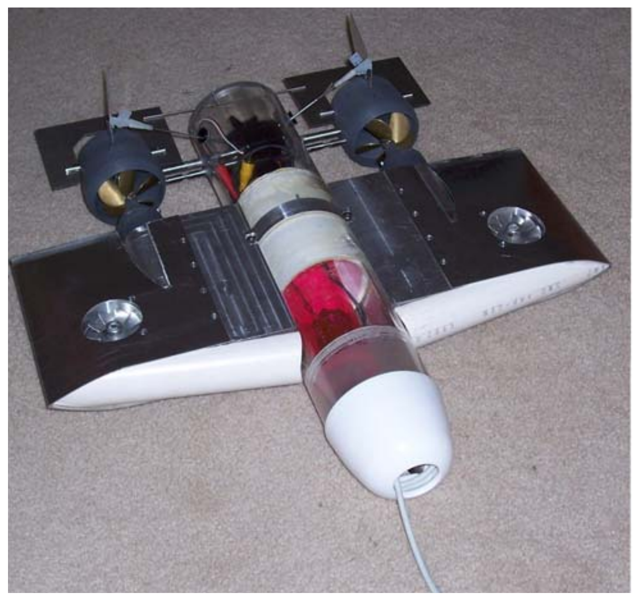
Abstract

Mate ROV Design, Construction and Competition, *Team Powerfish,* **University of California, Davis, CA:** With ROVs playing a key role in discovery and biological advancement, an ROV was designed to accomplish four tasks in a 30 minute period. The ROV must descend 13 meters and take a temperature measurement with in .5 degrees Celsius, reconnect a data cable, collect three probes and return them to the surface, and collect a 400 ml fluid sample with minimal dilution. The basic design limitation given was a maximum of 48 volts and 40 amps. With time being an issue the tasks were divided among two ROVs sharing the power. The ROV Com having the arm, can collect the probes and reconnect the data cable. The ROV probe takes temperature measurements and can take fluid samples. Using six 6V to 12V motors ROV Com was designed to make complicated small movements which include five degrees of freedom. This capability allows the ROV to open drawers and reconnect plugs, all while hovering. Designed to use its available power the ROV Probe has a propulsion system that allows it to reach speeds up to 1.6 m/s. It was designed with fans in the wings to control rotation and to allow for hovering. It is also equipped with a diode thermal sensor allowing for temperature reading up to .1 degrees Celsius in accuracy. The ROV Probe also can take up to 500 ml fluid sample at depths of 13 meters. Combined the two ROVs are able to successfully complete all tasks.

<u>POWERFISH COM & POWERFISH PROBE ROVS</u>

University of California Davis
Team: POWERFISH

ROV Com



ROV Probe

Team Advisor: Roger Davis

Team Members:

Jonathan Rogado	Mechanical Engineering
Preston Schmauch	Mechanical Engineering
Mark Sabugal	Mechanical Engineering
Garrett Griffith	Mech/Aero Engineering

Introduction

Underwater vehicles have played a key role in discovery of marine life, and underwater phenomenon. They have led to the discoveries of things ranging from black smokers to ocean floor bacteria that have capabilities through a process similar to photosynthesis only using sulfur instead on light. Along with those discoveries, some people lost their lives as vehicles imploded from the high pressure and the trips that did occur could only last hours at a time. With underwater ROVs the physical limitations have all but disappeared. Now we can search the ocean floors not only for hours but for days. ROVs are crucial to the continued discovery, study and understanding of deep sea marine life and it's effects on the world today.

Design Rationale

After a thorough assessment of the designated tasks, Team Powerfish attempted to determine the approach that would best utilize the unique skills of their members. Furthermore, the Team decided that the most effective course of action would be to take advantage of the competition's time bonuses. It was determined that the most efficient and effective approach would involve two ROVs each designed for two specific tasks. The similarities between the communications link and data probe retrieval necessitated their completion by one ROV, while fluid collection and temperature reading were allocated to the other ROV.

The decision to use two ROVs presented Team Powerfish with specific dilemmas. By choosing to use two ROVs instead of one, the Team relegated itself to having decreased power allotments per vehicle. Additionally, since each ROV is designed for only two specific tasks, should the functions of one ROV fail, only half of the required tasks would be completed.

Team Powerfish hoped that these dilemmas would be negated by the potential benefits of using two ROVs. By operating two ROVs during the competition, Team Powerfish will utilize the skills of each team member. In the Control Shack, each operator will be assigned to the controls that they are most adept at. Most importantly, applying two

ROVs to the four tasks could potentially decrease the total performance time, thereby increasing the point total.

The Com ROV, which completes the communications link and data probe retrieval tasks, has 5 thrusters that allow for 5 degrees of motion: two degrees of rotation and three for

5 degrees of motion for Com ROV

translation. The former two account for horizontal and front-to-back pivot while the latter three account for forward/reverse, hover, and lateral motion.

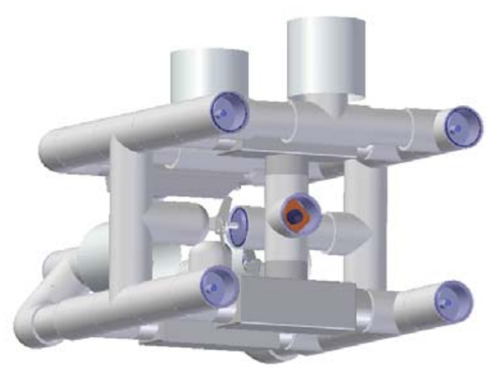
The onboard components of the Com ROV were designed with simplicity in mind. By avoiding complex components, any on site repairs would be minimal and the operation of the vehicle manageable. Black and white cameras were sufficient for the vision requirements for the ROVs operation. While the ROV Probe utilizes a color camera to meet the fluid collection demands of distinguishing red paint from its surroundings, the Com ROV did not require such cameras. The Com ROV requires less complexity in the camera system because its designated tasks do not require color recognition. By using the black and white cameras, Team Powerfish chose products that would decrease the cost of the ROV's construction. Another onboard component that was designed in an attempt to avoid complexity was the mechanism with which the tasks will be completed, a robotic arm. The arm is driven by servos that will allow it a full frame of motion and rotation without fully relying on a drive motor. This will allow the operators to position the ROV in a general area while the arm is rotated to the exact position.

CCD Camera used in ROV

In order to avoid unnecessary damages due to water penetration, Team Powerfish invested great time and effort into exhaustively waterproofing the Com ROV. O-rings were compressed between every lens or motor housing and the body of the vehicle to ensure tight seals at every intentional protrusion. Brackets were designed to fit on top of each lens/motor housing and apply further pressure to the seal. However, each of these lens and motor housings will serve as possible water entry points. The body of the vehicle is composed of Schedule 40 PVC sections that are designed to fit snugly into each other. Additionally, these sections have been primed and then cemented together with PVC primer and cement. Using a PVC structure allows the operators high impact resistance and ensures the safe arrival of the vehicle. As an extra fail safe, each of the five motors that power the vehicle was placed in a secure location within the PVC body. Should any of the primary waterproofing mechanisms fail, the invasive water will be diverted away from the motors and serve as a secondary defense against water damage.

Buoyancy is an influential factor for the Com ROV. Team Powerfish chose to hold this factor constant by building the body of the vehicle out of PVC. By using PVC for the bulk of the vehicle, the ROV is able to maintain buoyancy despite the pressure of deep water. By using a large PVC structure, the team was able to ensure maximum buoyancy to compensate for heavy onboard batteries and components. In order to easily manipulate the vehicle from the Control Shack, Team Powerfish designed the Com ROV with negative initial buoyancy. This will allow the vehicle a full range of buoyancy without hindering its performance.

In order to best meet the competition requirements, Team Powerfish chose to construct the Com ROV with the interchangeability of parts in mind. By relying upon mass produce items easily found at local hardware stores, initial manufacturing and subsequent re-designs were manageable. PVC pipe was an optimal material for the main body because it is available in standardized measures with large enough diameters to house the motors. Lens and motor housings that fit into the PVC protrusions were



fabricated from acrylic by the team based upon both factory given measures and personal measurements. Propellers, hubs, and universal brackets were also constructed by the team according to the standards upon which the PVC pipe was produced. In this way, each purchased and fabricated component was easily interchanged with other components of the correct size. By relying upon mass produced items, Team Powerfish was able to minimize the chance for error that comes with every prototype construction.

Design Challenge Encountered

The competition imposed limitations on voltage and amperage posed many difficulties to Team Powerfish and their design of the Com ROV. For example, to adhere to the 40 amperage regulation determined by the competition, the team was forced to re-design their first Com ROV controller. The initial prototype relied upon a motor actuation initiated by a simple switch. However, this switch pushed the vehicle's amperage draw above the limit, and the team was forced to formulate a solution to this problem. The team decided upon a variable voltage speed controller that would allow the operators to control the rate at which the motor reached activation. Another problem occurred in an early version of the Com ROV where the bulk of the voltage and amperage was placed in the onshore controllers. However, this configuration resulted in a voltage drop across the tether due to the distance it had to travel to reach the motors onboard the vessel. As such, the team decided to relocate the batteries to the vehicle itself. Although the competition regulations required the team to decrease the amperage to no more than 25 amps for

Motor speed controller and servo controller used in ROV

safety reasons, the loss of amperage was well worth the increase in voltage. Despite initial setbacks, Team Powerfish was able to design the Com ROV along all competition energy guidelines. The final version of the Com ROV adheres to all competition standards of voltage and amperage. The vehicle has 12 volts onboard and the onshore controllers will draw power from the sources onboard. The Probe ROV will have the surplus 36 volts in order to accomplish its tasks.

Trouble shooting techniques Com ROV

During all the phases of design, construction, and testing, Team Powerfish implemented simple troubleshooting techniques to minimize complications with the Com ROV. Waterproof seals, interfaces, and exits were inspected numerous times and tested for strength under impact conditions. Furthermore, these components were tested for their water resistant capabilities prior to the insertion of any electrical or mechanical components. These electrical and mechanical components, including motors, servos, wires, and tethers, were dry tested before being placed in the vehicle and again before the vehicle was submerged. Blades and their corresponding motors were tested both in air and in water to determine their amperage draw and voltage drop.

Future Improvements Com ROV

There are several ways that the Com ROV could be improved. First, a more compact design would allow for increased maneuverability. Second, a more aerodynamic shape would allow for better water flow around the body thus decreasing drag and increasing speed. Third, to improve the vehicle's water resistance, a possible improvement for further designs would be to decrease the chance of water entry at lens and motor housing protrusions. Fourth, the cameras in the current Com ROV are located in positions designed to give operators the best view of the communications link and data probe retrieval tasks. Future designs may involve the relocation of cameras in order to accommodate new tasks and give the operator the best view of all obstacles.

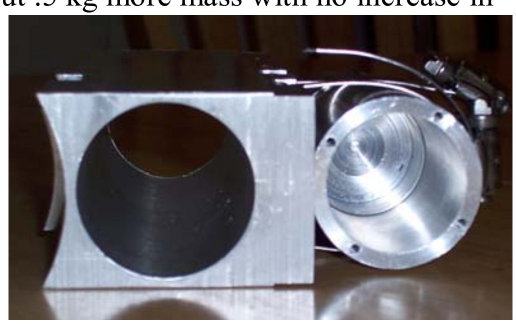
Skills and Lessons Learned Com ROV

Although Team Powerfish learned many important skills and lessons, the manufacturing of parts using different materials was the most crucial to the design of the ROV. Utilizing lathes, mills, drill presses, hole punches and many other manufacturing machines, Team Powerfish members became proficient in the development of acrylic, aluminum and sheet metal parts. This skill proved most beneficial as more custom parts were required throughout the design process. Team members further improved their working knowledge of manufacturing skills as the project was completed leading to higher quality part production.

ROV Probe

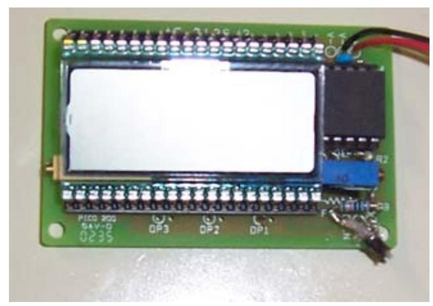
The design strategy for the ROV probe was to use the high pressure at 13 meters under water to power the fluid collection and then to add a thermal sensor to the tip of fluid collector for our temperature measurement. At 13 meters the static pressure is about 228.6 kPa, or about 2.25 times greater than atmospheric pressure. Using the gas law "Pressure1 *Volume1/Temperature1=Pressure2*Volume2/Temperature2" it was determined that about 900 ml of air at the surface would compress to about 400 ml at 13 meters under water. A 900 ml vessel of air would be taken down and when the fluid was ready to be collected, a solenoid valve would be opened and the fluid would be forced into our vessel. When the vessel returned to the surface the valve would be opened again and the now high internal pressure would force out the fluid.

Two problems needed to be resolved for this to be successful, the first is buoyancy. If a vehicle is neutrally buoyant and then takes on about .5 kg more mass with no increase in volume it will now sink like a rock. To overcome this, two 250ml bored out holes that initially have water in them would be filled with air. To accomplish this, air pressure from above would force the water out of the bored out holes using pistons and a valve. The back pressure on the piston at 13 meters is 334 N with the bore area of .00146 square meters. The pressure available at the surface is 60 psi or 413.6kPa. So 604 N of force would be available to move the piston and expel the water. This is enough to overcome the back pressure on the piston and the static friction between the bore surface and the piston o-rings.



The second problem is that once the sample fluid is inside the vessel there is still air inside also. When the air and the water are not separated sloshing and stability problems arise. This means that when the vehicle leans forward the cg (center of gravity) moves forward also and the vehicle tips. When the vehicle tips back the cg moves back. To solve the problem, a sealed tube with another solenoid valve was placed in the center of the vessel. Both valves would open at the same time so that while the vessel is filling with fluid the inner tube would be forced full of the air. Then when the valve closed the air and fluid would be separated and no cg change would occur.

To obtain an accurate temperature reading the ROV Probe uses a 1N4148 switching diode. When the diode is put in series with a 100k ohm resistor there is an almost linear relationship between forward voltage across the diode and temperature. For every 2 mV of voltage change there is a change in temperature by 1 degree Celsius. Between the range of -20 to 150 degrees Celsius the greatest variation is by 1.5 degrees, which is significant. To overcome this, the diode was integrated into a multi-meter board and was given scale and zero calibration. This way the sensor can be calibrated to be accurate over a certain range. In this case the sensor is very accurate between 30 to 40 degrees Celsius and diverges outside of these ranges. The only problem here was that a sensor with known accuracy had to be found first for calibration.



Propulsion Design

The goal of the design calculations was to obtain the optimal performance with the specified power restrictions of the ROV competition. Our team has selected to operate two specialized ROVs simultaneously to accomplish the underwater tasks. The power limitation for these ROV calculations was set at 18 Volts and 14 Amps. The motor and gearbox were first selected to operate within this range. The output shaft can operate at 195 radians/second (1862 RPM) with .08 Nm of torque while staying within the electrical power constraints. Using this power and the calculated total drag of the ROV, a theoretical top speed can be calculated. The propulsor blade shape can then be designed using this top speed and the rotational speed of the output shaft. Microsoft Excel spreadsheets were used to simulate multiple designs in short amounts of time. This discussion will explain the steps used to calculate the ROV's drag, top speed, and optimum propulsor blade shape.

The first step in the design process was to determine a general shape and size for the ROV so drag could be determined. Once the general shape was established, the drag analysis was carried out. The drag analysis simplified the actual shape of the ROV into simple shapes with know coefficients of drag. The ROV's shape was simulated using a combination of cylinders, elliptical cylinders, and flat plates. Drag equations and coefficients of drag were found in White's[1] book of fluid mechanics. A number of factors were considered in the drag analysis. The flow was first characterized as laminar or turbulent based on the Reynolds number. A Reynolds number greater than 5×10^5 was considered to indicate a turbulent external flow.

Reynolds Number: $$\mathrm{Re} = \frac{UL}{\upsilon} = \frac{velocity \times Length}{vis\cos ity}$$

Each component's drag was calculated by summing its surface drag and its pressure drag. The surface drag is due to fluid shear caused by the no slip condition at the surface of each piece. The pressure drag is a function of the frontal area and profile shape of each piece. In all calculations, the pressure drag dominated over the surface drag. To calculate the surface drag, each piece was simulated as a flat plate with exactly the same wetted surface area. The surface drag calculations used the following equations to find the coefficients of drag.

Surface Drag: Laminar if: $\mathrm{Re} < 5 * 10^5$

Laminar: $$C_d = \frac{1.328}{\sqrt{\mathrm{Re}}}$$

Turbulent: $$C_d = \frac{.031}{\sqrt[7]{\mathrm{Re}}}$$

---

[1] White, Frank M. ; Fluid Mechanics Fifth Edition , McGraw Hill 2003

From these calculated coefficients, the surface drag force was calculated as follows:

$$F_{drag} = C_d * (\frac{1}{2} * \rho * V^2 * A_{wetted\_surface\_area}) \qquad (V = \text{velocity of ROV})$$

$$(\rho = \text{density of water})$$

The pressure drag of each component was calculated in a very similar way. Instead of experimentally calculating the coefficients of pressure drag, tables in the fluids book were used to look up the coefficients. For example, the coefficient of drag for an elliptical cylinder with a length to height ratio of 4:1 is found to be $C_d = .35$. The pressure drag is then easily calculated using the equation below:

$$F_{drag} = C_d * (\frac{1}{2} * \rho * V^2 * A_{frontal\_area})$$

The total drag of the ROV is then the summation of the surface and pressure drags of all components. The drag was calculated for velocities ranging from 0 to 2 meters/second. The optimum operating velocity would be the velocity that achieves a .08 Nm torque load on the output shafts. (Assume shaft speed of 195 rad./sec.) In order to find this velocity, two power relations were used. The first power relation is that power is equal to a linear force multiplied by a linear velocity in the same direction as the force. For the second relation, power equals torque multiplied by angular velocity. These relations are summarized in the following equation:

$$P_{net} = F_{total\_drag} \times V = Torque \times \omega$$

The net power required was first calculated using the total drag forces and their corresponding velocities. The torque required to achieve this power at 195 rad./sec. was then calculated. Two propulsors were used and the propulsive efficiency was assumed to be 80%. The torque of each propulsor was calculated as follows:

$$P_{net\_out\_propulsors} = \frac{P_{net}}{\eta_{propeller}} \qquad (\text{Propulsive Efficiency} \approx 80\%)$$

$$Torque_{propulsor} = \frac{P_{net\_out\_propulsors}}{2 * \omega} \quad \text{(2 propulsors, } \omega = \text{motor speed in rad./sec.)}$$

The calculated torques at each respective velocity were compared to the design torque of .08 Nm. A velocity of 1.6 m/s was found to yield a torque of .0756 Nm. This velocity of 1.6 m/s was chosen to design the blade shapes around.

Blade Analysis

The blade shape analysis was based off velocity triangles for the water and blade velocities. These triangles show the absolute and relative velocities of the flowing water and the blades. A labeled diagram of these triangles follows on the next page.

The goal of the blade analysis was to find the blade size and general shape that would allow our ROV to operate efficiently at 1.6 m/s. A blade can be characterized by the outside diameter (O.D.), inside diameter (I.D.), and pitch of the blade. The hub to tip ratio was often used and is defined as the I.D. divided by the O.D. We were advised to design towards a 20-degree flow turn angle. (beta in the diagram). The effect of different numbers of blades was also investigated.

The process of calculating the flow turn angle involved using the momentum relation between a force, a mass flow, and a velocity change:

$$Fu = \dot{m} \times Cu_2$$

The force (Fu) comes from the force of the blade acting on the water. The $\dot{m}$ represents the mass flow of water through the propulsor. The velocity (Cu_2) is the velocity the water gains in the circumferential direction. These quantities are calculated as follows:

Circumferential force from blades:

$$Fu = \frac{Torque_{propulsor}}{r_{avg.}}$$

Mass Flow through Propulsor:

$$\dot{m} = \rho * V_0 * \pi * r_{OD}^2 * \left(1 - \frac{r_{ID}^2}{r_{OD}^2}\right) \quad (r_{ID}\text{=inside diameter , } r_{OD}\text{=outside diameter)}$$

$(V_0 = Velocity\_of\_ROV)$

Final Velocity of water in circumferential direction:

$Cu_2 = \frac{Fu}{\dot{m}}$ (Initial velocity $Cu_1 = 0$)

Knowing the circumferential (Cu2) and axial (Vo) velocities of the water allows the calculation of the flow turn angles. The blade velocity is also used. ($U = r_{avg.} \times \omega$). From the velocity triangles, the following relations are found:

Calculation of Blade Angles: Angles measured from axial line of propulsor.

Relative Angle: $\beta = \arctan\left(\frac{wu_i}{C_x}\right)$ $(wu_1 = U \;,\; wu_2 = U - Cu_2 \;,\; C_x = V)$

Absolute Angle: $\alpha = \arctan\left(\frac{Cu_i}{C_x}\right)$

The final design of the propulsor blades selected was a negotiation between our theoretical characteristics and the available characteristics from the manufacturer. The final blades chosen have an O.D. of 65 mm and an I.D. of 10.9 mm. This produces a hub to tip ratio of .168. These dimensions are very close to our theoretical dimensions calculated in Excel. (O.D.=66mm , hub to tip ratio=.15) The blades came with a predefined variable pitch, which creates more thrusting force. Our blade size was chosen slightly smaller than theoretical to account for this effect. This design will provide more than adequate thrust while staying within the electrical power constraints. The airfoil loading factor and solidity was calculated to estimate blade loading and the number of blades, that helped to choose an off the shelf propulsor. For larger ROVs with more power this would be critical in designing efficient propulsion blades that would be specially made for this purpose.

Nozzle

A converging nozzle was designed and placed after the propellers to increase the velocity at the exit. Also, a stator was added after the nozzle since the propellers will create swirl after accelerating the flow. The swirl is removed by using a stator. Both these additions increase the overall thrust of the vehicle.

To design the nozzle, the area reduction for the nozzle is calculated. The step-by-step process to obtain the area reduction is followed here. Knowing the power provided to the propeller and the mass flow through it, the pressure going into the nozzle can be calculated using the equation above.

$$Power = \frac{Drag \cdot V}{\eta_{efficiency}} = \frac{\dot{m} c_p \Delta T}{\rho} = \frac{\dot{m} \cdot (P_{T2} - P_{T1})}{\rho}$$

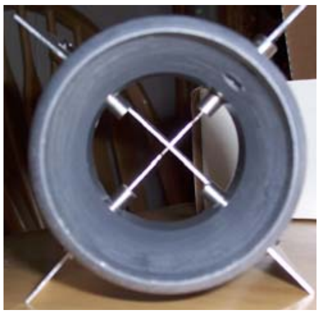
Using the data from the calculations tables, the *Power* is 14.72 Watts and the initial total pressure, P_{T1}, at a depth of 12 meters is 219.3 kPa. With a mass flow of 2.76 kg/s and the density of water at 997 kg/m^3, the final total pressure, P_{T2}, is 224.6 kPa. Next, the static pressure is solved using Bernoulli's equation, $P_2 = P_{T2} - \frac{1}{2}\rho C_2^2$,

where C_2, equal to 2.26 m/s, is the absolute velocity at the exit of the propeller. From this equation, $P_2 = 222.1$ kPa. The absolute axial velocity behind the propeller is calculated from the continuity equation, $C_{x3} = \frac{A_{x2}}{A_{x3}} C_{x2}$. C_{x2}, equal to 1.6 m/s, is the absolute axial velocity through the propeller. A_{x2} is the area through the propeller calculated from $A_{x2} = \pi(r_{tip}^2 - r_{hub}^2)$ where the tip radius, r_{tip}, of the blade is 3 cm and the hub radius, r_{hub}, is 0.45 cm. A_{x3} is the area after the propeller when the hub is no longer present, calculated using $A_{x3} = \pi \cdot r_{tip}^2$. This gives a value of 1.564 m/s into the nozzle for C_{x3}. Now that the initial values into the nozzle are calculated, the velocity, C_{xexit}, out of the nozzle can be calculated using the equation the below. C_{u2} is the rotational absolute velocity, equal to 1.59 m/s. The idea is to restrict the flow through the nozzle to use the high pressure that has been created.

$$P_2 + \frac{1}{2}\rho(C_{x3}^2 + C_{u2}^2) = P_{ambient} + \rho g z + \frac{1}{2}\rho C_{xexit}^2$$

By accelerating the flow through a small exit there is a pressure drop. Assuming the flow exits at the static pressure of 218.8 kPa at the depth of 12 meters, the velocity out of the nozzle, C_{xexit}, is 2.57 m/s. With this velocity, the exit area is calculated using $A_{exit} = \frac{C_{x3}}{C_{xexit}} A_{x3}$. The final value for the radius of the exit of the nozzle for this design is 2.5 cm.

A stator is added after the nozzle to take out the non usable swirl. The degree of swirl must be calculated to design the stator. The rotational velocity at the tip of the propeller is calculated from $U = r_{tip}\omega$ where omega is the rotational speed, 194.8 rad/s, the tip radius is 2.5 cm, and the axial absolute velocity, C_{xexit}, is 2.57 m/s. The absolute swirl angle is calculated from the equation $\alpha = \tan^{-1}\left(\frac{U}{C_{xexit}}\right)$. The swirl angle is 66.3°. The stator can be designed for this angle starting at the outer radius of the exit and varies from that to zero at the very center where U equals zero, this will give the best transition from swirl to no swirl. Thrust equals mass flow multiplied by velocity. With the use of the nozzle and the stator 56 percent more thrust can be achieved excluding losses.



Challenges and Troubleshooting ROV Probe

With this ROV problems came with buoyancy and waterproofing. With 80 percent weight of the vehicle made of aluminum at first the vehicle would sink very rapidly. Also the cg was located more to the rear and we couldn't add more weight to the front. In the end it took drilling holes in the aluminum and then capping them off as air pockets along with creating large air pockets in the wing to get the vehicle neutrally buoyant.

Water proofing the motors took very precise machining. As seen in the photo there is an oil seal and that was combined with an o-ring with just the right compression to stop leakage at the motor output shafts. With adjustments for weight and waterproofing our

parts began to be very detailed and complex especially to manufacture. At least 200 hours of shop time was spent on this vehicle alone. In the future different materials would be used that are cheaper and easier to machine and less detailed parts would be designed.

Applications

There are hundreds of applications that can be used from this project. Not only for underwater exploration but some of these techniques could be used for underwater repairs of vehicles or dams. Some of this technology is important for underwater pumps and water turbines. Also, in today's world, efficiency is a huge issue. By using ducted fans, stators and nozzles power systems can be built smaller and consume less power. This could be important when trying to explore areas with small opening but still having decent payload capabilities. All in all there are many applications for underwater ROVs.

Cameras

Several cameras are used on the vehicle for navigation and for aid in manipulator control. These draw 120 milliamps of current, so large conductors are not needed, and with on board power, only one line per camera for video signals is required. Tests were done across the tether for signal degradation due to both length and magnetic interference, and influence from both factors were minimal. Both color and black and white cameras were used.

DC Motor Control Considerations

Several approaches could be taken in addressing the issue of controlling the movement of the vehicle. Options fall into two categories: direct and indirect control.

With direct control, each motor is wired directly to the surface and the currents are controlled there. The advantage of this approach is low cost and simplicity. However, as more motors with higher currents are used in the device, this method

becomes impractical due to large voltage drops from high currents, and the need for large gage wire to handle the electrical loads, which impedes flexibility of the tether.

The issue of tether flexibility is best addressed with indirect control, where control signals are sent through the tether to control hardware on board the vehicle. For the larger vehicle, this was the approach chosen to control the many high current motors being used. Using a bi-directional motor controller, potentiometers create control signals for pulsed speed control which are sent to the hardware placed on the craft, which use that information to vary the speed of the motors. These controllers are capable of delivering up to 47 amps per motor controlled, which is well within the range of the drive motors; as well as provide variable speed control, which is critical for providing both the speed to traverse the large distance from the surface as well as precise control for navigation among the mission tasks. This approach works well because of the very low currents involved, which make voltage drops and resistances in control lines negligible and allow for a cheaper, thinner, more flexible cable. The tether for the larger vehicle being used is a 25 conductor 24 gage cable, which is sufficient for the low currents generated by control hardware. The batteries are placed on the vehicle to address any possible voltage drops across the tether.

Servo Motor Control

RC servos used in the mechanical arm require pulse width modulated (PWM) signals to control their positions. As with the dc motors, it is possible to send this directly to each servo, but this would take up precious space on the control tether. Therefore a serial signal controlled servo controller was used, which takes signals from a microcontroller on the surface and interprets those with an on board microcontroller, which generates the needed control signals.

Acknowledgements

ROV Com

Design:
Jonathan Rogado
Garret Griffith

Propulsion/Manufacturing:
Jonathan Rogado
Garret Griffith

Controls:
Mark Sabugal

ROV Probe

Design:
Preston Schmauch

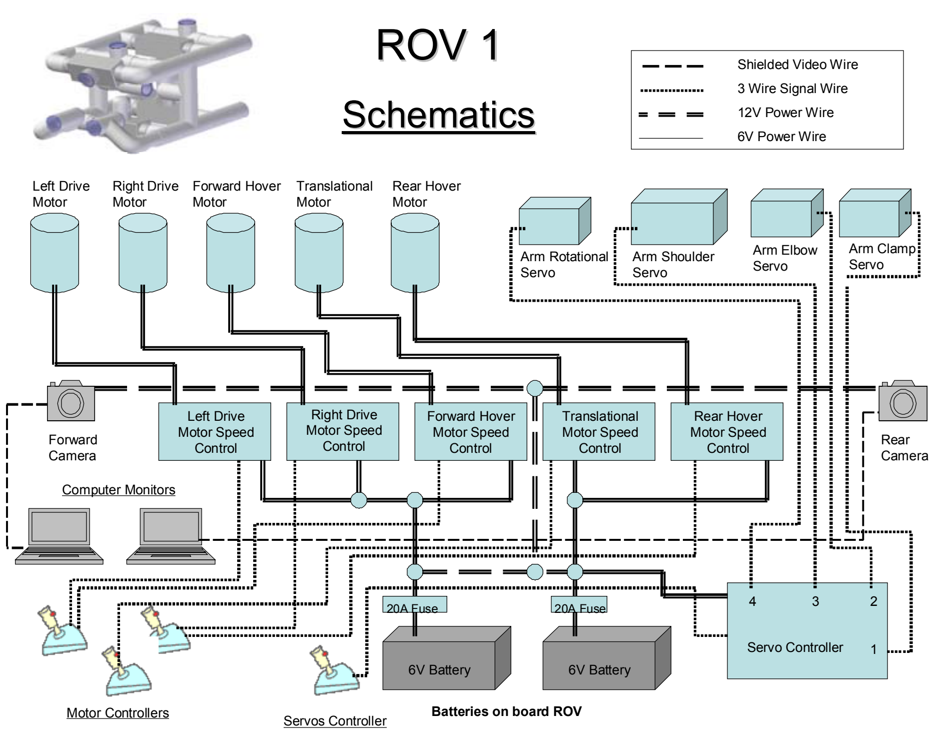
Propulsion/Manufacturing:
Preston Schmauch
Justin Smith
Daniel Boldt
Peter Fonda
Ryan Carpenter

Controls:
Preston Schmauch

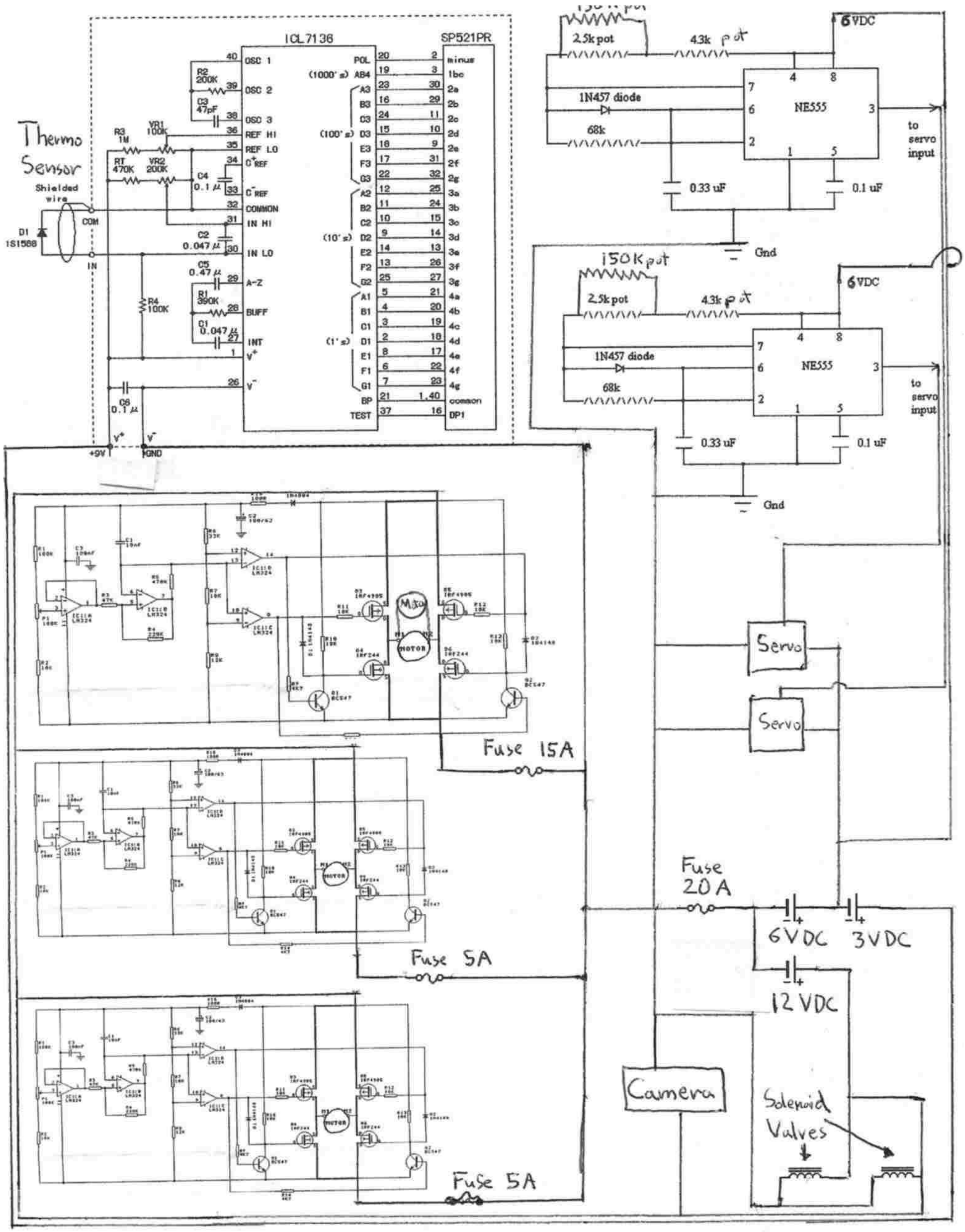
Mentoring/Guidance
(and the occasional reality check)

Professor Roger Davis

Editor
Preston Schmauch



ROV Probe Full Schematic



Expense Sheet

Receipts	Parts	Costs
Mate ROV Competition	**Donation**	**-100.00**
UCD Mechanical Engineering	**Donation**	**-1000.00**
Dean College of Engineering	**Donation**	**-1000.00**
RC Country	Plastic Propeller, Aluminum Tube	15.05
Hobby Engineering	2 Motor Controllers	49.23
AOP Tech	O-rings	13.64
84 Lumber	Sand Paper	4.67
All Electronics	Wing Motors	12.44
Napa Auto	Snap Rings	1.98
ACE Hardware	Screws, Rods, Drill Bit, SS Rods	18.94
HSC	Joystick, Solder, Resistors	15.49
HSC	Shrink Tube, Heat Sink, Resistors	8.50
Harbor Models	2 Brass Props 65mm	45.03
Stock Drive Products	Bevel Gears	21.07
IGUS	12 Wire Flex Cable 100 ft	128.43
Hobby Lobby	2 Gear Boxes 3.8:1	69.79
Interstate Plastics	Plastic	15.08
Grainger	2 Solenoid Valves	64.54
Carl's Electronics	Bi-directional motor Controller	28.90
Hobby-Lobby	2 gearboxes	69.79
Central Hobbies	2 servos	30.96
HSC Electronics	Electronic Parts, Controls, Pots	34.47
Ace Hardware	O-ring, screws	2.10
Taps Plastics	Plastic	7.22
HSC Electronics	Wire, Control Box	26.11
Radio Shack	Resistors, Circuit parts	15.98
McMaster-Carr	Aluminum Rod for motor housing	22.39
R/C Country	Servo and 2 connector packs	30.14
Grainger	3 Fan Blades	6.27
HSC Electronics	12V 6V Battery, and misc electronics	67.51
Anderson's Pipe	PVC Cap	4.02
HSC Electronics	CPU Fans and Pot Control	14.01
Kragen Auto Parts	Plastic-Weld, Silicone glue, Lube o-ring	15.27
Cardo Industries	Aluminum Sheet and rod	18.32
Kaman	Seals	21.46
HSC Electronics	Motors	10.37
REI	2 flashlights	22.44
Blue Collar Supply	Aluminum Plate	10.88
Mouser Electronics	Capacitors, Resistors, 555 timer chip	12.36
PVC parts	Home Depot	322.68
Controls, Cameras	Online	436.82
Cable	HSC	98.63
Air Hose, Tank	Ace Hardware	78.50
Servo, Pressure Reg		54.78
	Balance	**153.74**