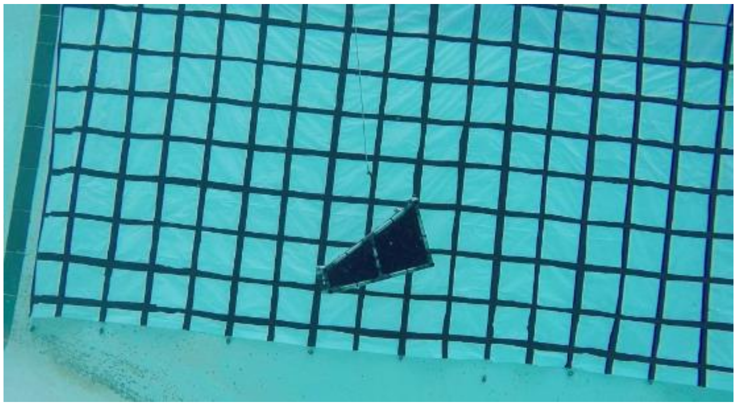


Figure 18*: Snap shot of the video of the second round of testing. Shows trapezoidal model being pulled through pool. Back drop was used as reference to measure tilt. No drag surface was attached to the top during this test*

Figure 19*: Snap shot of the video of the second round of testing. Shows trapezoidal model being pulled through pool. Back drop was used as reference to measure tilt. Drag surface was attached to the top during this test, resulted in a greater angle of tow.*

Figure 20*: Snap shot of the video of the second round of testing. Shows trapezoidal model being pulled through pool. Back drop was used as reference to measure tilt. Drag surface was not attached to the top during this test, but the bridle cable lengths had been augmented, resulted in a very level tow.*

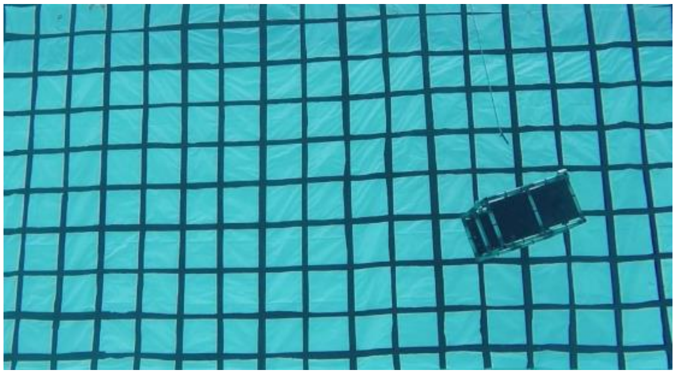


Figure 21: *Snap shot of the video of the second round of testing. Shows square model being pulled through pool. Back drop was used as reference to measure tilt. Towed with a tilt and was difficult to maintain yaw regardless of augmented tether lengths*

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. 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 Stress Analysis

After the material analysis was performed, and Aluminum 6061 was chosen as the material for the frame, a stress analysis was performed. A force analysis was first performed to consider all the forces that would be contributing to the stress in the frame. This was done to make sure that the aluminum chosen would have the structural integrity to support the weight of the components in addition to resisting the force of the tether.

2.5.1 Force Analysis Frame

The team considered 2 major forces that act on the vehicle while it is being towed. The first force was due to the weight of the components. The total weight of the components is 485 pounds. An extra 15 pounds was added to account for the aluminum unistrut bars that are used to mount the components in the structure. The total weight of components that was used in the stress analysis was 500 pounds. Additionally, an overestimation of drag force acting on the structure was calculated. This was done by calculating and summing all of the drag force acting on the components using Eq. 1.

$$Fdrag = \frac{1}{2} C_D \rho A V^2 \qquad \text{Eq. 1}$$

In this equation, C_D is the coefficient of drag. A coefficient of 1.2 was used for cylindrical components, and 2.2 was used for rectangular components. The variables $\rho, A,$ and V were the density of water, frontal area of the components, and velocity (5 mph). The summed drag force of the all the components was calculated to be 785 pounds.

Conclusively, the 2 forces included in the stress analysis was the 500 pounds of the components, and the 785 pounds of drag, with the body constrained at the connection sites. The sponsors also requested that a stress analysis be performed with the original weight of 900 pounds, just in case they have to add weight to the structure to make it function properly. Both of these analysis can be seen in the following sections.

2.5.2 Stress in Frame

The stress analysis was performed in Pro-E. Pro-E does not have the capability to perform Finite Element Analysis (FEA) on thin walled structures as this structure. What the group ended up doing to perform a stress analysis was creating a wire frame of the structure, and idealizing each beam as a hollow pipe with 2-3/8 inch outer diameter and 0.218 inch thickness. The frame was constrained at the front top mid beam, and at the two locations in the back top corners. The equipment loading was applied as a point force mid beam on each vertical support. The drag force was distributed along the frontal beams. These locations were picked because they would create the largest stresses. The performed stress anlysis for the 500 pound loading can be seen in Fig. 22. The maximim stress in this analysis was about 860 psi. With aluminums yield stress of 40,000 psi, there is a safety factor of about 47. The stress analysis for the 900 pound loading can be seen in Fig. 23. The maxiumim stress was about 1360 psi, so there is a safety factor of about 29.

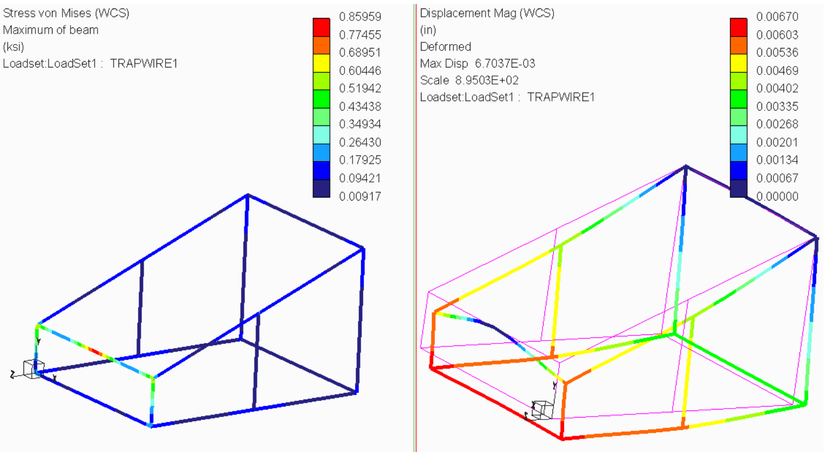


Figure 22: *Stress analysis (Left) and displacement analysis (Right) performed on the trapezoidal frame. This includes 500 pounds of components and 785 pounds of drag force. Red corresponds to a stress 0f 860 psi and 0.007 inches, while purple corresponds to 9 psi, and no displacement.*

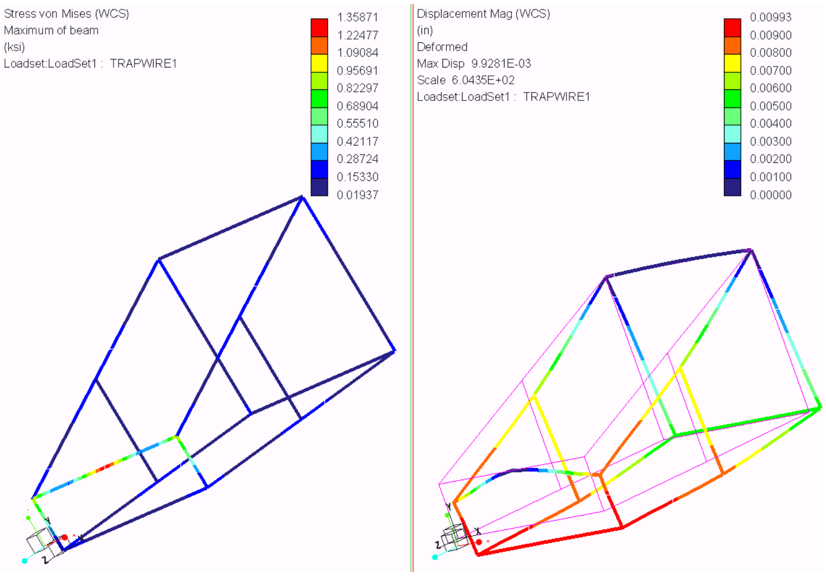


Figure 23: *Stress analysis (Left) and displacement analysis (Right) performed on the trapezoidal frame. This includes 900 pounds of components and 785 pounds of drag force. Red corresponds to a stress 0f 1359 psi and 0.01 inches, while purple corresponds to 19 psi, and no displacement.*

2.5.3 Stress at Connection Sites

This stress analysis was also performed in Pro-E. The connection block and its dimensions can be seen in Fig. 24.

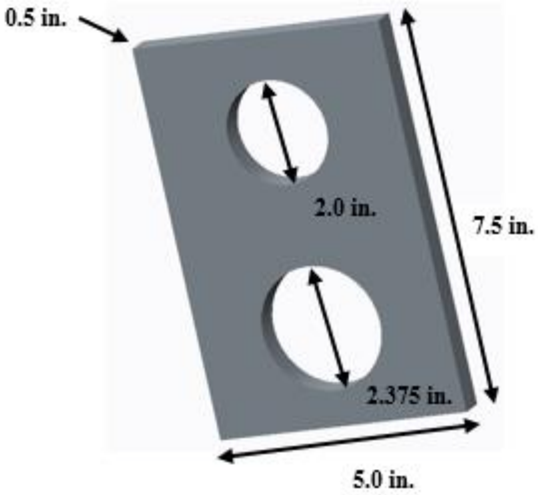


Figure 24: *CAD drawing of the connection block. The lower hole is what is welded to the aluminum frame, while the upper hole is where the bridle connects to the body.*

The block was constrained on a small fraction of the top surface of the upper hole, 0.2 inches of its circumferance. This is because a shackle will be connecting the block to the bridle and tether, so therefore the stress will be concentrated on that smaller surface rather than the entire diameter. The downward load was distributed on the entire surface of the lower hole. This is because the beam of the frame will be welded inside of this smaller hole, so the load will be distributed about the entire surface. frame was constrained at the front top mid beam, and at the two locations in the back top corners. Again, there were two different stress analyses were performed for a loading of 500 pounds and a loading of 900 pounds. The anlysis for the 500 pound loading can be seen in Fig. 25. The maximim stress in this analysis was about 460 psi. With aluminums yield stress of 40,000 psi, there is a safety factor of about 87. The stress analysis for the 900 pound loading can be seen in Fig. 26. The maxiumim stress was about 826 psi, so there is a safety factor of about 49.

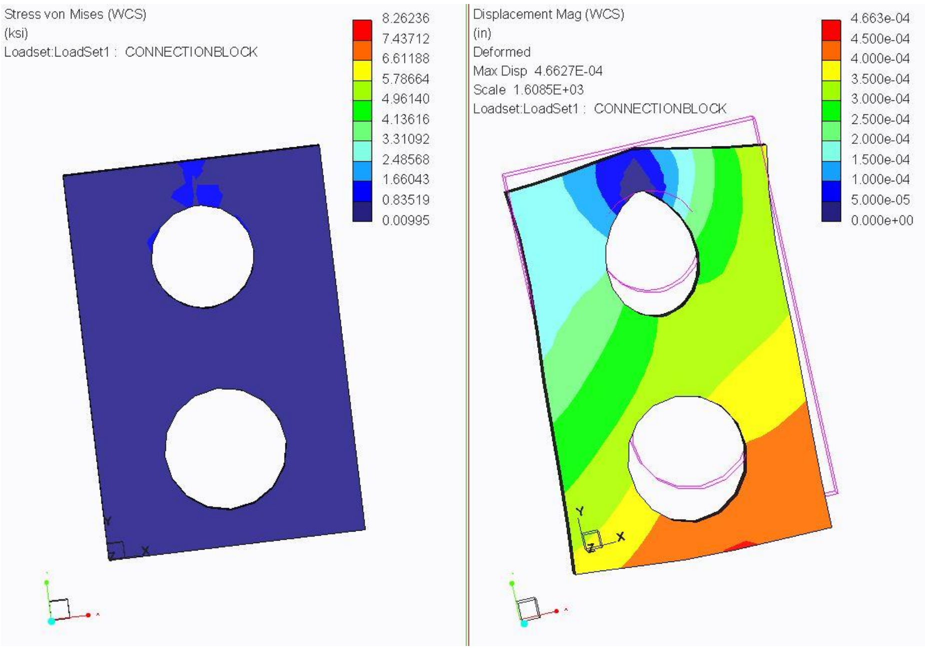


Figure 25: *Stress analysis (Left) and displacement analysis (Right) performed on the connection block. This includes 500 pounds of components. Red corresponds to a stress of 460 psi and 0.0003 inches, while purple corresponds to 5 psi, and no displacement.*

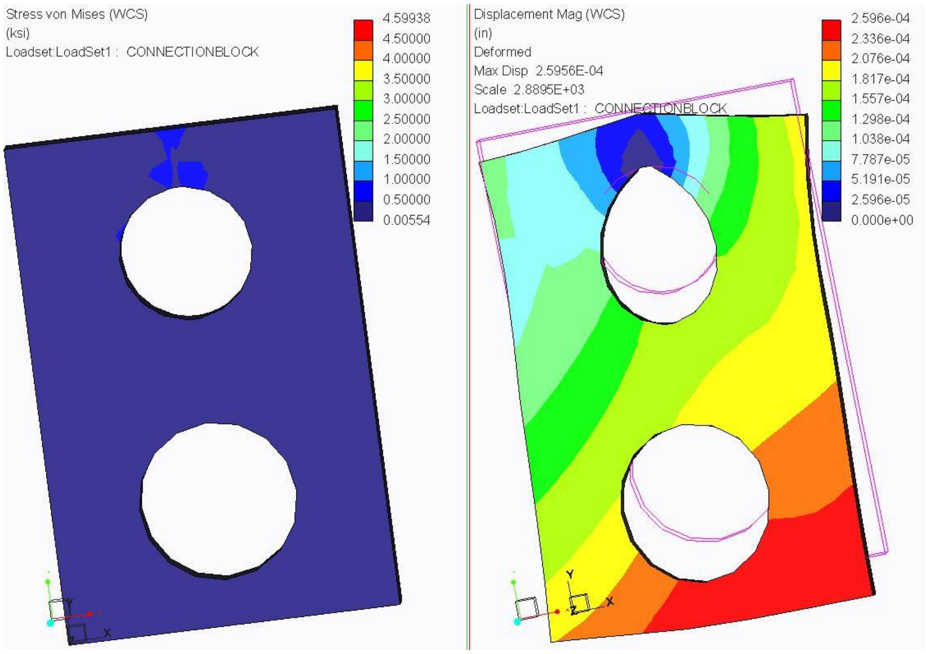


Figure 26: *Stress analysis (Left) and displacement analysis (Right) performed on the connection block. This includes 900 pounds of components. Red corresponds to a stress of 826 psi and 0.0005 inches, while purple corresponds to 10 psi, and no displacement.*

2.6 Additional Modifications to Frame

2.6.1 Feet

The "foot" addition to the frame acts as a buffer between the bottom of the housing structure and floor of the boat, protecting feet and equipment from being crushed. Fig. 26 is a foot with a small pipe protruding from it. This will be attached to the frame using screws; a small aluminum piece will be welded to the frame which will aid in bolting the foot to the frame. The main material will be made out High Density Polyethylene (HDPE) and will have a small pipe press fitted into it. The pipe also has a small hole to fit a pin.

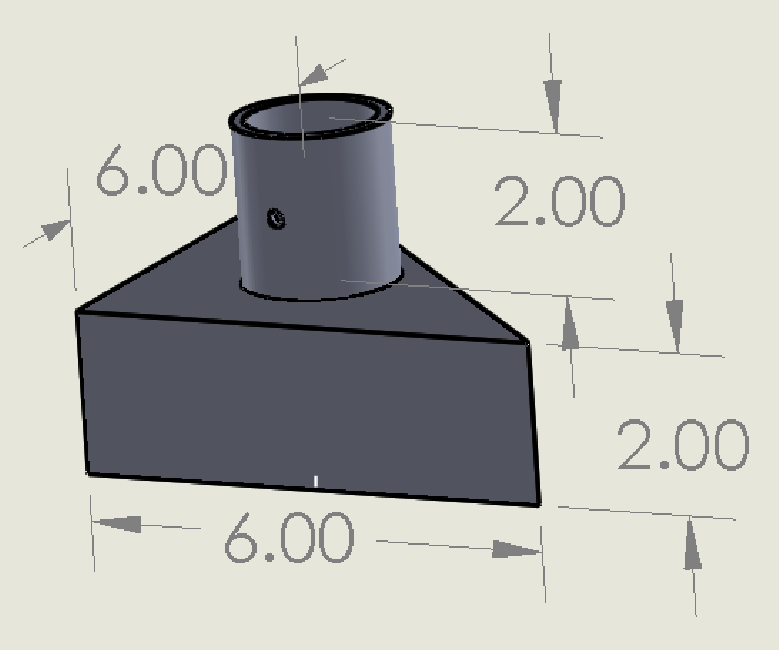


Figure 27: *Foot option with pipe and pin insert to prevent the foot prom falling out. Dimensions are in inches.*

2.6.2 Wheels

Although the "feet" act as a buffer between the housing and objects on the boat, the wheels will be used to transport the housing while not on the boat. The standard wheel can be seen in Appendix A. This wheel, found on McMaster-Carr, can withstand 220 pounds and has as a lock which could possibly be used on the boat as well to prevent the structure from uncontrollably rolling. Fig. 28 leverages a welded aluminum pipe with a small hole towards the top of the pipe with the same diameter as that of Fig. 27.

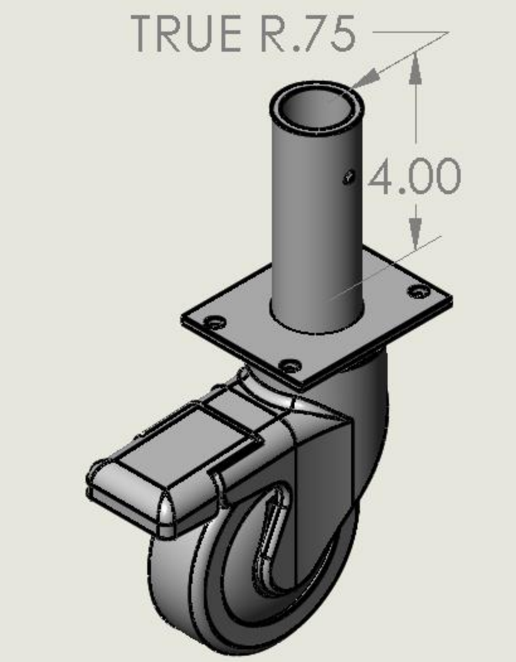


Figure 28: *Modified wheel design with added pipe to attach to the foot. Dimensions in inches.*

2.6.3 Wheel and Foot Assembled

Fig. 29 utilizes a pin as the main form of attachment. The wheel is fit through the foot and when in the right position, uses a pin to secure it in place. This design was thought to be the most user friendly for the sponsors as per their request.

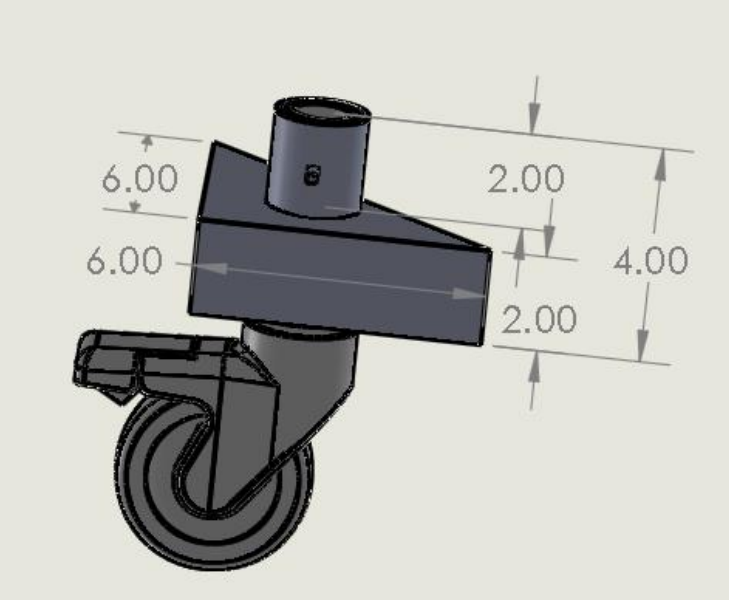


Figure 29: *Foot and wheel assembly attachment utilizing a pin to secure the wheel to the foot. Dimensions in inches.*

2.6.4 Side Panels

As aforementioned, in order to ensure the TOV tows straight, side panels need to be added. Fig. 30 left is the back panel and Fig. 30 right is the front panel. Both will be attached using hose clamps which will go through the holes of the panels and wrap around the piping of the TOV.

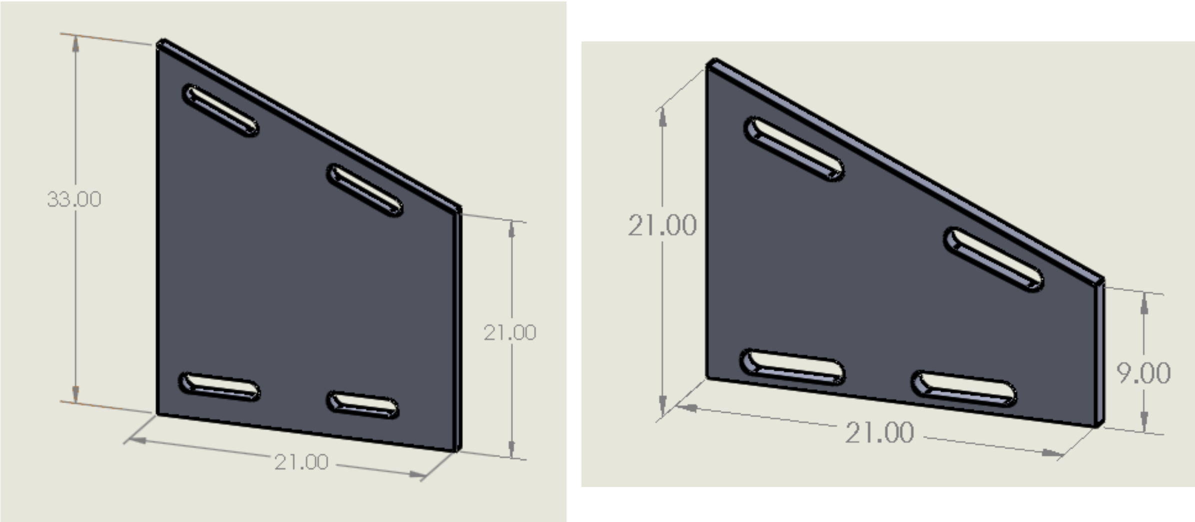


Figure 30*: Back (left) and Front (right) side panels of final design. Dimensions in inches.*

2.6.5 Bridle

Consisting of one main attachment point above the housing structure, the oblong master link, and tethers which attach to the TOV, its main purpose is to aid in the stabilization of the system, an example of this system can be seen in Fig. 31. The stabilization is corrected by varying the lengths of the tethers as mentioned in section 2.3.4. The tether is turned around on a thimble and crimped at the sleeve to attach to the oblong master link. The other end of each cable are turned around and crimped around the shackle at the connection points on the frame.

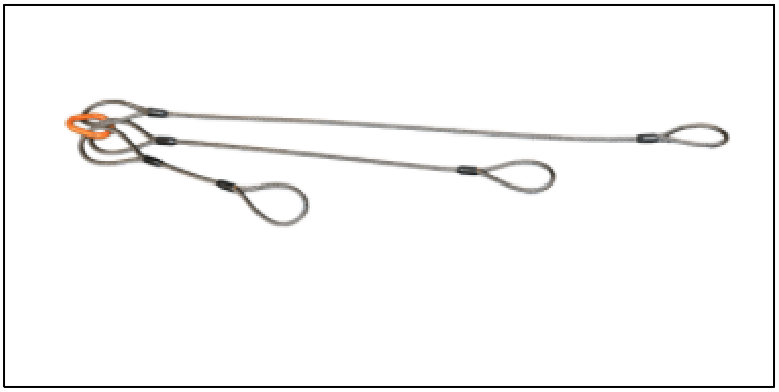


Figure 31: *Image of the 3-cable bridle meeting at oblong master link, similar to the one utilized with the TOV. The yellow oblong master link attaches to the winch's towing cable and each of the 3 loops is crimpled around a lifting shackle, which is attached to each of the TOV's three connection sites.*

2.6.6 Unistrut

To attach the equipment inside the TOV, various lengths of slotted Aluminum 6061 unistrut will be attached to the main frame using U-bolts. Unistrut will be attached to the frame length wise and additional unistrut will be attached to the length wise attachments widthwise depending upon where the component needs to be placed. A nut and bolt connects the pieces of unistrut together. See Appendix A for the CAD drawings of the unistrut.

2.7 Final Design

Through experimentation, theoretical engineering analysis, and aesthetic desire of the sponsors, the final design was completed and can be seen in Fig. 32. The prototype will be made out of aluminum and have a two foot height differential, 3 foot to 1 foot, as previously mentioned in section 2.2.2. Its base will be 4ft x 5ft which increases the area able to look directly at the ocean floor by 2 ft^2 compared to the original FSU TOV. With all the piping, the final prototype will weigh 177 lbs. The tether location attachment points will have three locations: one in the front and two in the back. Additionally, ABS side panels and feet will be added and can be seen in Fig. 32 on the sides and bottom of the prototype, respectively. Fig. 33 is an example of what all the equipment would look like if it were in the TOV.

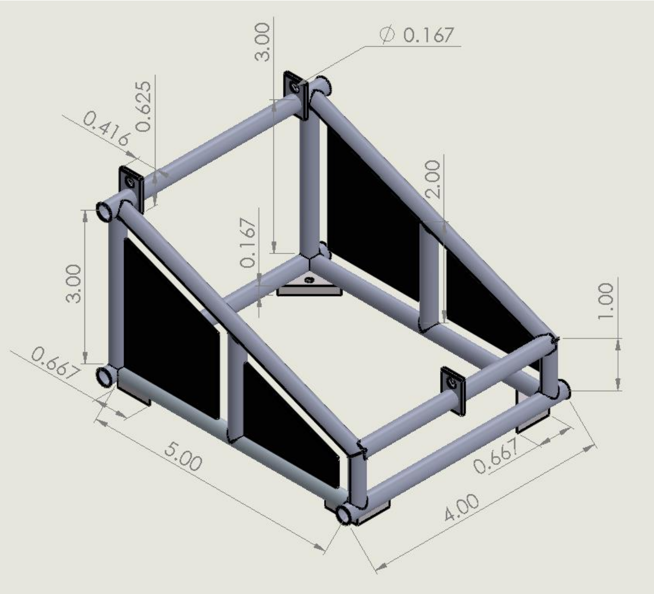


Figure 32: *Final TOV frame design with foot and side panel attachments. Dimensions in feet.*

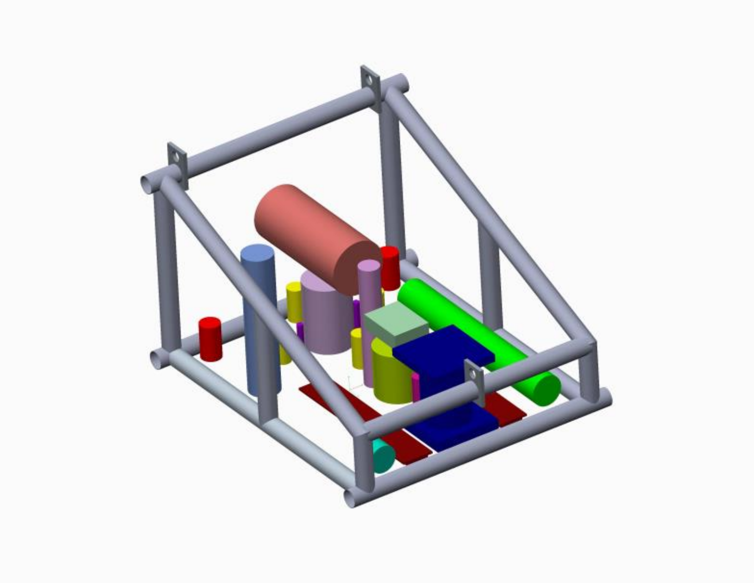


Figure 33: *CAD drawing of the TOV frame with all of the components placed appropriately. To see the itemized list of components, refer to Appendix B*

2.8 Product Specifications

2.8.1 Design Specifications

- Geometric dimensions: A request from our sponsors was to increase the footprint area, the area parallel to the ocean floor. Therefore, an additional 2ft^2 was added to the final design. Now any equipment which needs direct sight of the ocean floor can easily be placed in a specified orientation in the TOV to do so.
- Weight: The new design will be much lighter than the previous TOV by 400 lbs. with all the equipment attached to the system. The previous TOV was made out of galvanized steel which is much heavier than the aluminum that the new design will be made from.
- Cost: Made out of a less expensive material with the ability to have inexpensive machining by going through the engineering college’s machine shop, the overall design of the structure is more cost effective.
- Minimization of Height: To aid in mobility, it was asked to decrease the height of the overall structure. Although the systems maximum height has the same height as the original TOV, its smallest height is one foot. Therefore, the overall height of the system was decreased.
- Modular: Data collecting equipment must be able to move about the frame. As previously mentioned, this will be completed through the addition of unistrut channels that can be moved about the frame to satisfy needed orientation and placement desires.
- Consistently Oriented Feet: The feet on the current TOV are zip tied to the structure, this allows the feet to spin around the housing. To fix this, new feet will be added to the structure that will be bolted on to a piece of aluminum welded onto the main frame.
- Holds all data collecting equipment: The new frame must have a large enough volume and footprint to hold all data collecting equipment. As previously mentioned, there must be a large enough footprint to allow the necessary pieces of equipment to have a clear view of the ocean floor. With this in mind, the foot print was increased by two squared

feet and the volume was decreased by 14 cubic feet.

2.8.2 Performance Specifications

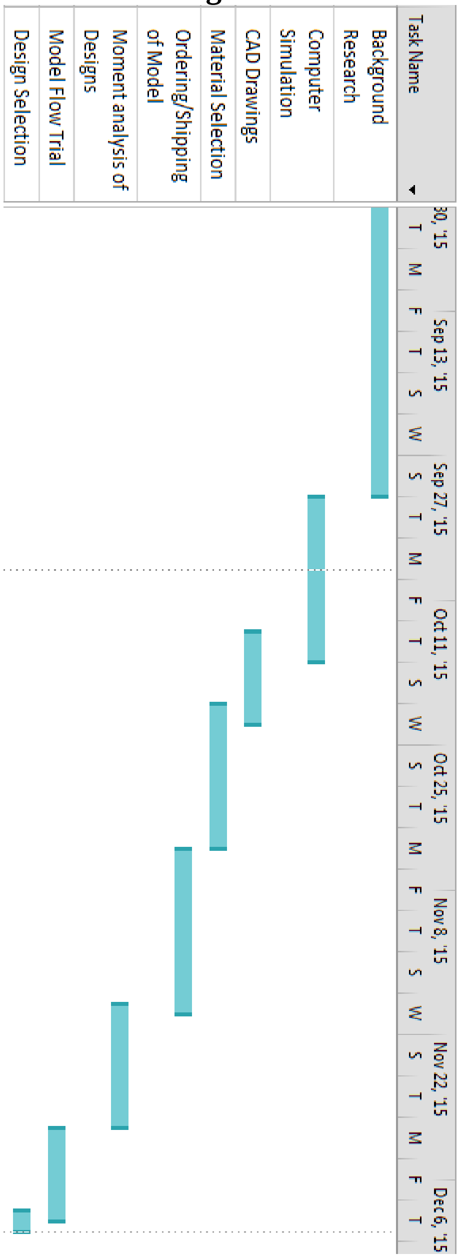
- Water Resistant: The structure will be used at great ocean depths so its material must be resistant to rust and wear from the salt water. The aluminum pipes will have zinc-chromate plating to take care of possible corrosion issues.
- Fixed Orientation: To ensure the system remains parallel to the ocean floor, tether lengths will be varied. Although the optimum tether lengths were found during testing, this will not be definite until this concept is tested in the final cruise.
- Wheels: To increase mobility, it was requested to have removable wheels on the TOV. With various designs for attachment, the wheels will be corrosion resistant and have locks.
- Side Panels: Water flows easily throughout the system since it is an open design. Without side panels, the system would spin without any direction to be guided in. The addition of side panels creates a force both inside and outside the structure which forces the structure to tow parallel to the direction of the panels.
- Resistant to pressures occurring at 2000+ meters: The vehicle's operating depth is approximately 2000 meters. Therefore, the new frame must be able to resist the large forces that occur due to the water pressure. The new frame is an open piping design which allows water to equalize easily once submerged.

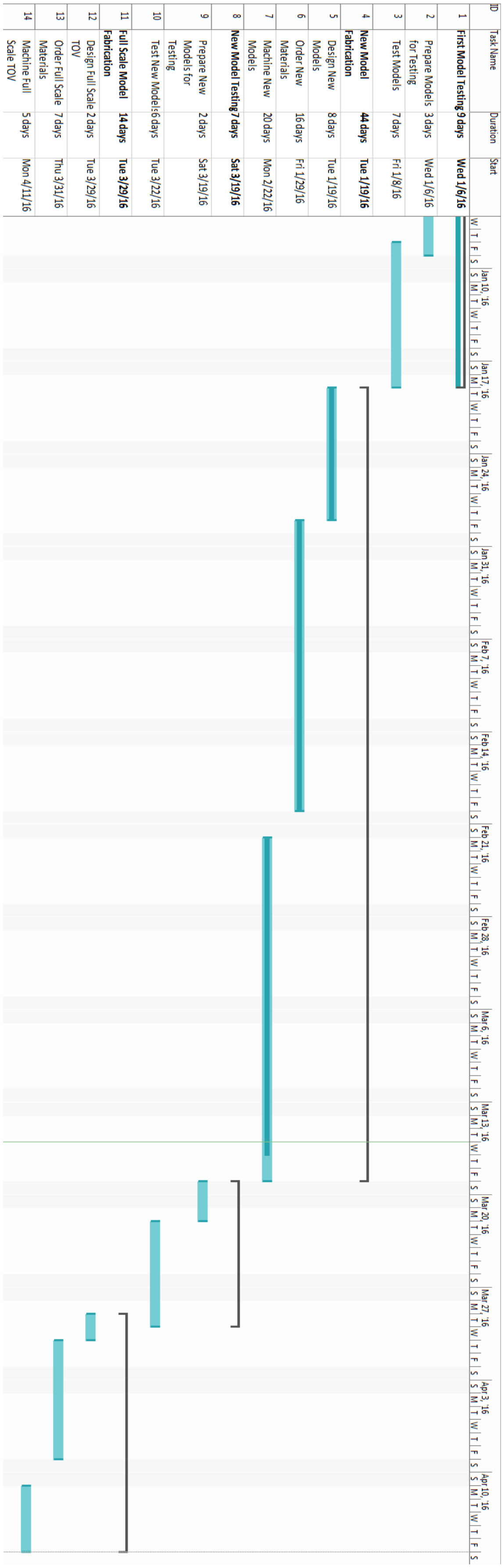
3 Scheduling and Resource Allocation

3.1 Gantt Chart

Illustrated in Table 2 is Team 21's Gantt chart. This provides the breakdown as a timeline with specific tasks that have been conducted throughout the year. The lengths of the bars are indicative of the duration of each task. These Gantt charts show what the team has been doing at each point in the semester.

Table 2: Gantt Chart Outlining Future Work for Design Project





ID	Task Name	Duration	Start
1	**First Model Testing**	**9 days**	**Wed 1/6/16**
2	Prepare Models for Testing	3 days	Wed 1/6/16
3	Test Models	7 days	Fri 1/8/16
4	**New Model Fabrication**	**44 days**	**Tue 1/19/16**
5	Design New Models	8 days	Tue 1/19/16
6	Order New Materials	16 days	Fri 1/29/16
7	Machine New Models	20 days	Mon 2/22/16
8	**New Model Testing**	**7 days**	**Sat 3/19/16**
9	Prepare New Models for Testing	2 days	Sat 3/19/16
10	Test New Models	6 days	Tue 3/22/16
11	**Full Scale Model Fabrication**	**14 days**	**Tue 3/29/16**
12	Design Full Scale TOV	2 days	Tue 3/29/16
13	Order Full Scale Materials	7 days	Thu 3/31/16
14	Machine Full Scale TOV	5 days	Mon 4/11/16

3.2 Resource Allocation

This team only has 3 members, therefore, it was decided as a team to do most of the work together including experiments, experimental analysis, and conceptual designs. However, some tasks were broken up between the members as seen below:

- William: Analysis of various materials, cost analysis on these materials, and video editing throughout testing.
- Kasey: Performed the stress analysis on both the frame and tether locations attached to the frame; this included calculations of safety factor, analysis of stress, and analysis of deformation.
- Chelsea: Created the drawings for the full size prototype, newer models, feet, and wheels.

3.3 Financial Allocation

The overall cost for the prototype will be $1,822.22. This includes the cost of the material, the wheels, the unistrut, and the zinc-chromate plating. The material needed is made up of ten 6ft long and five 4ft long, 3in diameter piping. If anything goes wrong during machining, an extra pipe for each length will be additionally ordered making the total cost of the material $1,016. Four wheels are needed, one for each bottom corner. The system will weigh a maximum of 550 lbs. with all the equipment loaded. Therefore, each wheel with the ability to withstand 250 lbs. is more than enough to hold the entire structure. The total cost of the four wheels will be $54. Although the sponsors already have unistrut, it is made out of steel so to avoid dissimilar metal problems, aluminum unistrut will be ordered. It is estimated that the needed amount will be two 5 ft. long, ten 4 ft. long two 3 ft. long, and two 1 ft. long unistrut channels, bringing its total cost to $312.22. Lastly, the zinc-chromate plating process is estimated to be $440, which is necessary due to the operating conditions being in the ocean. This total cost brings us in under budget by $177.78. For a more visual breakup of the cost, Figure 4 below is a pie chart of the cost break down. Luckily, if any unforeseen issues occur, the project sponsors said that additional funding is available if necessary.

Aside, no similar products are on the market. This is a product made on an individual need basis. Therefore, other prototypes similar to this project do not have information regarding funding or total cost of the project. While some universities have TOVs, the information regarding cost and products used to build the structure is not readily available.

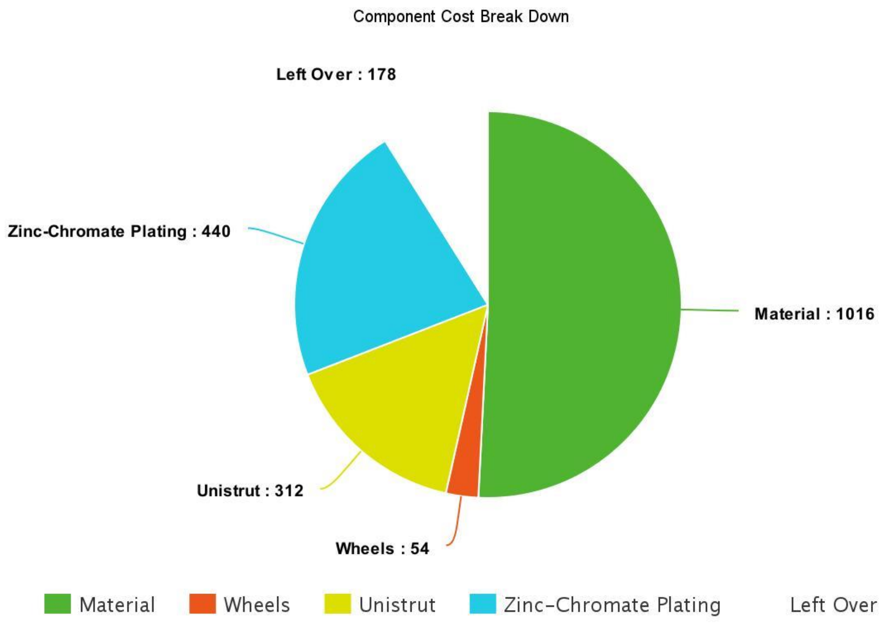


Figure 34*: Pie Chart of individual component costs of budget.*

4 Results

Prior to completion of the experimental analysis, preliminary examination steered the team to rule out some of the designs and favor a few designs over the rest. Two designs, the cylindrical design and the tapered trapezoidal design, as seen in Figs. 7 and 8 in section 2.2.1, have been eliminated due to theoretical analysis in system performance. The cylindrical design would have a tendency to spin around the bridal while the tapered trapezoidal design would make the addition of side panel not only difficult, but useless since it would obstruct the flow of water too greatly, again, making the system unstable.

The two designs that were deemed useful were the square and trapezoidal designs, Figs. 9 and 10 in section 2.2.2. Both have smaller volumes than the current TOV, a smaller over all height which aids in deployment, the ability to easily add side surfaces which would create balancing drag forces to eliminate yaw and reduce translation motion, larger bottom surface areas, and would be made out of aluminum. Making the material out of aluminum would greatly reduce the weight of the system by about 400 lbs.

It was decided to perform experimental analysis on these designs. Once machined, a grid background was created and placed along the wall of the test pool. The models were dragged in front of this background to determine whether the system was towing parallel to the bottom. Although the square model does have a more evenly distributed weight throughout the structure, it would spin towards the grid even with side panels. The trapezoidal model with the top drag surface, while creating more tension in the cable reducing the overall parabolic tendency the cable has, forced the housing to have a steeper slope towards the bottom making it severely not parallel to the floor. After the top surface was removed and the bridle cable lengths were augmented, the trapezoidal model towed very straight at parallel to the floor.

4.1 Risk and Safety Analysis

The risk and safety analysis document is attached with this document in appendix E. 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 mobile design, which tows parallel to the ocean floor. 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 fabricated. These models are scaled down from the full scale models using a 5.5 scale. After testing both models, it was clear that the trapezoidal model would perform the best. It was able to tow straight with the addition of side panels and it was able to tow parallel to the ocean floor after adjusting the tether lengths. This designs completes the sponsor specification mentioned in the previous paragraph as well as additional requests with the addition of feet and removable wheels.

This new frame design is better than the previous frame design because it is lighter, was more cost effective, is rigged to utilize wheels to ease in transportation, has a larger footprint area, has a smaller average height, a smaller volume, feet that maintain a consistent orientation, and should tow at a more parallel angle.

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 am Kasey Raymo and I'm graduating in April 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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Appendix A

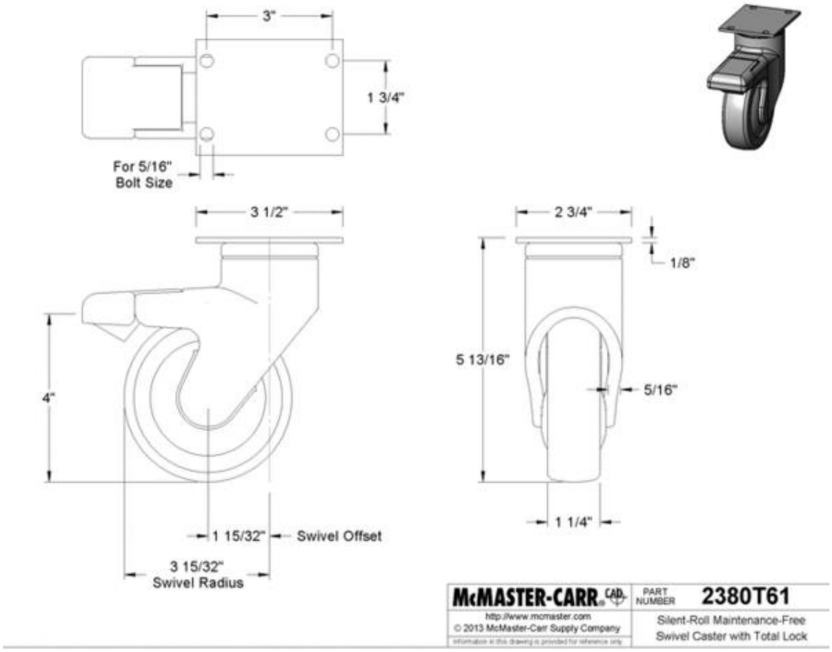
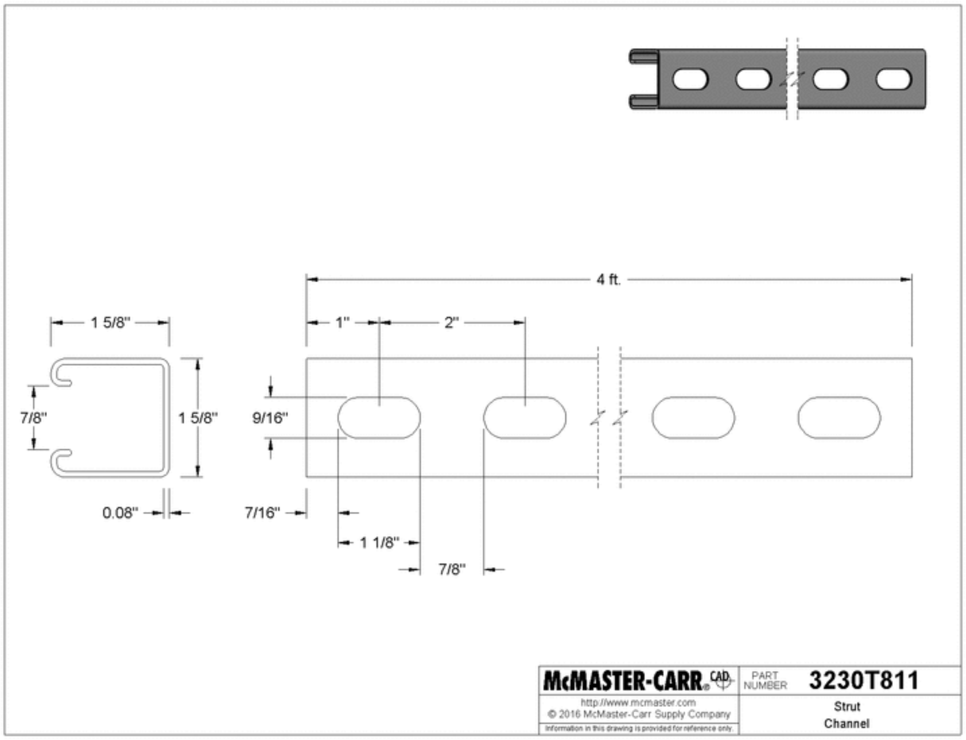
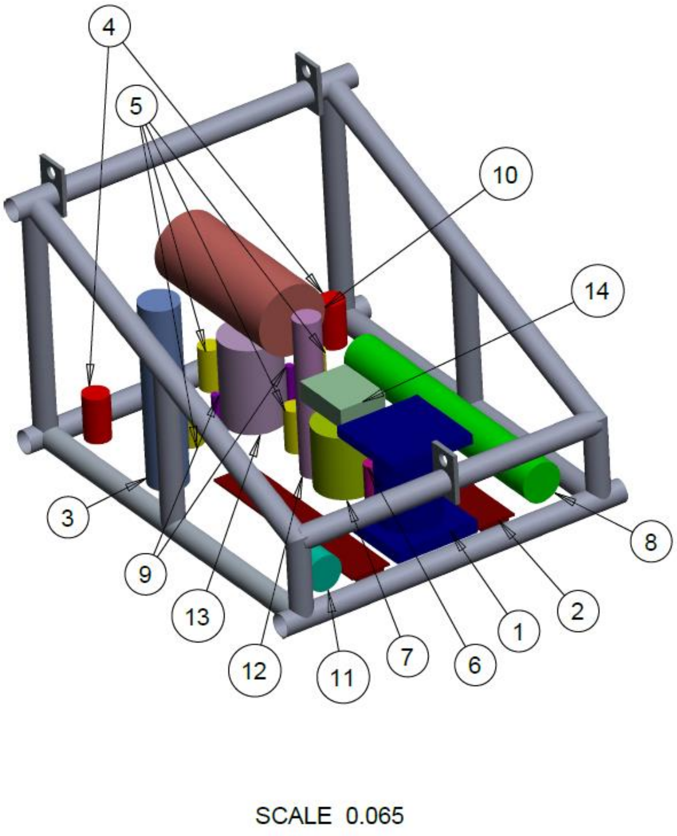


Figure BLANK: basic wheel from McMaster-Carr.



Appendix B



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DRAWN BY: KASEY RAYMO	MATERIAL: AL6061	DATE: 04/08/16	
REV: 0	SCALE 0.065	SHT: 1 of 1	DRAWING NUMBER: SP16-KRA-SD-AS-001

Number	Quantity	Name
1	1	Sub-Bottom Profiler Transmitter
2	1	Sub-Bottom Profiler Railings
3	1	Track Link 500 Series
4	2	Lantern Shark
5	4	LED Multi-Sea Light
6	1	Multi-Sea Cam
7	1	Navigator DVL
8	1	Pressure Housing
9	2	Sea Laser 100
10	1	Nexus Sea Bottle
11	1	SBE SeaCAT Profiler
12	1	Release Mechanism
13	1	Still Camera
14	1	Linear Power Converter

Appendix C

Operation Manual

Group 21
New Housing Structure for Deep Sea Equipment

Earth, Ocean and Atmospheric Science

Members:
Team Leader – William Hodges – wrh12
Lead Mechanical Engineer – Chelsea Dodge – cad12e
Financial Advisor – Kasey Raymo – kjr12e

Faculty Advisor:
Dr. Camilo Ordonez

Sponsor:
Florida State University’s Earth, Ocean, and Atmospheric Science Group
Ian MacDonald

Instructors:
Dr. Nikhil Gupta
Dr. Chiang Shih

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ABSTRACT

The purpose of this design project was to design a new frame for Florida State University's tether-operated vehicle (TOV). The purpose for this vehicle is for surveying and exploring the ocean floor. Florida State's TOV consists of a galvanized steel frame with an array of surveying equipment and unistrut bars for attaching the equipment. The current TOV has too much empty space, is difficult to move around, and does not tow parallel to the ocean floor. The redesigned frame for FSU's TOV addresses these issues. This operation manual provides important information and instruction for how to operate the new frame. It functions by rigging up all the necessary components and dragging behind a cruise ship via a steel braided cable as the various surveying equipment collects data and transmits it back up to the boat by means of a fiber optic cable. In order to do this the equipment, bridle, and the side panels are attached to the frame. As with any design, there are some sources that could cause failure. These are addressed in the manual and recommendations on trouble shooting and proper maintenance are provided. Also listed in the manual are some recommendations on spare parts that will make the operation of the TOV more convenient for the user.

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 for making the time to meet with us at least twice a month and helping us on deciding on proper analysis techniques and vital design decisions. Additionally, we would like to thank our advisor, Dr. Camilo Ordoñez, for also providing advice on proper testing techniques and aiding during the analysis of the testing results. Finally, we would like to thank Dr. Patrick Hollis for helping the design team perform the stress analysis.

I. Introduction

Tether operated vehicles (TOVs) are utilized to survey and explore the ocean floor. This project was to design a new frame for Florida State University's TOV. This new frame is made from aluminum 6061 treated for corrosion resistance. An array of aluminum unistrut is used to attach the 17 pieces of data collecting equipment to the frame. A bridle made of steel cables attaches to the 3 connection points on the frame. The TOV will tow parallel to the ocean floor due to the specified lengths of the steel cables creating balanced the moments. Plastic side surfaces are utilized to create drag forces perpendicular to the flow, causing the vehicle to remain moving in a straight line. Feet have been incorporated to the frame to prevent the frame from settling on anything unfavorable (feet, equipment, etc.). The feet are attached so that they do not have any range of motion. They are also specialized so that the wheels provided are easily attachable and detachable. The TOV is launched off of cruise ships using an A-frame, and its altitude once in the water is controlled by a steel cable attached to a winch and pulley system. The entire system and electronics are wired back to the boat using a fiber optic cable.

This document is a guide to show how the TOV is assembled and operated, how to recognize and solve the potential problems associated with this product, how to perform regular maintenance, and provides an inventory of the components of this design.

II. Functional analysis / Functional Diagram

The frame and all of its connected equipment will function under the water as the cruise ship is dragging it. This is where it fulfills its purpose of surveying and exploring the ocean floor. Its function can be broken down into two main components, the towing and the data collecting and transmission. This section describes these components of the TOV's function

a. Towing

The frame of the TOV has 3 connection points. These can be seen below in Figure (2) in section IV. At these connection points, the 3 ends of the 3-cable bridle that is included with the TOV are attached via a lifting shackle. This bridle is made of braided steel. The lengths of the 3 cables that make up this bridle are designed so that the TOV maintains a towing angle that is parallel to the ocean floor. This bridle was designed to constrain the pitch and roll of the structure. The 3 cables of the bridle converge at the top to an oblong master link. The oblong master link is the piece that attaches to the winch's towing cable. The bridle looks something like Figure (1). The ends of each cable are turned around and crimped around the shackle at the connection points on the frame. Surfaces attached to the side of the frame are utilized to create drag forces perpendicular to the flow, ensuring that the frame does not drift to the left or right, or move about the yaw axis. These can also be seen in Figure (2). Once the vehicle is tethered, it is launched into the water and given time to sink to the desired depth. The altitude in the water is manually controlled on the boat using a winch and pulley system.

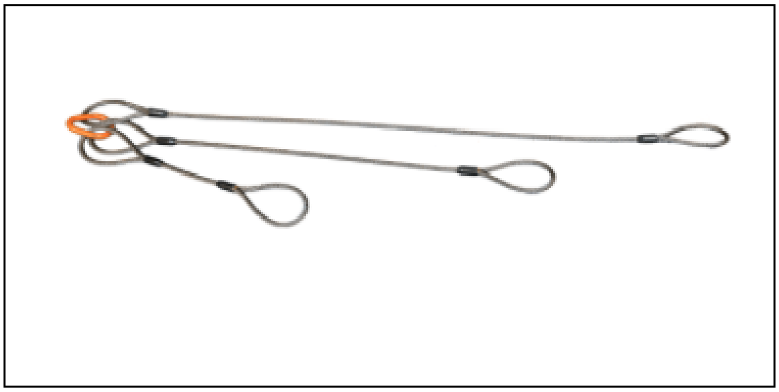

Figure 1: *Image of the 3-cable bridle meeting at oblong master link, similar to the one utilized with the TOV. The yellow oblong master link attaches to the winch's towing cable and each of the 3 loops is crimpled around a lifting shackle, which is attached to each of the TOV's three connection sites.*

b. Data Collecting and Transmission

Once the TOV is in the water at the desired depth and is being towed at the desired speed and orientation, the remaining function is of the components. Many pieces of equipment may be interchangeably utilized with this frame, but a list of the 17 pieces of equipment that this TOV was designed to hold and be used with can be seen in Table (1) below. This list consists of various lights, cameras, lasers, surveying and transmission devices, and electronics and their housings. The Nexus Sea Bottle is the device that collects the data from the components and transmits up to the boat by means of a fiber optic cable.

Table 1: *List of the 17 pieces of equipment that this TOV was designed to be used with, though these are not the only equipment that may be utilized.*

Component Name	Category	Number
Sub-Bottom Profiler	Surveying	1
Lantern Shark	Lights	2
LED Multi-Sea Light	Lights	4
Multi-Sea Cam	Camera	1
Navigator DVL	Surveying	1
SBE SeaCAT Profiler	Surveying	1
Sea Laser 100	Laser	2
Nexus Sea Bottle	Transmission	1
Track Link 500 Series	Surveying	1
Release Mechanism	Surveying	1
Still Camera	Camera	1
Linear Power Converter	Electronics	1

III. Project/Product Specification

Below is a list of the key components for the TOV and their specifications.

a. Frame

The frame dimensions can be seen in Figure (BLANK). It was machined from Aluminum 6061 piping with a 2-3/8 inch outer diameter at a 0.218 inch wall thickness. Its mechanical properties can be seen in Table (2).

Table 2: *Table showing some mechanical properties of the aluminum used for the frame*

Brinell Hardness	95
Tensile Strength	45,000 psi
Yield Strength	40,000 psi

b. Lifting Shackle

The three lifting shackles provided with this TOV are Lehigh's galvanized steel anchor shackles. They are 3/8 of an inch, weigh a third of a pound each, and have a loading capacity of 2000 pounds. A more complete specification char can be seen in Appendix (A).

c. Oblong Master Link

The oblong master link that this TOV is designed to be used with is Peerless Chain's Double grade 100 model. It is made of steel and has a coating in plastic to prevent corrosion. It has a length of 4-15/16 inches and a width of 2-11/32 inches. It weighs 7400 pounds and has a load limit of 7400 pounds.

d. Unistrut

Various lengths of slotted Aluminum 6061 unistrut are utilized on this TOV to attach the equipment to the frame. See Appendix (A) for the CAD drawings of the unistrut.

e. Wheels

The wheels that are supplied with this TOV are the Focus FTC34105HD models. There are 4 of them. They are polyurethane wheels with braking mechanisms. Each wheel has a load capacity of 250 pounds and have a ¾ inch by 1 inch #10 threaded stem. They have a height of 7.1 inches, width of 1.5 inches, and a weight of 9.1 pounds.

f. Side Panels

The side panels were laser cut to specific lengths using half inch ABS plastic which has yield strength of 8790 psi.

IV. Product assembly

This section shows the assembled TOV with the key components attached. The arrangement of the unistrut array and equipment varies by user and by their needs, so the inside has been left empty. A list of the parts can be seen in Table (3). (The bridle has not yet been designed in the actual project so the assembled drawing does not include the bridle. The wheels have also been omitted because they have not been ordered or been drawn in CAD.)

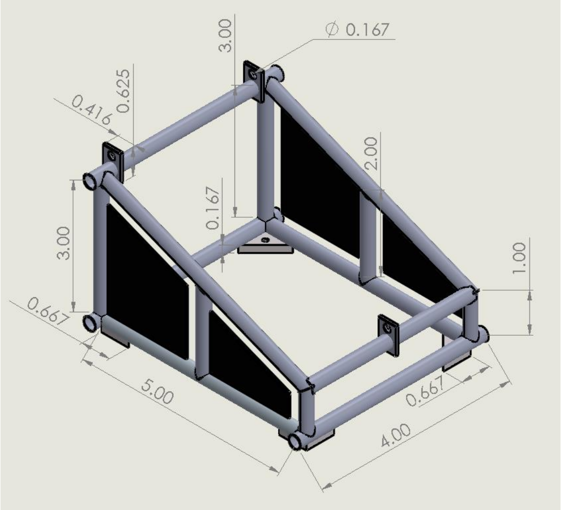

Figure 2: *CAD drawing of the final TOV design. This model incorporated the frame, the side panels, and the feet. Dimensions shown are in feet.*

Table 3: *Part list corresponding to the assembly of the TOV seen in Figure (3)*

Part #	Name	Quantity
1	Frame	1
2	Side Panel	4
3	Feet	4
4	Wheel	4
5	Shackle	3
6	Bridle	1
7	Master Link	1

V. Operation Instructions

This TOV is designed so that it can be rigged to most towing systems for universal usage. These operations instructions will tell the user how to prepare the TOV so that it will be ready to attach to any towing cable and launched off of most boats.

a. Attaching Equipment to Frame

The unistrut attaches to the frame using U-bolts. Depending upon the user's needs, you may want to set up 1-2 layers for equipment. Each components attaches differently. You must refer to that components user manual to read how to mount it. Unistrut it attached to the frame length wise, and more unistrut is attached to those widthwise, depending up where the component needs to be placed. A nut a bolt connects the pieces of unistrut to each other. The assembly of the internal array is entirely up to the user and depends on their needs.

b. Attaching Bridle to Frame

The bridle is attached to the frame by means of lifting shackles. To attach, remove the pin of the shackle so that the cross bar can be opened. Hook the shackle around the connection points on the TOV, close the cross bar, and reinsert the pin. Once this is attached, the TOV is ready to be attached to a towing cable in preparation to be launched.

c. Attaching Side Panels

The side panels come attached to the frame, but if for any reason they become detached, they are simple to reattach. They attach to the frame using simple hose clamps. Attach each side loosely to the corresponding area of the frame. Tighten each hose clamp a little bit at a time so that the load will be applied equally to all of the clamps, minimizing malfunction. These must be tide tight enough so that the panel does not have the freedom to move, this will make the side panels most effective.

VI. Troubleshooting

Although this TOV is designed for high reliability, it is possible that you may experience some troubleshooting. Below is a list of some possible problems you may encounter and suggested solutions. Reference this section if you experience problems operating the TOV.

a. Potential Problems

i. Not Towing Straight – If the vehicle experiences problematic pitch yaw or roll during towing, refer to solution i below.
ii. Wheels not rolling – If the wheels are jammed into place or the locking mechanism is not functioning, attempt solution ii below.
iii. Failure of Hose Clamp – The side panels are attached to the frame via hose clamps. While these side panels do not experience very high forces, there is always a chance that these hose clamps will experience failure. If this occurs refer to section VII. Regular maintenance subsection d. Component replacement.
iv. Failure of Lifting Shackle – The lifting shackle is rated for a weight significantly higher than it is designed to experience. Though if failure occurs, refer to section VII. Regular maintenance subsection d. Component replacement.
v. Fracture of Frame – If a fracture in the frame occurs, the TOV must be taken to a shop to be repaired. It is not recommended to attempt to repair the frame by oneself due to the danger that is caused by welding equipment. Also, one should make sure that most of the full integrity is restored before using the frame again. Professional welding services are recommended.
vi. Failure of Oblong Master Link – The oblong master link is rated for a weight significantly higher than it is designed to experience though if failure occurs refer to section VII. Regular maintenance subsection d. Component replacement.
vii. Failure of Unistrut – The Aluminum unistrut is rated for loads higher than what they are expected to experience during towing. If failure still occurs, refer to section VII. Regular maintenance subsection d. Component replacement.

b. Potential Solutions

i. Visually inspect the bridle and ensure that no twisting or tangling has occurred. If a problematic pitch continues and the vehicle is lower in the front, it is recommended to shorten the front cable of the bridle. If it is lower in the back, it is recommended to shorten the back two cables of the bridle.

ii. Visually inspect the wheels for debris and attempt to remove any debris found. If the debris has caused damage to the component, refer to section VII. Regular maintenance subsection d. Component replacement.

VII. Regular Maintenance

Although this TOV is more than capable of holding the 17 pieces of equipment it was designed for, plus much more, it is always important to perform regular maintenance in order to ensure prevent failure and ensure safety.

a. Pre-Cruise Inspection

Before using the TOV, the user should perform a visual inspection to make sure there are no obvious points of weakness that could be subject to failure.

i. Check the welds to make sure that their integrity remains in-tact and there are no obvious points of weakness or fracture. If a weld does not look in-tact, do not proceed with use in a cruise.
ii. Make sure all of the feet are tightly fastened to the frame and none are wiggling or loose. This will ensure safety during deployment and retrieval.
iii. Make sure all the unistrut that has been bolted on are tightly fastened to the flame and there is no room for movement. This will prevent parts from coming loose underwater.
iv. Make sure that the lock on the wheels remains effective before attaching them to the feet. This will ensure safety when the wheels are attached to the vehicle.

b. Proper Cleaning

The vehicle should be thoroughly cleaned after each use. The vehicle is subjected to marine plant and wild life while cruising under the water and this can dry and cause damage to the waterproofing of the frame or compromise the integrity of the material.

c. Proper Storage

The user should ensure that the TOV is stored in a safe, clean, and dry environment while not in use. Prolonged exposure to harsh environments could compromise the integrity of the waterproofing techniques that were applied to the aluminum or cause corrosion. The user should also not store the TOV with all of the equipment attached. After cruises, the equipment should be detached until the next cruise.

d. Component Replacement

This TOV utilizes mostly off the shelf items.

i. Unistrut Fracture – The aluminum unistrut used on this TOV is easily available off of most metals websites. It is not recommended to repair a failed piece of unistrut, but instead to replace it with a new piece.
ii. Lifting shackle and oblong master link – Both of these components are also universally available at many home improvement stores and websites. If failure or corrosion occurs in either of these pieces, it is recommended to replace with a piece of equal or greater loading value.
iii. Hose Clamps – Hose clamps are also universally available at any home improvement stores. If failure occurs in these components, it is recommended to replace with apiece of equal or greater loading value.
iv. Wheels – Many kinds of lockable wheels are commercially available. If failure occurs in one of the wheels, it is recommended to replace the wheel with the exact model so that there will not be discrepancies among the 4 wheels. If that specific model is not available, it is recommended to replace all of the wheels.

VIII. Required Spare Parts

This TOV does not require any spare parts, though it would be convenient to have a few just in case a component experiences failure. Some of the components, which you may want to keep a back-up of, are listed below.

- Various lengths of Aluminum unistrut
- Lifting shackles of equal or greater load ratings
- Oblong master links of equal or greater load ratings
- Hose clamps of equal or greater load ratings with similar size ranges
- Individual or sets of wheels

IX. Conclusion

In conclusion, proper maintenance and storage will prevent most issues. It is important to perform regular inspections of the TOV especially before use. This is a large product with much weight that could prove hazardous, so it is important to always practice safety procedures and caution while handling and interacting with it. This TOV is designed to support the weight of more than 900 pounds of loading, which is significantly more than the expected loading (SEE IF YOU CAN FIND ACTUAL NUMBER). If the user identifies a problem on the frame, it is recommended that a professional be hired to fix the issue in order to maintain as much of the TOV’s structural integrity as possible. Most of the components not including the frame are commercially available in many home improvement stores and need only be replaced if necessary.

X. References

[1]https://www.metalsdepot.com/products/alum2.phtml?page=pipe&LimAcc=%20&aident=

[2] http://www.mcmaster.com/#3230t26/=11sdux0

[3] http://www.homedepot.com/p/Lehigh-2000-lb-x-3-8-in-Galvanized-Steel-Anchor-Shackle-7202S-6/100315094

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[5]https://www.fastenal.com/products/details/0523403?term=oblong+link&r=~|categoryl1:%22601922%20Lifting%20and%20Rigging%22|~%20~|categoryl2:%22601933%20Lifting%20Hooks%20and%20Attachments%22|~%20~|categoryl3:%22609107%20Master%20Links%22|~

XI. Appendix

The first figure shows the CAD drawing for the unistrut used to mount the equipment in the structure. The second figure shows the specification sheet of the lifting shackle.

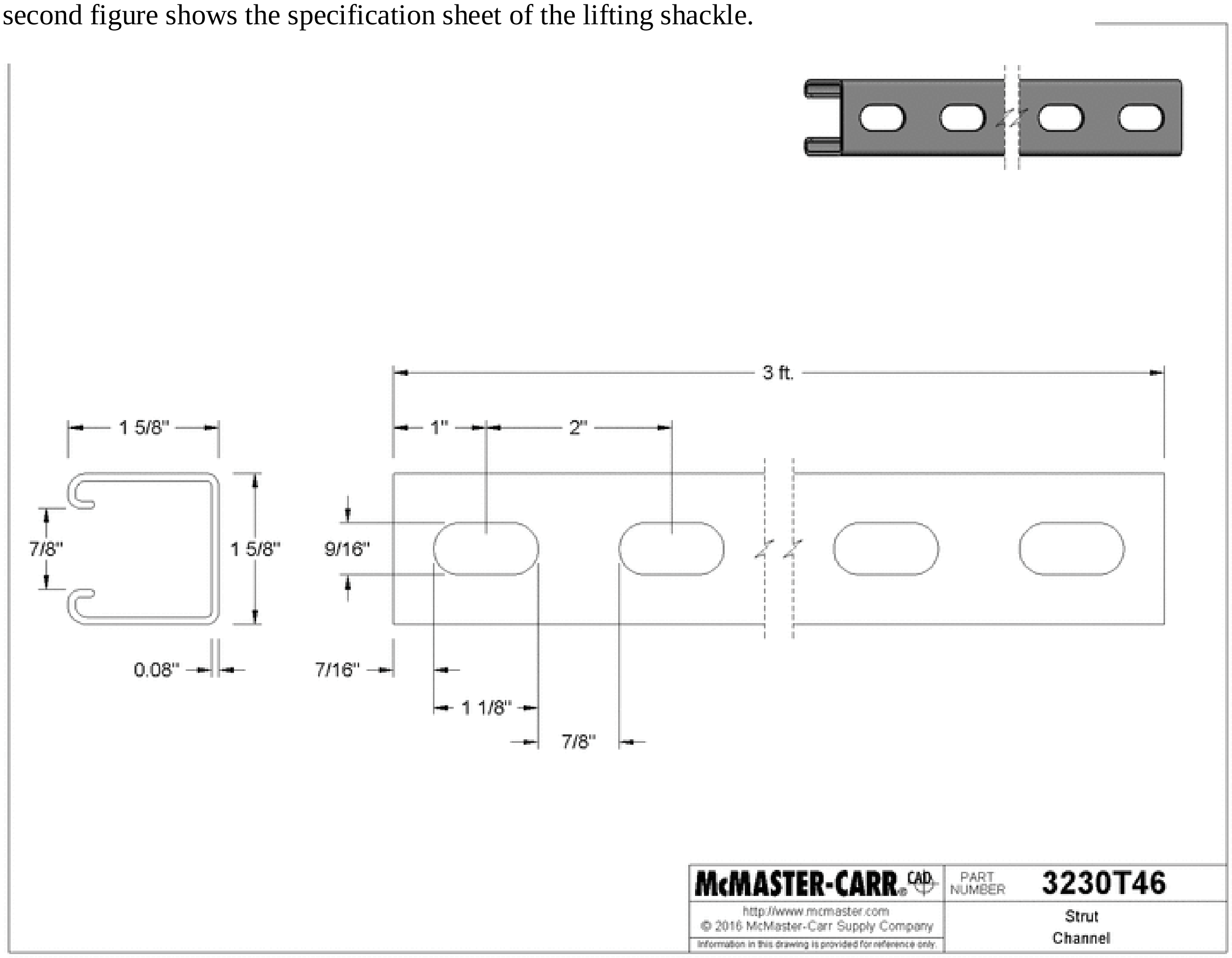
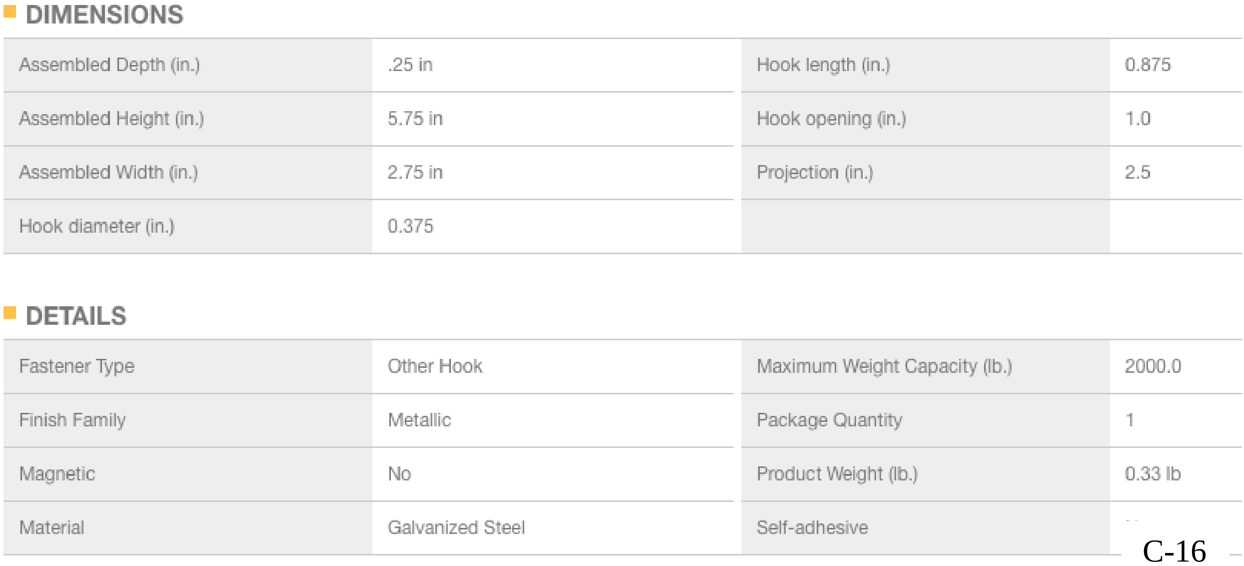


Figure 4: *CAD drawing of the unistrut used for mounting equipment to the frame*



DIMENSIONS

Assembled Depth (in.)	.25 in	Hook length (in.)	0.875
Assembled Height (in.)	5.75 in	Hook opening (in.)	1.0
Assembled Width (in.)	2.75 in	Projection (in.)	2.5
Hook diameter (in.)	0.375		

DETAILS

Fastener Type	Other Hook	Maximum Weight Capacity (lb.)	2000.0
Finish Family	Metallic	Package Quantity	1
Magnetic	No	Product Weight (lb.)	0.33 lb
Material	Galvanized Steel	Self-adhesive	

Figure 5: *Specification Sheet for the lifting shackle*

Appendix D

Design for Manufacturing, Reliability, and Economics

Group 21
New Housing Structure for Deep Sea Equipment

Earth, Ocean and Atmospheric Science

Members:
Team Leader – William Hodges – wrh12
Lead Mechanical Engineer – Chelsea Dodge – cad12e
Financial Advisor – Kasey Raymo – kjr12e

Faculty Advisor:
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Sponsor:
Florida State University's Earth, Ocean, and Atmospheric Science Group
Ian MacDonald
Instructors:
Dr. Nikhil Gupta
Dr. Chiang Shih

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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 (TOV). A TOV is an underwater vehicle dragged behind a boat to survey, in this case, the ocean floor. 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. Through the design process, this group was able to analyze and choose the best model to both aesthetically please the sponsor as well as complete the desired tasks to fix the aforementioned problems. This document contains a detailed description of the manufacturing process, the systems reliability, and the structures economics. Included is a detailed process on how to assemble the newly designed TOV, how it was confirmed that the system can withstand large forces as well as environmental effects, and lastly, the cost breakup of the final design.

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 for making the time to meet with us at least twice a month and helping us on decide on proper analysis techniques and vital design decisions. Additionally, we would like to thank our advisor, Dr. Camilo Ordoñez, for also providing advice on proper testing techniques and aiding during the analysis of the testing results. Finally, we would like to thank Dr. Patrick Hollis for helping the design team perform the stress analysis.

1. Introduction

The Earth, Ocean, and Atmospheric Science (EOAS) group at Florida State University is interested in updating their current aquatic TOV to a smaller, lighter, more modular, levelly oriented, and easily portable design. A TOV is an underwater submersible that it attached via a cable (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 6,600 ft. (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. After brainstorming possible new designs, analysis approach techniques, and performing experiments, a design was chosen. Below is a detailed explanation on how to manufacture the housing, its reliability, as well as its total cost.

2. Design for Manufacturing

Although the final prototype has not been built, based off previous model testing and engineering analysis, the design chosen, the model in Figure 1a, will have an expected necessary performance to complete system operation. Two models were tested and both were able to tow straight without the simulated equipment weight. Adjusting the lengths of the cable attachments of the model allowed the model in Figure 1a to tow parallel to the ocean floor, these lengths will be scaled up for the final prototype. Below is the final models analyzed during the last testing. Both were machined as is, however, both had additional open tubes like that of the back horizontal tubes of Figure 1a for ease of machining.

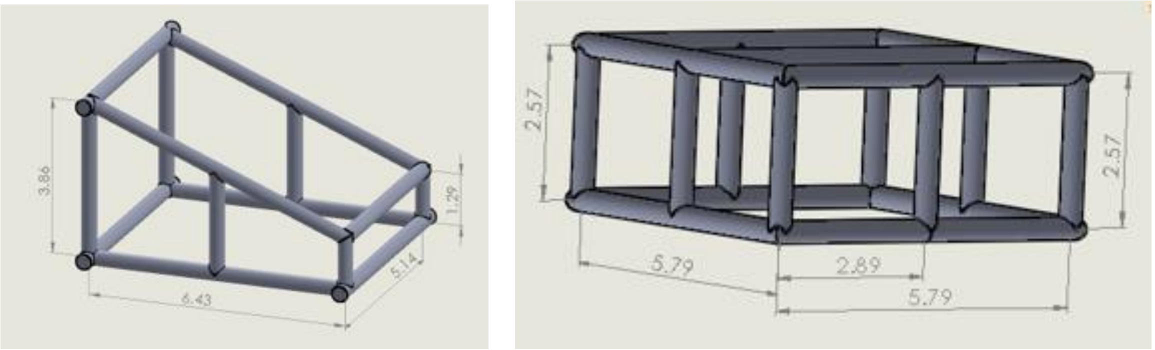

Figure 1a: Final trapezoidal model in inches.   Figure 1b: Final square model in inches.

Figure 1: Final model designs.

Even though the final prototype has not yet been machined, the process for the prototype has been thoroughly thought out and discussed with the project sponsors. Once the final model is machined, with all necessary holes for the zinc-chromate plating, it will be taken to be plated to ensure the prototypes ability to withstand the environmental weathering of the ocean. When returned, the system will undergo internal attachments starting with U Clamps along the inner side of the bars on the housing. Available technicians who are familiar with attachment techniques of the U Clamps will aid us in attachment. When secured, unistrut will be attached using similar metal screws to the U Clamps in various positions which will be measured out to ensure the equipment will have enough space between unistruts. Again, when secured, the equipment will be attached onto the unistrut; previous testing was conducted and showed that as long as the equipment remained within the tether attachment points, the system would remain balanced above water. The equipment is attached to the unistrut with U Clamps and screws depending on the size and weight of the equipment.

Following internal equipment attachment, external equipment will be secured, i.e. side panels and tether points. The side panels will have long holes which will be attached to the housing using hose clamps. The tether will be attached to the housing at predetermined locations machined on the prototype using lifting shackles which can withstand 2000 lbs. There will be three tethers: two attached to the back of the model and one attached to the front. The two attached to the back will be rigid rods while the front one will be adjustable in case an issue with parallel towing occurs.

The total assembly process is projected to take a maximum of three days to include the time it takes to find the best placements of all the inside equipment and attachment tools; it is similar to a puzzle as pieces must be moved around to find its optimum placement and orientation. The amount of attachment tools will be minimized throughout the process, however, its simplicity is key in tool mobility, ease of placement, as well as user friendly operation. Below is the final prototype design:

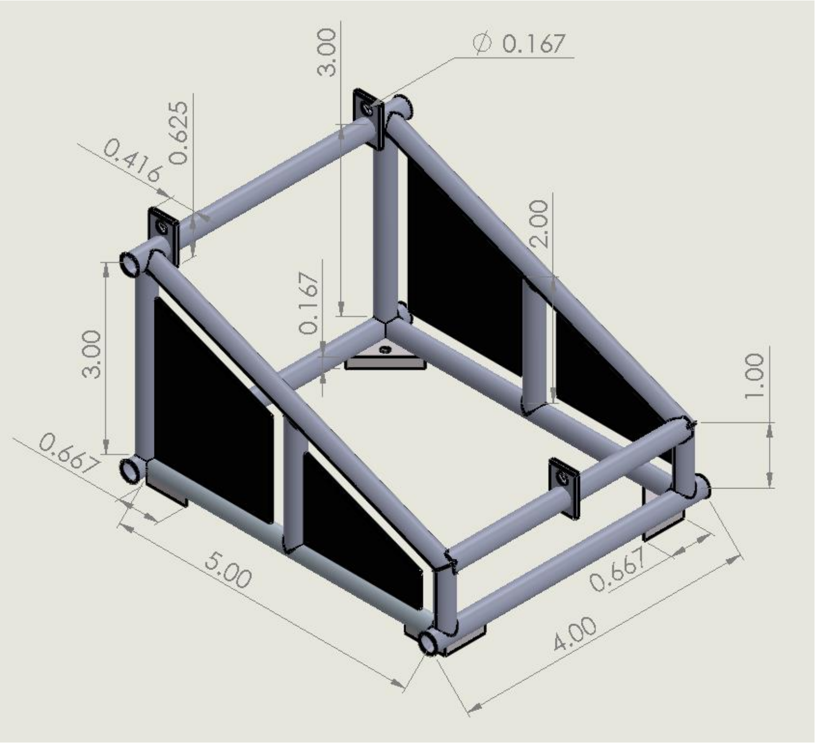

Figure 2: Final prototype, in feet.

3. Design for Reliability

As previously mentioned, the final prototype has not been finished. However, the models have been tested multiple times. During the first testing, the system ran smoothly and no damages or changes occurred to the model. While testing, the model did hit the wall but this did not affect the models shape or cause any damage to the housing. The previous TOV owned by the oceanography department withstood decades of use which leads us to believe that our model will perform similarly; this was confirmed in the stress analysis conducted which showed there will be little to no damage when a large force of 10 times its own weight is acted upon the housing. The main reasons for this analysis was to guarantee all the equipment inside would not deform the housing and to ensure that any large objects, such as rocks, on the ocean floor would not drastically damage the housing. If an issue with deformation did occur, the sponsors have a list of the materials which need to be ordered for the design as well as the CAD files. Therefore, if the model was critically damaged, the sponsors will have the necessary information to solve the issue, and bring the required information to a professional machinist to fix the problem at hand.

Figure 3 is an example of the stress and deformation analysis performed on the final design to ensure that the equipment weight will not deform the model. In this analysis, the equipment and frontal drag loads are applied mid beam and the constraints are applied at the tether locations. As seen on the left in Figure 3, the largest stress is on the front tether location with a stress value of 860 psi. The majority of the model has a stress between 9 and 90 psi, therefore, most of the model does not experience large stresses. Even the largest stress calculated (860 psi) falls well within Aluminum 6061's yield stress of 40,000 psi, which gives a calculated safety factor of 47. The right analysis in Figure 3 is the deformation analysis. It is exaggerated as the largest deformation is 0.0067 in. In regards to this design, which is 5 ft. at its largest and 1 foot at its smallest, the deformation can be considered negligible.

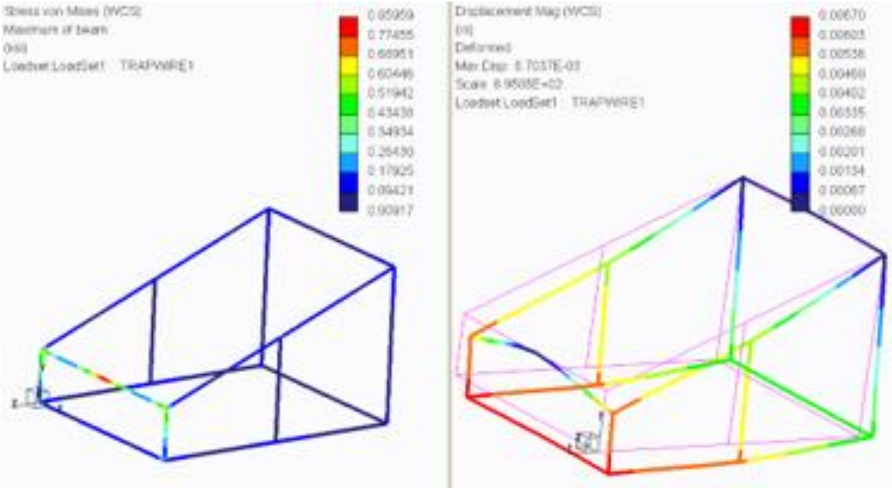

Figure 3: Stress and displacement analysis of final design.

Besides large force impacts, the housing will be coated with zinc-chromate plating to ensure corrosion will not occur. To help with this, the housing should be kept in a dry and clean environment to reduce wear and tear. Additionally, there are external components such as the wheels, hose clamps, lifting shackles, oblong master links, and unistrut that are also subject to wearing down after many uses. Again, the sponsors will be given the list of parts that are ordered in case replacement is necessary.

4. Design for Economics

The overall cost for the prototype will be $1,822.22. This includes the cost of the material, the wheels, the unistrut, and the zinc-chromate plating. The material needed is made up of ten 6ft long and five 4ft long, 3in diameter piping. If anything goes wrong during machining, an extra pipe for each length will be additionally ordered making the total cost of the material $1,016. Four wheels are needed, one for each bottom corner. The system will weigh a maximum of 550 lbs. with all the equipment loaded. Therefore, each wheel with the ability to withstand 250 lbs. is more than enough to hold the entire structure. The total cost of the four wheels will be $54. Although the sponsors already have unistrut, it is made out of steel so to avoid dissimilar metal problems, aluminum unistrut will be ordered. It is estimated that the needed amount will be two 5 ft. long, ten 4 ft. long two 3 ft. long, and two 1 ft. long unistrut channels, bringing its total cost to $312.22. Lastly, the zinc-chromate plating process is estimated to be $440, which is necessary due to the operating conditions being in the ocean. This total cost brings us in under budget by $177.78. For a more visual breakup of the cost, Figure 4 below is a pie chart of the cost break down. Luckily, if any unforeseen issues occur, the project sponsors said that additional funding is available if necessary.

Aside, no similar products are on the market. This is a product made on an individual need basis. Therefore, other prototypes similar to this project do not have information regarding funding or total cost of the project. While some universities have TOVs, the information regarding cost and products used to build the structure is not readily available.

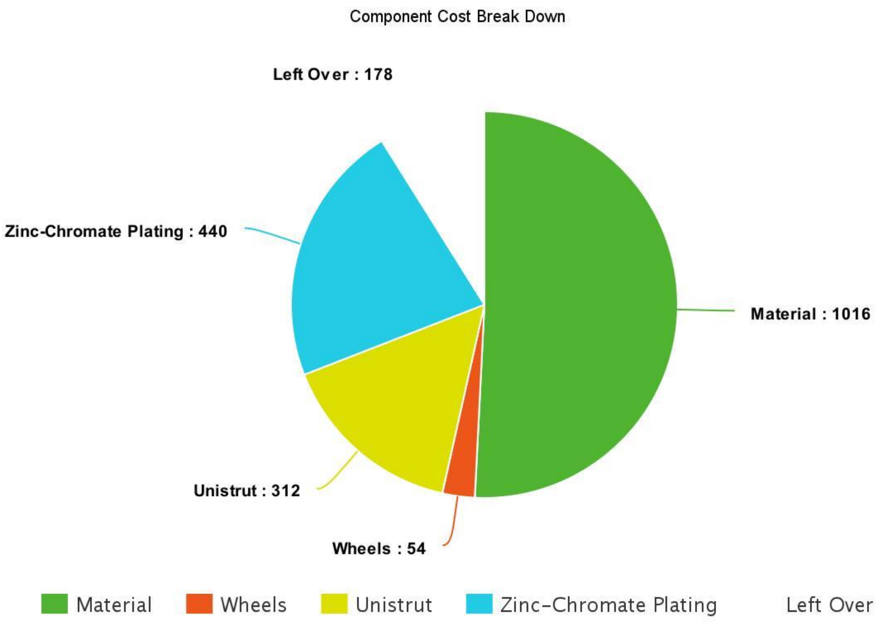

Figure 4: Pie Chart of individual component costs of budget.

5. Conclusion

4

The Florida State University EOAS group is interested in updating their current aquatic tethered operated vehicle to a smaller, lighter, more modular, levelly oriented, and easily portable design. Through the design process, this group was able to analyze and choose the best model to both aesthetically please the sponsor as well as complete the desired tasks to fix the aforementioned problems. The assembly process is complex in that it is similar to that of a puzzle – pieces must be moved around to find the optimum position and orientation to fit inside the model. This process is expected to take a maximum of three days to complete. Upon completion of a thorough stress analysis, it was clear that the system could withstand large forces acting on the housing. Therefore, if the structure runs into something, its ability to maintain structural integrity is guaranteed up to a load of 40,000 psi. Finally, the cost of the system, which includes necessary material ($1016), wheels ($54), unistrut ($312.22), and the zinc-chromate plating ($440), is estimated to be $1822.22.

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[1] http://www.mcmaster.com/#strut-channel-systems/=11s3ncc
[2] http://lccc.galvanizeit.org/report/f24e978ab316ad8ccd9b337855e99860

Risk Assessment
Safety Plan

Project information:

New Housing Structure for Deep Sea Equipment	02/22/2016
Name of Project	Date of submission

Team Member	Phone Number	e-mail
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Faculty mentor	Phone Number	e-mail
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I. Project description:

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- 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 a standardization when analyzing the potential designs.

II. Describe the steps for your project:

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.

III. Given that many accidents result from an unexpected reaction or event, go back through the steps of the project and imagine what could go wrong to make what seems to be a safe and well-regulated process turn into one that could result in an accident. (See examples)

Throughout the project, a majority of the issues could be seen in assembly. However, because we have been educated on proper use of safety equipment such as when glasses, hard hats, ear plugs, and appropriate clothing, hopefully this risk will be highly reduced. Because the current TOV is around 1000lbs, it is expected that the updated design will be heavy as well making transportation a possible accident. Because there is electrical equipment underwater, it is possible that the water proofing of the electrical systems could be damaged and possibly electrocute someone. This could be avoided by checking all electrical equipment before touching and ensuring that all power is off before touching electrical equipment. Vehicle assembly areas are prone to become slippery due to the sea water. This could be avoided through proper footwear. Lastly, the deployment and retrieval of the TOV can cause hazards when lifting off the surface of the boat and placement back onto the boat. If the water is rough, it could cause the system to move unexpectedly, creating a highly stressful and dangerous situation.

IV. Perform online research to identify any accidents that have occurred using your materials, equipment or process. State how you could avoid having this hazardous situation arise in your project.

The University of Mississippi had a TOV where the tether snapped under pressure and dropped the vehicle to the ocean floor. This problem is luckily avoided in our project because the current tether is able to withstand a weight of 900lbs. Our project will be lighter since one of our main design specifications is to reduce the size. Also, we are looking into using a lighter material than the previous galvanized steel, making the structure to be lighter and causing less stress on the tether.

V. For each identified hazard or "what if" situation noted above, describe one or more measures that will be taken to mitigate the hazard. (See examples of engineering controls, administrative controls, special work practices and PPE).

There will be a risk associated with the machining, assembly and transportation of the fabricate vehicle. One of the highest risk with regards to the transportation is found when deploying and retrieving the vehicle. Since it will be deployed and retrieved while on the boat in the water, adversity will come due to the rocking of the boat and the simple fact that the half ton vehicle is hoisted by a single tether. On the boat, each team member will have at least 3 points of contact with a nonmoving part relative to the boat. This mean that at least both feet and one hand will be touching the boat or a piece of the boat that is attached at all times while the boat is in out of the dock. When machining, many unintentional accidents can occure that include, but are not limited to, metal fragments piercing skin or entering the eye, metal members may fall on legs and feet. For these instances, proper attire will be worn, ie. Safety glasses and closed toed shoes. Additionally, particular attention will be paid when moving part and individual surroundings

VI. 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").

Many of these have been addresses in the previous section V. All team members on the boat must be sure that they are in tune with the controller of the winch. This is because if any one of the two (ground worker or winch controller) are not aware of their surroundings and where each person is, sever damage may occur. Preferably, every team member should wear boots that have a strong form over the toes like in steel toe boots. It has yet to be determined if the team members will be doing the machining or a machine shop technician will be responsible for fabrication. If the team members are in charge of fabrication, supervision either a technician or at least another team member will be required. This will ensure that if anything goes wrong, someone who is competent may seek emergency assistance.

VII. Thinking about the accidents that have occurred or that you have identified as a risk, describe emergency response procedures to use.

The ship will be manned with a plethora of seasoned seamen who have done what we will be doing for the first time, for many years. If someone is severely injured while at sea, the vehicle will immediately be retrieved and we will begin our return to land, likely simultaneously. By the time we return, there should be medical assistance at the scene that can treat the injured. For emergencies in a machine shop, we will contact the lab manager and any other pertinent contact that we would have become aware of prior to begin working in the shop.

VIII. List emergency response contact information:

- Call 911 for injuries, fires or other emergency situations
- Call your department representative to report a facility concern

Name	Phone Number	Faculty or other COE emergency contact	Phone Number
		Camilo Ordoñez	(850) 645-1014
		Nikhil Gupta	(850) 410-6201
		Chiang Shih	(850) 410-6321

IX. Safety review signatures

- Faculty Review update (required for project changes and as specified by faculty mentor)
- Updated safety reviews should occur for the following reasons:
  1. Faculty requires second review by this date:
  2. Faculty requires discussion and possibly a new safety review BEFORE proceeding with step(s)
  3. An accident or unexpected event has occurred (these must be reported to the faculty, who will decide if a new safety review should be performed.
  4. Changes have been made to the project.

Team Member	Date	Faculty mentor	Date
Chelsea Dodge	02/22/16	Camilo Ordoñez	02/22/16
William R. Hodges	02/22/16		
Kasey Raymo	02/22/16		