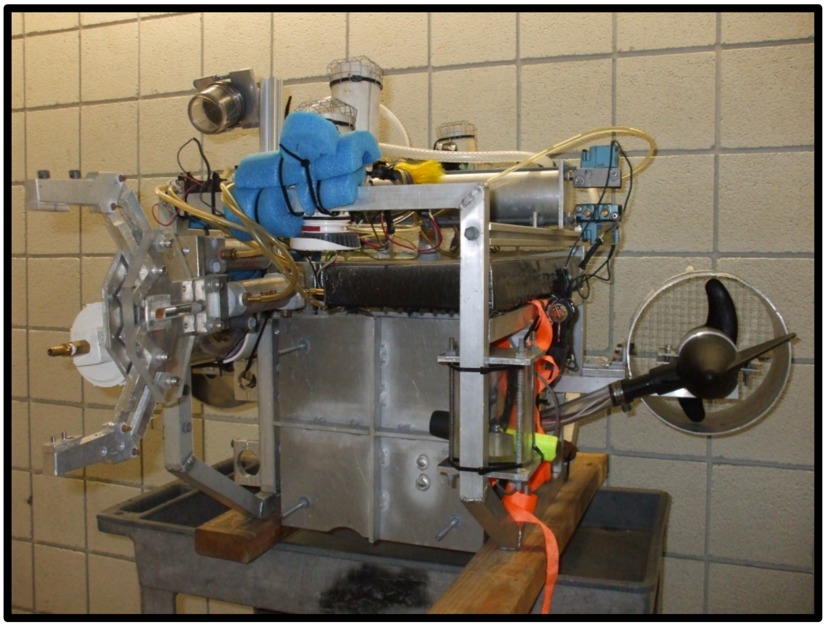
ASME-TECH
Texas A&M University

Aggie Hydronautic Engineering (AHE)

Presents:

MMET-1



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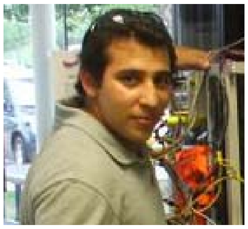

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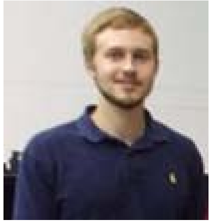

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I. ABSTRACT

The following report describes the design and fabrication of the underwater remote operated vehicle (ROV), “MMET-1”, by the members of Aggie Hydronautic Engineering for the 2011 Marine Advanced Technology Education Center(MATE) ROV competition. The goal of the project was to construct an ROV capable of completing the specified mission tasks with a budget of $2,400. The mission tasks involved the simulated capping of a subsea wellhead failure similar to the Deepwater Horizon accident in 2010. The MMET-1 was designed to exceed specified operating pressures and requirements. It is equipped with 4 manipulator arms mounted to a rigid fully welded Aluminum frame. Each arm features a unique end effector actuated by pneumatic cylinders designed to perform a specific task. Pitch motion is performed by two 1100 gallon per hour bilge pump motors fitted with props. Yaw motion is performed using two 30lb thrust motors mounted horizontally on either side of the MMET-1. Depth positioning can be controlled by filling and emptying a dynamic ballast tank with water. A simple system utilizing small propellers is used to suck biological samples harmlessly into a collection basket. The pilot of the MMET-1 utilizes 2 driving cameras and a board of toggle switches hardwired to each component to provide simple, durable, and trouble free operation. Aggie Hydronautic Engineering is a small team of dedicated engineering professionals that is dedicated to providing cost effective solutions tailored to unique subsea technical problems.

II. PHOTOS/CAD DRAWINGS/CAD MODELS

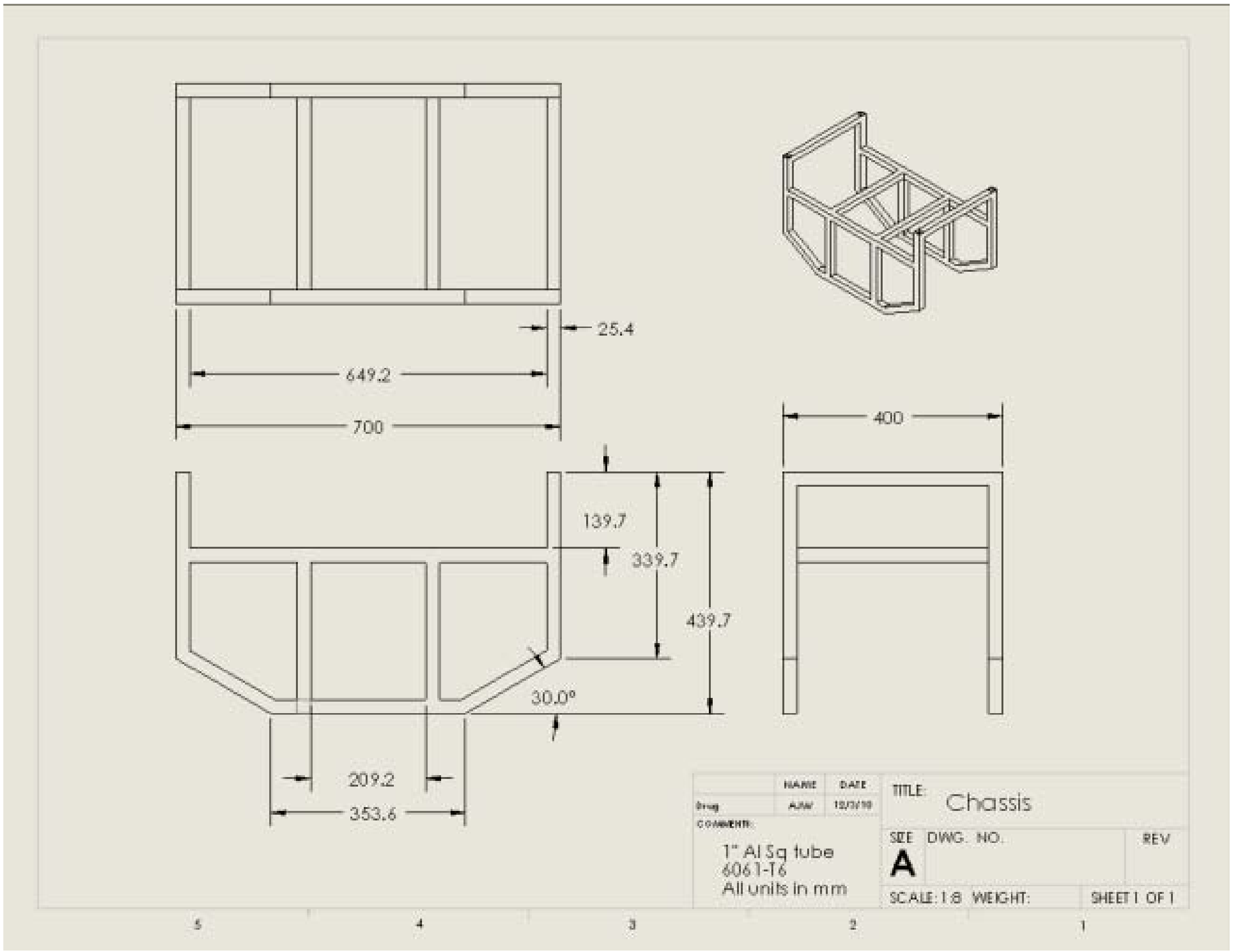


Figure1: Chassis Drawing

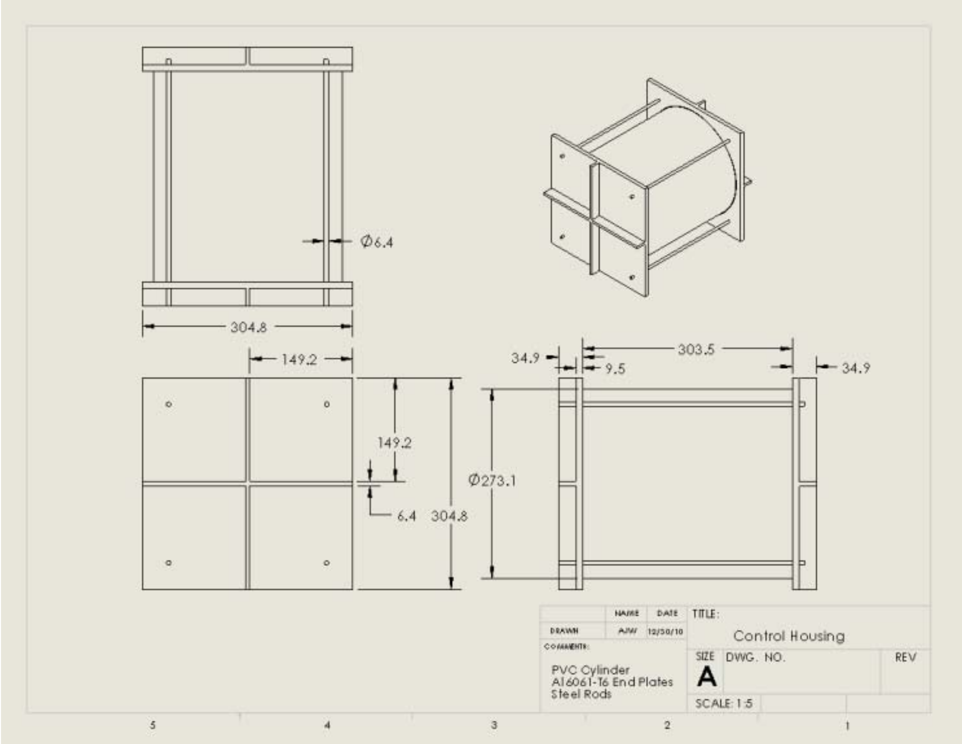


Figure 2: Control Housing Drawing

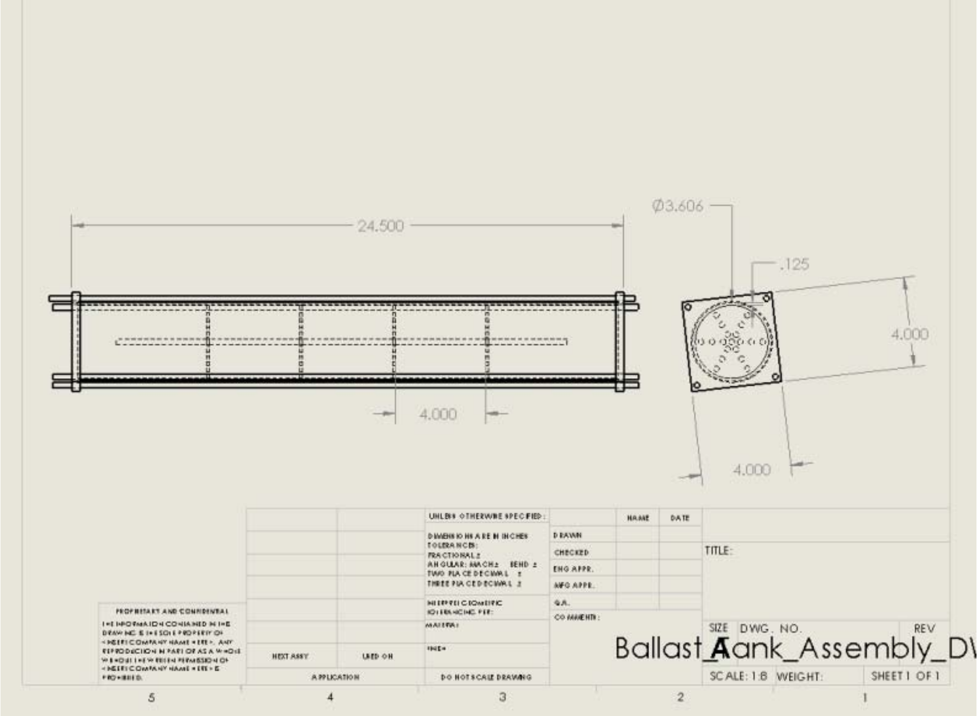


Figure 3: Dynamic Ballast Tank Drawing

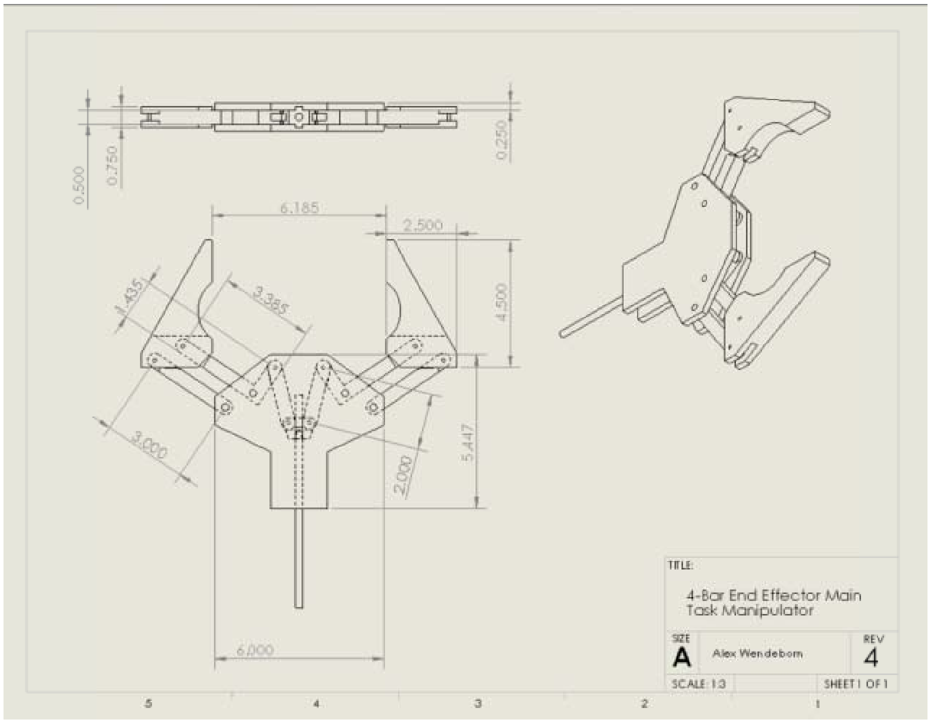


Figure 1: Main Task Arm End Effector Drawing

Figure 5: Fabricating 40.64cm stroke pneumatic actuator

Figure 6: Tool arm and Anchor arm under construction

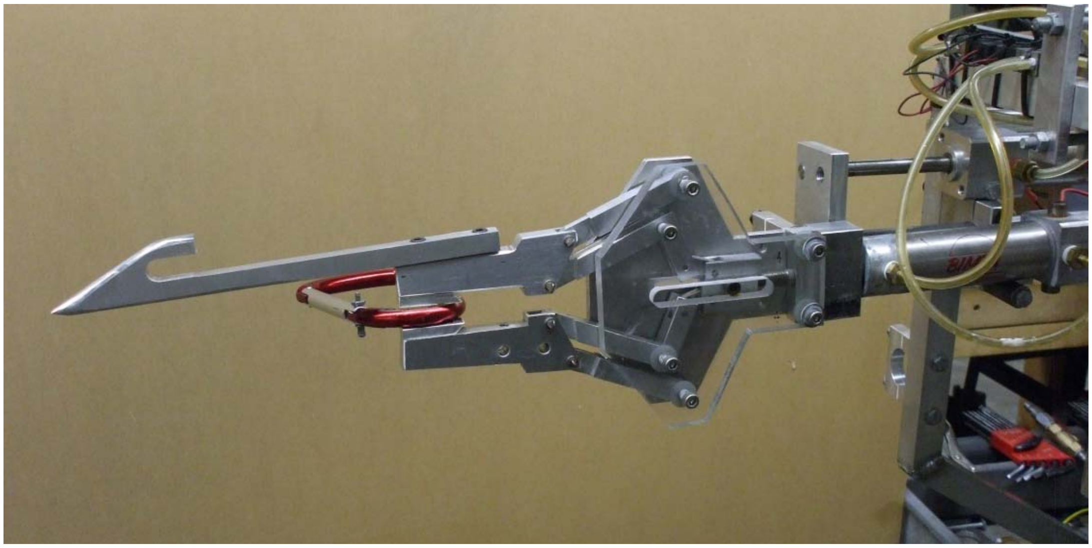


Figure 7: Complete Main task manipulator arm as used in regional qualifier

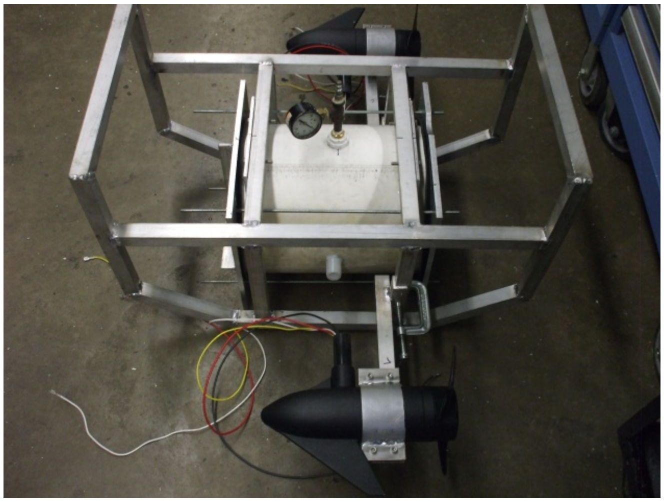


Figure 8: Control Housing Complete, Fitting Motor Mounts

Figure 9: Completed Chassis

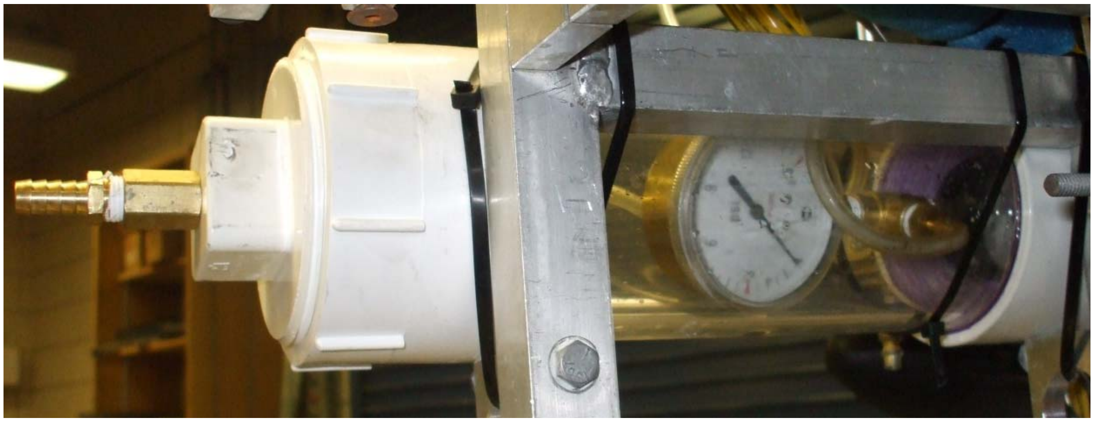


Figure 10: Pressure/Depth Gauge

***All machining, welding, fabrication, and assembly was performed by members of Aggie Hydronautic Engineering

Figure 2: Turning/Drilling motor couplings

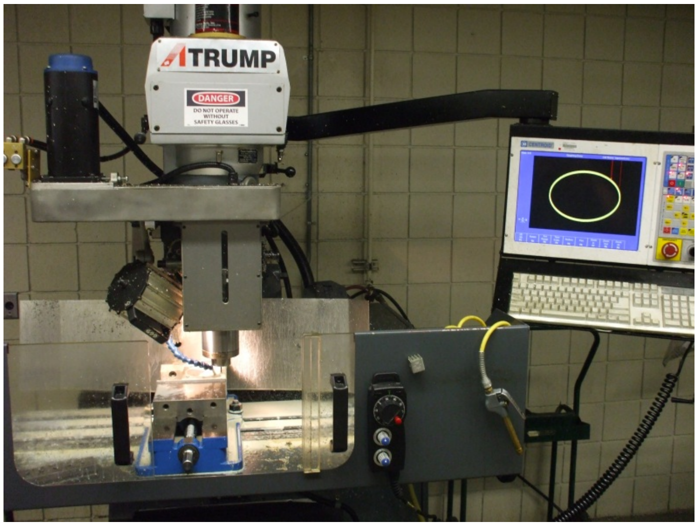


Figure 12: Milling O-ring grooves in end caps for dynamic ballast tank on Trump/Centroid CNC

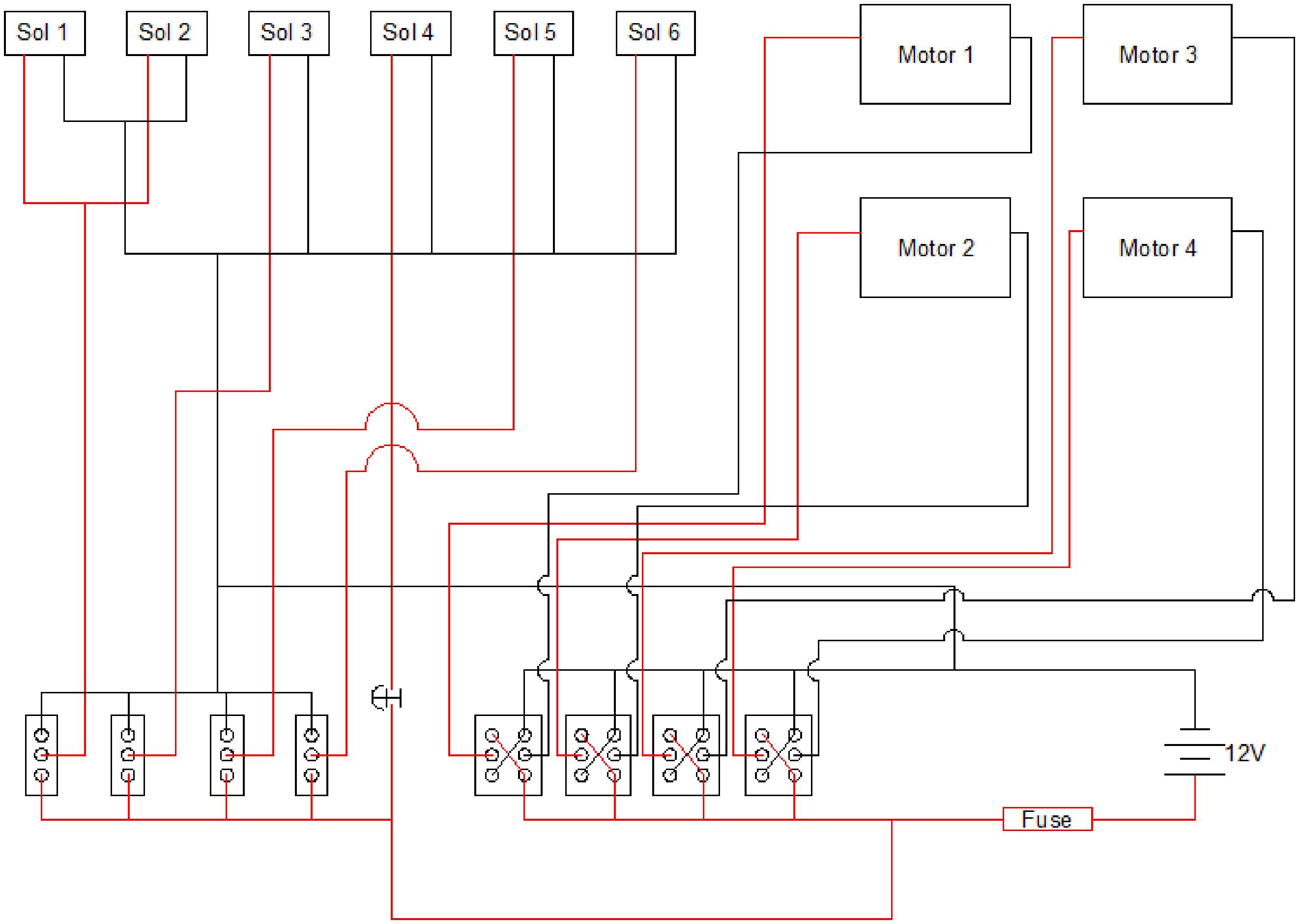
Figure 13: Milling Ballast tank mounts

III. BUDGET/EXPENSE SHEET

Raw Materials and Hardware Total=	$569.68
Control System and Electronic Total=	$2,358.51
Labor Value Total=	$14,980.00
Sponsorhip and Funding Total=	$2,700.00
Total Value	$17,908.19
Total Cost (Actual Expenditures)	$2,640.19
Remaining Funds	$59.81

***for a detailed budget/expense report see Appendix A

IV. ELECTRICAL SCHEMATIC



V. VEHICLE SYSTEMS/DESIGN RATIONALE

Chassis

The MMET-1 chassis is constructed from one inch 6061-T6 aluminum square tubing with one-eighth inch wall thickness and fully welded joints. Welding was the favored method of joining, because welded joints offer higher rigidity, lower weight, equal strength, and a more streamlined design in comparison to mechanical joining methods. The overall dimensions are70x44X40 centimeters. 6061-T6 aluminum square tubing was the material of choice based on its abundant supply, strength, low cost, and robust weldability. Aluminum offers a lower weight in comparison to stainless steel, which is crucial for ease of transportation. Square tubing was chosen, because it offers flexibility in mount design for each component. The chassis was the foundation for the design process. Its design offers flexibility for change in components (see Figure 14).

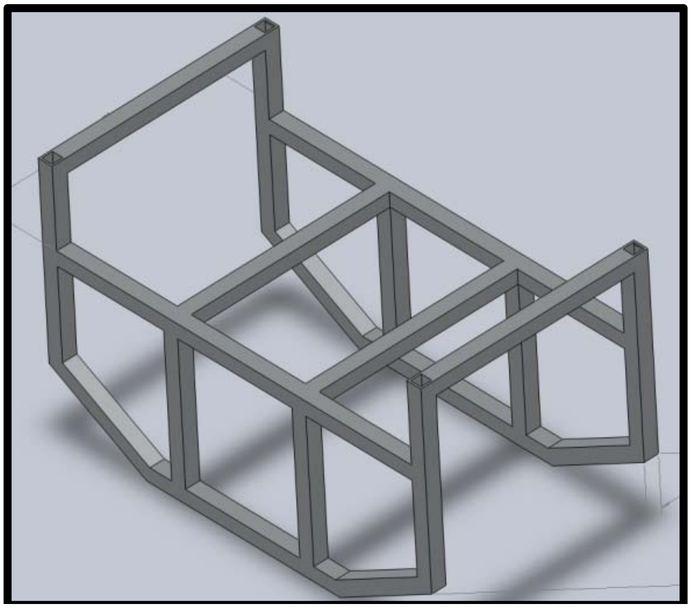


Figure 34: Chassis Solid Model

Note: Each joint was welded by a MMET-1 member using a Gas Tungsten Arc Welder

Propulsion

Two thirty pound thrust trolling motors drive the MMET-1's forward, aft, port, and stern movements. The motors run on twelve volts of DC power. While running two motors simultaneously, the system draws less than fifteen amps of current. Each motor is placed just rear of the vehicle's center, 90 centimeters apart, for weight balance and a zero turn radius. Trolling motors were chosen, because they were accessible, offered the power required to drive the vehicle, came in a waterproof housing, and required no machining of the motor housings. The trolling motors were modified by adding extra O-rings at the front and rear seal to create water tight seals which would function at increased depth (see Figure 13). Each motor is mounted on welded aluminum brackets which have been bolted to the chassis and surrounded by an aluminum shroud for safety precautions and prop protection. The motors are connected to the control housing with rubber tubing which is clamped in place by a hose clamp, creating a waterproof seal. Four bilge pump motors control bow and stern pitch, as well as up and down movements. These are mounted in aluminum brackets with PVC shrouds around the props.

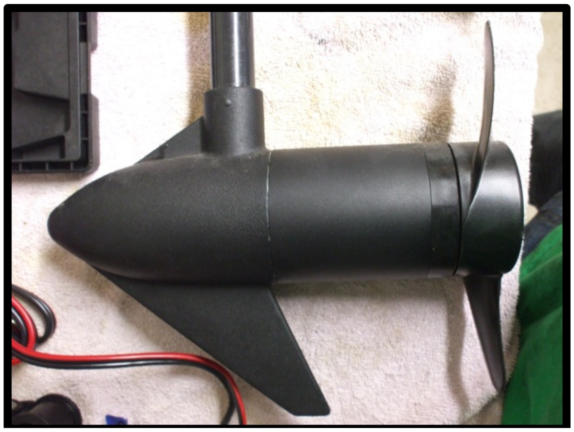


Figure 15: 30lb Thrust Trolling Motor

Figure 16: Trolling Motor sealing surfaces

Note: Each motor was purchased. All mounts and guards were machined and welded by a MMET-1 team member.

Buoyancy

The MMET-1 comes equipped with two buoyancy systems: static and dynamic buoyancy. A static buoyancy system is a buoyancy system which does not change. A dynamic buoyancy system is a buoyancy system which is able to change the amount of buoyancy it provides. Rather than rely solely on static buoyancy combined with up/down motors for depth control, a dynamic buoyancy system has been added to maintain neutral buoyancy at different depths. The MMET-1 chassis is weighted to maintain neutral buoyancy at forty feet of depth with the dynamic tank half full of water. This is to allow for buoyancy to be added or subtracted as needed.

Static

The static buoyancy system is crafted from two part polyurethane foam coated with marine epoxy. This system is essential for providing the MMET-1 with neutral buoyancy at forty feet (12.19 meters) of depth. The volume of the static buoyancy system required for neutral buoyancy at forty feet (12.19 meters) of depth was calculated using the weight of the ROV, the density of the foam, and the density of water. Extra buoyancy has been added to compensate for weights which have been added to balance the ROV. The polyurethane foam was the preferred material because of its closed cell structure, and its compressive strength of 655 KPa**.** This rates the foam to 56.44 meters of depth **[(655KPa-101.3KPa)/9.81KN/m^3]**, offering the ability for repeated use at the tasks' forty feet (12.19 meters) of depth. A plywood mold was constructed to form the desired shape. The foam was then mixed, poured, and allowed to cure for forty-eight hours (see Figure 17). Once the foam was fully cured, it was carefully removed, and sanded to a flat, smooth finish. Finally, it was coated with colored marine epoxy to provide it with a glossy appearance. The foam was then mounted to the top of the chassis, and secured in place underneath 80/20 aluminum T-slot running along each side of the ROV. This location was chosen so that the center of gravity would be low on the ROV to prevent rolling.

Figure 17: 2-Part Polyurethane static buoyancy in mold

Dynamic

The dynamic buoyancy system consists of a three inch aluminum pipe capped on each end (see Figure 8**)** capable of displacing 1,853.33 cubic centimeters of water. Four solenoids control the system, and a venturi tube creates the vacuum necessary to pull the water through the solenoids into the tank. One solenoid allows air into the chamber, a second solenoid opens a vent to allow water in, a third solenoid vents the venturi, and a fourth solenoid allows air into the venturi. When the third and fourth solenoids are used in unison, a vacuum is created. After a vacuum has been placed on the chamber, the second solenoid is opened to allow water into the chamber. To remove the water from the chamber, the first solenoid is opened to allow air in. Then the third solenoid is opened to allow the water in the chamber to exit through the venturi. The initial design relied on the pressure of the incoming water to fill the tank, but the water pressure alone was not enough to force air out of the tank. This necessitated the addition of the venturi to remove the air from the chamber (see Figure 19).

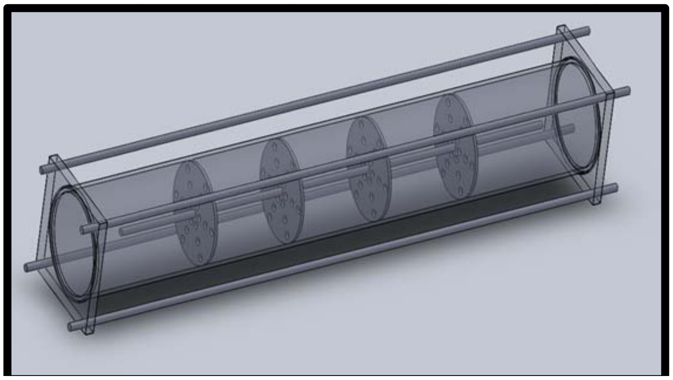


Figure 18: Dynamic Ballast Tank Solid Model

Figure 19: Dynamic ballast tank

Manipulators

Due to the variety of tasks required to be completed for the mission, the MMET-1 comes equipped with three different manipulator arms. Three arms offer the ability to complete the tasks subsequently in the fifteen minutes allotted without resurfacing, as well as reserve modes of task completion in the case of a single system failure. Each arm is driven by pneumatic actuators. While hydraulic actuators offer more power, they were not a logical choice due to their substantial weight and cost. Pneumatic actuators were also an obvious choice, because they could tap into the air system which operates the dynamic buoyancy of the MMET-1. Each pneumatic actuator is controlled by a solenoid.

Tool Arm

The anchor arm is machined from 6061 aluminum and Lexan, and includes two pneumatic actuators: one for clamping, and one for extension. 6061 aluminum was the material of choice for the linkages, jaws, and support plate due to its low cost, machinability, high strength, and corrosion resistance. Lexan was chosen for the front plate of the arm because of its corrosion resistance, strength, and low friction. Friction may cause failure due to the seizure of moving parts. This risk has been reduced by the low friction coefficient of Lexan, aluminum, and the placement of nylon washers between all moving parts. Its aluminum jaws have been fitted with two pins to secure a carabineer until it has been attached to the riser pipe's U-bolt (see Figure 9). The pins also prevent the PVC ring attached to the Velcro from slipping out of the tool arm's jaws. The tool arm is located on the front right of the vehicle 25 centimeters above the anchor arm.

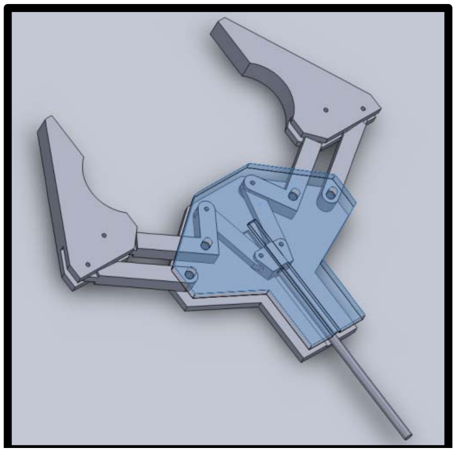


Figure 4: Main Task Arm Solid Model

Figure 16: Tool arm and Anchor arm under construction

Anchor Arm

The anchor arm has the same construction as the tool arm, but its jaws have been machined to fit around the shaft of the well head. The anchor arm is located on the front lower right of the vehicle. This location was selected so that when clamped, the tool arm is in position to remove the Velcro, with minimal camera view interference by the well head.

Capping Arm

The capping arm has the same construction as the tool arm, but is fitted with a one quarter inch drive pneumatic ratchet in addition to its clamping jaws. The pneumatic ratchet was added to drive the mechanism which clamps the cap onto the open well head.

Note: All machining was completed by members of the MMET-1 team. Actuators were purchased.

Payload

Carabineer

A modified carabineer will be used to remove the riser pipe from the well head. The carabineer has been ground flat and drilled so that it can be placed in the tool arm's jaw pins. The stock spring which operates the carabineers latch has been replaced with a spring of less force, lowering the level of force required to attach the carabineer to the U-bolt of the riser pipe.

Well Head Cap

A hex head toggle bolt with a gasket will be used to cap the well. A magnet will keep the bolt attached to the ratchet until it has been lowered into the well head and tightened. The wings of the toggle bolt will be used to force the gasket against the well head to seal the well.

Specimen Collection System

The specimen collection system is located at the rear of the MMET-1's chassis. It consists of a cage to hold the specimen, a folding door to contain the specimen, and a motor to blow the specimen into the cage. The motor is made from a bilge pump which has been mounted at the rear of the control housing. A shroud has been placed around the prop for safety precautions.

Pressure Gauge

Depth is measured with a pressure gauge which was purchased and then waterproofed. The waterproofing was completed by threading the orifice of the pressure gauge into a PVC cap, then sealing the cap to an acrylic tube with epoxy. The other open side of the acrylic tube was then capped with a threaded plug (see Figure 20).

Syringe

A two hundred and fifty milliliter syringe is installed at the rear of the MMET-1, just to the right of the pressure gauge. The syringe size was chosen so that it has the capacity to draw well over the one hundred milliliter sample required for full points. A pneumatic actuator controlled by a solenoid operates the syringe.

Umbilical

The umbilical provides the electrical power for the MMET-1 to conduct its tasks. The design of the umbilical is crucial in that it can hinder movement depending on placement and the amount of drag produced by its surface area. For this reason, the diameter of the umbilical needed to be minimized as much as possible. The MMET-1 provided two mounting points, the top plane and the back plane. After looking over the tasks, it was determined that yaw was the most important motion that MMET-1 needed to conduct to accomplish the tasks. The umbilical was mounted in the center of the top plane of the MMET-1 to allow for improved yaw. The umbilical also needed to be free of rough and non-uniform surfaces to reduce drag. This was accomplished by packaging all of the electrical and signal cables into a 16mm diameter garden hose. The electrical consist of a positive cable and a ground cable for main power to the entire system. The signal wire is comprised of two cat5 cables. The only item not packaged inside of the umbilical is a pneumatic airline, which feeds the entire pneumatic system for MMET-1. The final design and build of the umbilical satisfied all the requirements that were set out. However, due to long lead times for acquiring components of the adriuno control system, a second umbilical had to be built specifically for the qualifier at NASA Neutral Buoyancy Lab on April 30th. The second umbilical consisted of ten 14 gauge wires for parallel circuitry for six motors and one cat5 for six solenoids. Both umbilicals provided the capability of being removed from the MMET-1.

Control System

The control system will consist of a mega arduino 2560, two pro 328 arduinos, a 2x5 sabertooth motor controller, and a 2X12 sabertooth motor controller. The mega arduino will provide the controls for all of the ROV with the two pro 328s comprising the redundant control system in case of failure of the main arduino. The arduino provides variable speed control through the sabertooth motor controllers via the digital outputs of the arduino. The higher end 2X12 sabertooth provides power to the two horizontal Minkota trollyings, as these motors demand higher amperage at around 10 amps peak. The 2X12 sabertooths accomplish this need by providing 12 amps under continuous usage and 25 amperes peak for short moments. The 2X5 sabertooths provide 5 amperes while continuously running and 10 amperes peak for short moments. The 2X5 sabertooths run the lower demanding 1200 GPH bilge pump motors for vertical movement. All of the solenoids that are being operated onboard the MMET-1 will be triggered via solid state relays. These solid state relays will receive power from the arduino allowing the entire system to operate off the mega arduino. Since the power given by MATE is 48 volts and the system runs on 12 volts, converters were required to step down voltage.

A 48 to 12 volt converter will be utilized first to get power to motor controllers, arduinos and solid state relays. A second converter from 12 to 24 volts is utilized to provide power to six other solenoids that require higher voltage. The proposed system is under construction as long lead times halted construction of the intended system before the qualifier. For this reason a temporary system had to be built to qualify for the international competition.

The temporary system consisted of toggle switches attached in parallel to provide the same voltage for all motors and solenoids. The toggle switches are two directional allowing for the current direction to be reversed, which allowed for forward and reverse control of each motor. The solenoids were run off one direction toggle switches, since the direction of current did not matter for the solenoids. The toggle switches were organized into two categories, which consisted of driver controls and payload controls. The two types of switches were placed into two separate project boxes obtained from RadioShack. Both the boxes are attached in parallel to the main leads for power. The positive main lead contained a 40 amperage fuse to satisfy the safety regulations outlined by MATE in the build specifications manual.

The two control methods make their connections and house the critical components in a container located onboard MMET-1 to prevent contact with water. The housing consists of 10” diameter by 305mm PVC tubing section, two 305x305x6.35mm aluminum plates, four ¼” X 20 all threads, two gaskets, and eight nuts. The two aluminum plates had the PVC tubing cross section removed via CNC machine. The gasket material is overlaid on the plates and compressed on the PVC housing by the all threads and nuts. The housing has passed testing of 40 psi to verify that the container can hold a watertight seal. The container also has built in heat sinks to allow for the heat from the control system to be transferred to the aluminum plates, which will then dissipate the heat to the surrounding water. The control housing provides the system with a means to lower operating temperature and isolate the system from water to allow the MMET-1 to operate at a maximum depth of 30.5 meters.

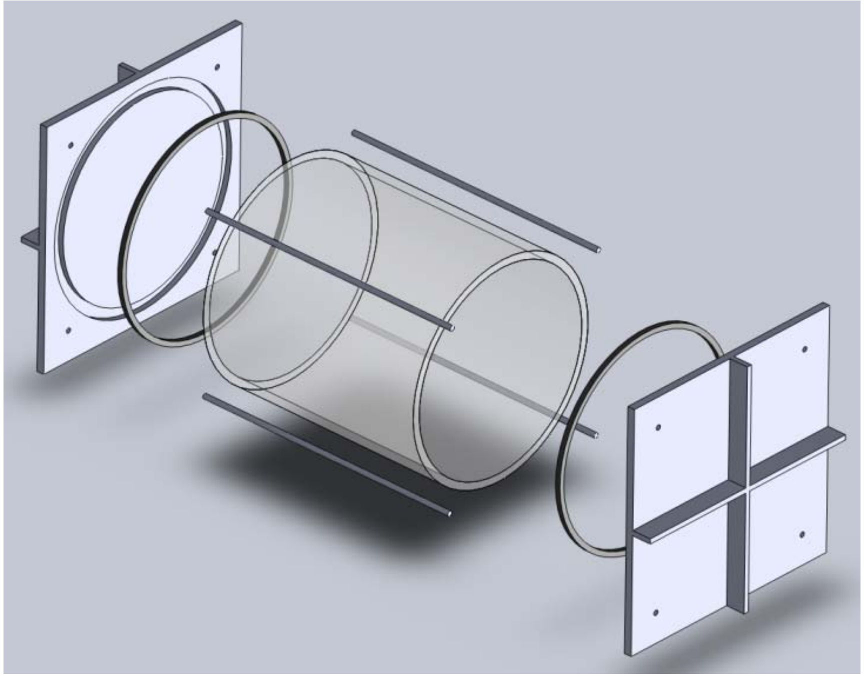


Figure 20: Control Housing Exploded Solid Model

Camera System

The MMET-1 is equipped with five cameras to provide all necessary perspectives to operate the vehicle, and complete the tasks in the allotted fifteen minutes. Four cameras consist of a SWANN security camera in a waterproof housing. This was an obvious design choice, because these cameras could be purchased and waterproofed at a much lower price than a dive camera. The drive camera is a dive camera purchased from Lights-Camera-Action, rated for 30 meters of depth. This camera was chosen for its viewing quality and reliability in the case of failure of the waterproof housing of the other cameras.

Drive Camera

The drive camera is located at the front of the control housing centered on the chassis. This location was chosen so that the chassis can be seen in the cameras peripherals, offering a perspective of where the vehicle is in comparison to the task. This location also offers a view of each of the manipulator arms. If the waterproof housings of the other cameras fail, the tasks can still be completed with the drive camera.

Tool Arm Camera

The tool arm camera is mounted on an 80/20 aluminum T-slot mounted on the chassis 25 centimeters over the tool arm. The 80/20 aluminum T-slot offers the ability to adjust camera height. Its location was selected to provide a top perspective of the tool arm and its position in relation to the task. The housing is constructed from polycarbonate, with all seals epoxied for waterproofing.

Capping Arm Camera

The capping arm camera is constructed in the same manner as the tool arm camera. It is mounted on the chassis over the capping arm. This location offers a top perspective of the capping arm's position in relation to the task.

Specimen Collection Camera

The specimen collection camera is located at the rear of the control housing, underneath the static buoyancy system. It is aimed downward to provide a perspective of the specimen collection system, so that the MMET-1 can center its collection system over the specimen. Its housing consists of a three-and-one-half inch diameter acrylic tubing capped on each end with aluminum plates. The camera was waterproofed by an O-ring seal. A machined groove in the aluminum plate allows for an O-ring to be placed between the acrylic tube and the aluminum plate. Acrylic was chosen for its optical clarity.

Gauge Camera

The gauge camera is located at the rear of the MMET-1, underneath the static buoyancy system. This location offers a view of the pressure gauge for depth measurement, and the syringe for water sample collection. The gauge camera is designed in the same manner as the specimen collection camera.

Task Completion

Task 1

Task 1 involves removing the damaged riser pipe from the well head. A line must be attached to the U-bolt connected to the riser pipe, a cut must be simulated by removing the Velcro strip connected to the riser pipe, and the riser pipe must be removed from the area.

To complete this task, the carabineer will we placed in the jaws of the tool arm prior to the start of the mission. The MMET-1 will then submerge, and attach the carabineer to the U-bolt by pressing the carabineer's latch through the U-bolt's edge. The MMET-1 will release the carabineer, and align the tool arm's open jaws with the PVC ring attached to the well head. Once this has been aligned, the anchor arm will extend to the well head and close its jaws around it. The tool arm will then close its jaws over the PVC ring. To remove the Velcro, the anchor arm will retract, and the tool arm will extend. This will shear the Velcro. The MMET-1 will then release the well head and PVC ring, and withdraw from the site. The riser will then be removed by pulling the line attached to the carabineer at the surface.

Task 2

Task 2 requires the MMET-1 to cap the well head after the damaged riser pipe has been removed. A cap must be designed and constructed prior to the competition, it must be carried to the well head and mounted, and it must prevent the oil from flowing once mounted. Full points are not awarded if the oil resumes flow during the mission. Task 2 may begin only after Task 1 has been completed.

Prior to the start of the mission, the cap will be attached to the ratchet mounted on the MMET-1's capping arm. After Task 1 is completed, the MMET-1 will place the cap over the well head. The pneumatic ratchet connected to the capping arm will then tighten a toggle bolt at the top of the cap. The wings of the toggle bolt will catch on the inside lip of the well, and a gasket will seal off the top of the well as it is tightened. Once this is done, the MMET-1 will lift away from the well, disconnecting the bolt from the ratchet.

Task 3

Task 3 is the sampling of water at a specified depth for oil. Before the task can be attempted, a chart must be interpreted to determine the proper depth at which to sample. The basis for scoring are the proper evaluation of the chart, accuracy of depth reading at the sample site, collection of the sample, the volume of the sample, and the return of the sample to the surface.

This will be the last task conducted last, because it may require changing. The chart will be interpreted, and then the MMET-1 will proceed to the specified depth. Once the proper depth has been reached, the pressure gauge will be consulted for a verification of depth. The MMET-1 will then drive the syringe mounted on its rear into the sample bucket. A sample will be drawn into the syringe by retracting the actuator connected to the syringes plunger. The sample will be kept in the syringe until the MMET-1 surfaces.

Task 4

Task 4 is the collection of biological samples from the seafloor. This task requires a sample to be gathered from three different types of organisms. Scoring is based upon the ROV removing each sample from the seafloor, having control of the sample, and returning the sample to the surface.

After Task 1 and Task 2 have been completed, the MMET-1 will proceed to the biological samples. The gap between the sample collection blower motor and the sample collection cage will be centered over the sample. The MMET-1 will drop to the seafloor, and then initiate the sample collection blower motor. The sample will be carried through the sample collection system's one way door, and into the sample collection cage. This will be done for each of the biological samples. The samples will remain in the sample collection cage until the mission has been completed.

The Design Process

The 2011 M.A.T.E. ROV Competition was first presented to Texas A&M ASME-Tech in September 2010. Rudimentary design concepts, budget capabilities, and work schedules were discussed during general meetings throughout November. An ROV team was formed during November, and ROV specific meetings began to be held. The first meetings covered chassis, buoyancy, control system, and manipulator design. Materials, dimensions, joining processes, and structures were discussed. In December, the team members were assigned to specific areas: chassis and components, electrical and controls, payload and propulsion, and construction.

During the holiday break, the task props were constructed and meetings were held covering: payload tools - location and materials; control system housing - material and design; time line - construction goals, practice time, and semester schedules. In January, the chassis was constructed, the static buoyancy system was molded and finished, and linkage for the manipulator arms was machined. The remaining components for the tool arm were machined in February, and the tool arm was assembled. The ballast tank for the dynamic buoyancy system was cut to length and turned, its end caps were machined, and the trolling motors were purchased. During March, the control housing was cut to length and turned, its end caps were machined, and the control housing, motors, buoyancy systems, tool arm, and tool arm camera were installed. Buoyancy was adjusted in late March after experimental testing, and mission testing began for the regional qualifier. Construction and design of the remaining manipulator arms, payload tools, controls, and remaining cameras continued through April and May. The regional qualifying competition was completed in mid-April.

VI. CHALLENGES

Access to machine shops was a challenge during construction of the MMET-1. Although there are several machine shops on campus, most are unavailable for use by anyone outside of their department and are open for only several hours each weekday which often overlapped class times. At first, the solution to this was working in one campus machine shop during gaps between classes, but the shop only had two mills which were often in use for other projects. The eventual solution to this problem was working in a machine shop after hours while supervised by a team member who worked as a shop tech. This allowed consistent and weekend access to machine shops.

A challenge faced during testing was getting the manipulator arm to move forward and backward. The force generated by the pneumatic cylinder was not strong enough to fully extend or retract the arm, so as a solution we switched to a larger diameter cylinder. After the cylinder was changed out, the arm would extend without problem, but once extended it would not retract. This was fixed by placing a Delrin roller underneath the arm as a support which would cause minimal friction so that less of its weight was put on the extension cylinder.

VII. TROUBLESHOOTING TECHNIQUES

The most extensive troubleshooting was done to fix the control system so that it would work while the ROV was submerged. The controls worked when the ROV was dry, but when it was placed in water each individual switch would trigger all motors instead of just the one it was connected to. To troubleshoot the control system a multi-meter was used to ensure continuity of all lines in the tether from the topside controller to the onboard control housing and from the housing to the individual motors and solenoids to check to see if any had been damaged or connected incorrectly. The multi-meter showed that all wires were carrying current and connected correctly, and once everything was dry the system ran correctly so it was determined that the problem must have been the common ground once the ROV was wet. There were extra lines run through the tether and available in the control housing so changing the system to individual grounds was a quick solution which could have easily been undone in little time if this solution had not worked.

Although the MMET-1 functioned correctly in a shallow pool, when testing in a dive pool it was unable to surface when after going to the bottom. By visual inspection, the vertical motors were working properly, so the dynamic ballast system needed to be checked. To troubleshoot the dynamic buoyancy system the MMET-1 was placed outside of water with the intake hose to the tank placed inside a small container of water which showed that it was not working properly. Testing all lines with a multi-meter was the first step which showed that the control system was connected properly, but the way the solenoids were connected to the switches reduced the power to the solenoids preventing one from opening. By adding an extra switch so that each solenoid had its own electrical line this problem was fixed. The system was still not providing suction so the venturi was checked to see if it was the problem. The venturi was originally placed before the solenoid which controlled flow through it causing the exit diameter to be too small to allow it to work. Moving the solenoid to before the venturi allowed for unobstructed flow and created suction. The MMET-1 was at this point able to use its dynamic buoyancy system and vertical motors to move vertically in shallow water, but as it went deeper the force from the water above increased to a point where it could no longer surface. This was fixed by replacing the two small bilge pump motors with two trolling motors and adding buoyancy to the tether to allow it to stay neutrally buoyant as it went deeper.

All components were individually tested before being added to the MMET-1 to ensure they worked, and were tested again once added to check for proper connection to the control system. Parts such as the camera housing were pressure tested by putting them inside a clear container so that if they failed it would be visible, but no projectiles would fly towards anyone. They were connected to an airline and the regulator was set slightly above the pressure they would be exposed to in the water.

VIII. FUTURE IMPROVEMENT

One improvement planned for next year is the design of the control housing. Although the current design is functional, it is excessively large and the gasket seal has been problematic. Currently, the control housing takes up the majority of the space inside the frame which could instead hold tooling or make the MMET-1 more compact by moving components currently on the outside to inside the frame. It is held shut by four threaded rods running through plates on either side of the housing, and when the nuts are over tightened the gasket gets cut and must be replaced. A smaller tube with one end capped and the other threaded on would solve both of these issues. The threads would provide a more effective and reliable seal without the worry of damaging a gasket. This would reduce excessive buoyancy because the large volume of water displaced by the housing would be eliminated. The current method for running wires into the control housing from the tether uses a bulkhead fitting. This fitting is constructed of PVC fittings and two part epoxy. This design could be improved by utilizing a submersible connection so that the tether could be disconnected from the housing for storage and there would be no risk of water entering the housing because it would remain sealed. These types of submersible connections can also include threads so there would be no risk of the connection coming undone while underwater.

IX. LESSONS LEARNED

Designing the MMET-1 with the plan of using as few premade parts as possible allowed for extensive practice of technical skills such as designing and machining parts. The manipulator is the best example of this which includes about a dozen parts which were all designed and built using solid works and on campus machine shops. The amount of machining required for the MMET-1 ensured that this was a group effort that gave experience with band saws, vertical mills, lathes, and CNC programming. Knowledge of electrical systems was also gained during the planning and troubleshooting of the control system and dynamic ballast tank.

During the year, the importance of communication and scheduling became obvious. At first, scheduling conflicts caused absences at team meetings and slowed the design phase, but once this was corrected progress quickly increased. Dividing up the work allowed multiple parts to be worked on at the same time, but lack of communication about the control system led to problems when integrating separate systems and troubleshooting. This was fixed by improving communication and using Google Docs to share files, which also allowed more independent work to be done outside of meetings.

X. REFLECTIONS

Alex Wendeborn- Working on this project has provided valuable experience solving practical engineering problems. The specific nature of the competition has also provided experience leading to employment in a position involving underwater ROVs for use in the installation of subsea oilfield equipment. Leadership skills were gained that assisted in earning the position mentioned above. In addition, the project honed personal time management skills, patience, and the ability to work in a realistic engineering team environment. The intention of the project was to engage in a realistic engineering competition in order to earn recognition and positive attention for the Texas A&M Manufacturing and Mechanical Engineering Department. With respect to this goal the project is considered a success.

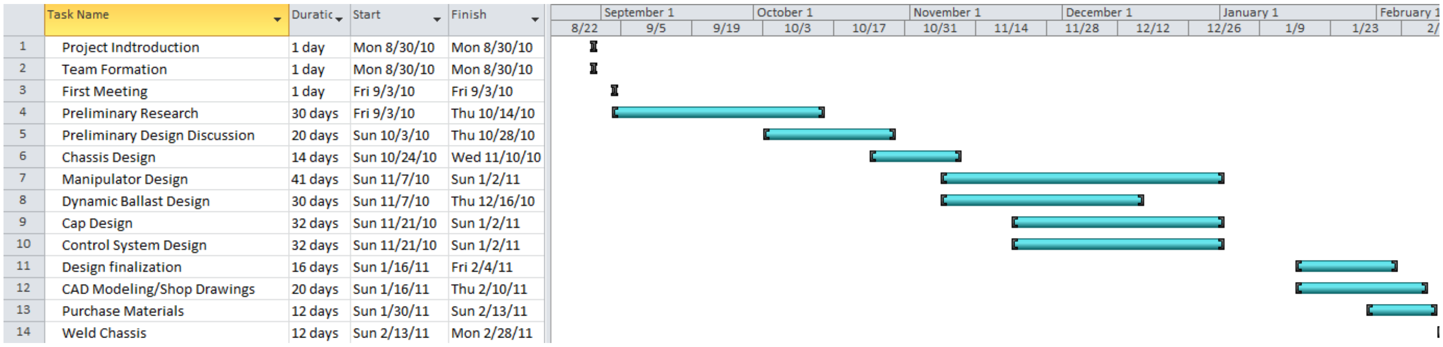
Angel Torres- I have gained a lot of experience throughout the four years that I have competed in the Mate competition. This year however is different in that the knowledge that I have gained through course work has improved design and team management skills dramatically. The one item that affected both the team and I was the time available to tackle the project. Our studies absorb much of our time, but the passion and desire to be successful has pushed each team member to work endless nights to solve problems and troubleshoot. The hardships of the project have allowed me to become a better team member and leader as well.

Ryan Broussard- The experience I have gained through this project has been invaluable. I was offered a chance to apply the knowledge I have gained in my coursework to an engineering project. Many of the challenges we have faced during the design, construction, and technical report are indistinguishable from what we will see in the professional world. Not only did I experience the design process, I discovered my passion and potential for engineering. This project has earned me valuable interpersonal skills which will be crucial for success in my career.

Tyler Conchewski- Working on the MMET-1 was a fun experience which will help me during the rest of college and in industry. Having practice going from the design phase, through production, testing, and writing a technical report will be useful for engineering projects during the rest of college and my career afterwards. This was my first year working on a design project so it gave me an opportunity to apply what I have been learning in my classes and I learned how to work with a group of engineers on a project.

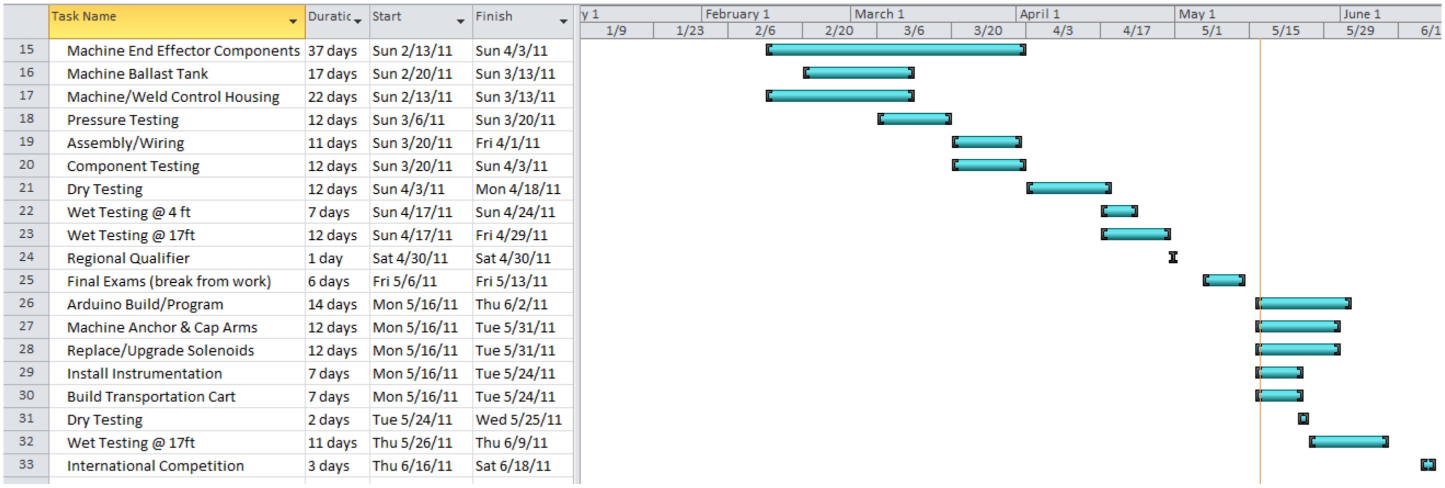
XI. TEAMWORK

Design/Fabrication Schedule:



	Task Name	Duratic	Start	Finish
1	Project Indtroduction	1 day	Mon 8/30/10	Mon 8/30/10
2	Team Formation	1 day	Mon 8/30/10	Mon 8/30/10
3	First Meeting	1 day	Fri 9/3/10	Fri 9/3/10
4	Preliminary Research	30 days	Fri 9/3/10	Thu 10/14/10
5	Preliminary Design Discussion	20 days	Sun 10/3/10	Thu 10/28/10
6	Chassis Design	14 days	Sun 10/24/10	Wed 11/10/10
7	Manipulator Design	41 days	Sun 11/7/10	Sun 1/2/11
8	Dynamic Ballast Design	30 days	Sun 11/7/10	Thu 12/16/10
9	Cap Design	32 days	Sun 11/21/10	Sun 1/2/11
10	Control System Design	32 days	Sun 11/21/10	Sun 1/2/11
11	Design finalization	16 days	Sun 1/16/11	Fri 2/4/11
12	CAD Modeling/Shop Drawings	20 days	Sun 1/16/11	Thu 2/10/11
13	Purchase Materials	12 days	Sun 1/30/11	Sun 2/13/11
14	Weld Chassis	12 days	Sun 2/13/11	Mon 2/28/11

Figure 5: Gantt chart A



	Task Name	Duratic	Start	Finish
15	Machine End Effector Components	37 days	Sun 2/13/11	Sun 4/3/11
16	Machine Ballast Tank	17 days	Sun 2/20/11	Sun 3/13/11
17	Machine/Weld Control Housing	22 days	Sun 2/13/11	Sun 3/13/11
18	Pressure Testing	12 days	Sun 3/6/11	Sun 3/20/11
19	Assembly/Wiring	11 days	Sun 3/20/11	Fri 4/1/11
20	Component Testing	12 days	Sun 3/20/11	Sun 4/3/11
21	Dry Testing	12 days	Sun 4/3/11	Mon 4/18/11
22	Wet Testing @ 4 ft	7 days	Sun 4/17/11	Sun 4/24/11
23	Wet Testing @ 17ft	12 days	Sun 4/17/11	Fri 4/29/11
24	Regional Qualifier	1 day	Sat 4/30/11	Sat 4/30/11
25	Final Exams (break from work)	6 days	Fri 5/6/11	Fri 5/13/11
26	Arduino Build/Program	14 days	Mon 5/16/11	Thu 6/2/11
27	Machine Anchor & Cap Arms	12 days	Mon 5/16/11	Tue 5/31/11
28	Replace/Upgrade Solenoids	12 days	Mon 5/16/11	Tue 5/31/11
29	Install Instrumentation	7 days	Mon 5/16/11	Tue 5/24/11
30	Build Transportation Cart	7 days	Mon 5/16/11	Tue 5/24/11
31	Dry Testing	2 days	Tue 5/24/11	Wed 5/25/11
32	Wet Testing @ 17ft	11 days	Thu 5/26/11	Thu 6/9/11
33	International Competition	3 days	Thu 6/16/11	Sat 6/18/11

Figure 6: Gantt chart B

XII. ACKNOWLEDGEMENTS

Special thanks go out to Mr. Troy Pierce of ALCOA Fastening Systems in Waco, TX for his work in arranging his company’s sponsorship for the project. Additionally, the following individuals are acknowledged for their valuable technical and moral support:

Mr. Michael Golla, professor, ETID Department, Texas A&M University
Dr. Jorge Alvarado, professor, MMET Department, Texas A&M University

Mr. Golla and Dr. Alvarado were very helpful by providing leads for sourcing materials. They also provided advice regarding aspects of the design of MMET-1, especially with respect to the pneumatic systems. Dr. Alvarado also allowed access to several teaching laboratories for the purpose of testing.

Finally, Aggie Hydronautic Engineering extends its gratitude to Mrs. Lynne Barber, the Assistant Director of Aquatics at the Texas A&M University Recreation Center dive pool. Mrs. Barber was very generous in allowing testing to be conducted in the dive pool. This testing was instrumental in ensuring the function of the seals on the MMET-1 and also provided necessary practice of mission tasks.

APPENDIX

A. Detailed Expenditures/Budget

RAW MATERIALS AND HARDWARE

Description	Material	Dimension	Qty.	Unit Price	Total Price	Supplier
Square Tube	Aluminum 6061	1"x1"x.125"	30'	n/a	$48.78	Brazos Industries (Bryan,TX)
Plate/Sheet	Aluminum 6061	13"x48"x.125"	1	n/a	$19.10	Brazos Industries (Bryan,TX)
Plate	Aluminum 6061	18"x18"x.25"	1	n/a	$21.10	Brazos Industries (Bryan,TX)
Plate	Aluminum 6061	2"x24"x.5"	1	n/a	$8.82	Brazos Industries (Bryan,TX)
Plate	Aluminum 6061	2"x24"x.75"	1	n/a	$13.25	Brazos Industries (Bryan,TX)
Plate	Aluminum 6061	12"x4"x.5"	1	n/a	$8.80	Brazos Industries (Bryan,TX)
Pipe	Aluminum 6061	3" Sch 10	6'	n/a	$33.00	Brazos Industries (Bryan,TX)
O rings AS568B #: 234	Black Nitrile (Buna-N)	3" x 3.25" x .125"	8	$1.50	$12.00	Bryan Hose and Gasket (Bryan, TX)
O rings AS568B #: 236	Black Nitrile (Buna-N)	3.25" x 3.5" x .125"	8	$1.50	$12.00	Bryan Hose and Gasket (Bryan, TX)
O rings AS568B #: 449	Black Nitrile (Buna-N)	10" x 10.5 x .25"	4	$1.50	$6.00	Bryan Hose and Gasket (Bryan, TX)
Square Ring Material	Black Nitrile (Buna-N)	.25" x .25" x 6'	1	$1.50	$1.50	Bryan Hose and Gasket (Bryan, TX)
Rubber Sheet (gasket material)	Black Nitrile (Buna-N)	2' x 2' x .125"	2	$22.00	$44.00	Bryan Hose and Gasket (Bryan, TX)
Threaded rod	Steel	1/4"-20 x 72"	4	$3.96	$15.84	Home Depot, College Station, TX (http://www.homedepot.com)
Polyeurethane foam	Part A and Part B	1.5 ft^3 expanded	1	$120.00	$120.00	Bryan Marine Supply, Bryan, TX
Stainless Steel Hardware	Stainless Steel	1/4"-20, 5/16"-18	1	$50.00	$50.00	Home Depot, College Station, TX (http://www.homedepot.com)
Braided Vinyl Tubing	Vinyl and fiberglass	3/8" x 10'	1	$7.99	$7.99	Home Depot, College Station, TX (http://www.homedepot.com)
Clear Vinyl Tubing	Vinyl and fiberglass	1" x 1'	3	$2.50	$7.50	Home Depot, College Station, TX (http://www.homedepot.com)
Clear Vinyl Tubing	Vinyl	1/4"x 200'	1	$50.00	$50.00	
Brass Fittings	Brass	Various	30	$3.00	$90.00	Home Depot, College Station, TX (http://www.homedepot.com)
		Raw Materials and Hardware Total=			**$569.68**	

CONTROL SYSTEM AND ELECTRONICS

Product	Description	Dimension	Qty.	Unit Price	Total Price	Supplier
Arduino Pro 328 - 5V/16MHz		n/a	2	$19.95	$39.90	NKC Electronics (http://www.nkcelectronics.com/)
Freeduino Protoshield KIT for Arduino		n/a	1	$9.99	$9.99	NKC Electronics (http://www.nkcelectronics.com/)
Pin header pack for Arduino		n/a	3	$1.95	$5.85	NKC Electronics (http://www.nkcelectronics.com/)
Arduino Ethernet Shield		n/a	2	$38.00	$76.00	NKC Electronics (http://www.nkcelectronics.com/)
Shipping		n/a	1	$7.74	$7.74	NKC Electronics (http://www.nkcelectronics.com/)
Sabertooth 2X12	Motor Controller		1	$79.99	$79.99	Dimension Engineering, LLC (http://www.dimensionengineering.com/)
Sabertooth 2X5	Motor Controller		1	$59.99	$59.99	Dimension Engineering, LLC (http://www.dimensionengineering.com/)
Arduino Mega 2560	Mega with 6" USB type B cable		1	$56.73	$56.73	Liquidware (http://www.liquidware.com/)
Minn Kota 30-30 Trolling Motor		n/a	2	$98.00	$196.00	Academy (College Station, TX)
Bilge pump Motor	1100 gph		4	$34.00	$136.00	Academy (College Station, TX)

Cerrowire 300 ft. 12-Gauge Stranded	Donated (value estimated)	500ft	1	$50.00	$50.00	Estimated Value (salvaged)
Cerrowire 500 ft. 14-Gauge Stranded	THHN Blue Single-Conductor Electrical Wire	500ft	1	$77.00	$77.00	Home Depot, College Station, TX (http://www.homedepot.com)
Garden hose (tether sheath)	garden hose	150'x 3/4" I.D	1	$39.97	$39.97	Home Depot, College Station, TX (http://www.homedepot.com)
Various Electrical connections	butt splice, wire nuts, M/F connectors	various	1	$40.00	$40.00	Home Depot, College Station, TX (http://www.homedepot.com)
Electrical Switches	double throw, 3 position		10	$2.00	$20.00	Estimated Value (salvaged)
Solenoid Air Valve	MAC , 5/3, 150psi		3	$50.00	$150.00	Price Estimated (salvaged from damaged CMM)
Solenoid Air Valve	Rainbird sprinkler soleniod		1	$14.00	$14.00	Home Depot, College Station, TX (http://www.homedepot.com)
Pneumatic Venturi			1	$20.00	$20.00	Estimated Value (salvaged)
BIMBA AIR CYLINDERS # BF-173-D	Stainless steel, double acting		1	$14.99	$14.99	ebay
Solenoid Air Valve bank	Numatics #: 031SS4154 (bank of 6)		1	$55.00	$55.00	ebay
Digital camera			2	$25.00	$50.00	Estimated Value (salvaged)
Pressure Guage	0-15 psi		1	$20.00	$20.00	Estimated Value (salvaged)
		Control System and Electronic Total=			**$2,358.51**	
LABOR VALUE (In-House, no cost to team)						
Type	**Description**	**# of Workers**	**Hrs.**	**Value/hr**	**Total Cost**	**Location**
Design		4	100	$40.00	$4,000.00	Texas A&M, College Station, TX
Modeling	Solid Works 2010	4	50	$30.00	$1,500.00	Texas A&M Student Computing Center, College Station, TX
Manual Machining		4	200	$24.00	$4,800.00	Texas A&M Mechanical Engineering Machine Shop, College Station, TX
CNC Machining	Trump Centroid vertical Mill	1	15	$24.00	$360.00	Texas A&M Mechanical Engineering Machine Shop, College Station, TX
Welding	GTAW, Miller Synchrowave 250	1	20	$24.00	$480.00	Texas A&M Mechanical Engineering Machine Shop, College Station, TX
Assembly		4	100	$24.00	$2,400.00	Texas A&M Mechanical Engineering Machine Shop, College Station, TX
Technical Report		4	60	$24.00	$1,440.00	Texas A&M Student Computing Center, College Station, TX
		Labor Value Total=			**$14,980.00**	

Sponsorships and Funding						
Company/Sponsor	**Type**	**Location**			**Amount**	
ALCOA Fastening Systems	Sponsorship	Waco, TX			$500.00	
Alex Wendeborn	Sponsorship	College Station, TX			$700.00	
Angel Torres	Sponsorship	College Station, TX			$500.00	
ASME-Tech, TAMU student chapter	Budget Allocation	College Station, TX			$1,000.00	
		Sponsorship and Funding Total=			**$2,700.00**	
TOTALS						
Total Value =					**$17,908.19**	
Total Cost(Actual Expenditures) =					**$2,640.19**	
Funding less Actual Expenditures=					**$59.81**	