Contents

Building Your ROV
A Manual for High School Students

1. MISSION or SCOPE

The mission (or scope of work) of a robot is what it must do. You can also think of the mission as the objective or goal. What is it that you want the robot to do to complete the mission? The mission is the starting point in design. Knowing precisely what a robot must do and what limits there are to the design are the MOST important elements of design. If you get this wrong, by misinterpreting the tasks of the mission, you will not design the best robot. A *Mission Scope* is this detailed series of tasks a robot must perform. It also outlines the constraints, limitations or parameters, of the design (such as size, weight, power use, etc.)

(For example, retrieving a toy fish from the bottom of a swimming pool, or collecting some lost scientific probes, or patching a leak in a barrel may be described in the Mission document, but this is not adequately precise for you to design a robot)

For all robotics competitions. – really, for all competitions – the rules of the game must be clearly stated and understood by the participants. In robotics competitions the "*Mission Scope*" is a document which does exactly that. In the Underwater Robotics competitions, a new, different Mission Scope is developed and provided to teams, each year. The Mission Scope originates in a Theme real-life problem, situation or project. That document is your starting point and end point !

From the Mission Scope, you'll learn exactly what is required of your ROV…what mission tasks it must perform, in what sequence and in how much time. You'll also learn from the Mission Scope what your limitations are in terms of the size or electrical power allowed for your robot; the equipment you can, must or should not use, the number of people who are allowed to operate the robot, and a number of other rules. These rules are very specific and are used to make the competition a level playing field for all teams.

From your Mission Scope you will be able to evaluate how well you've designed and built your robot. If it performs the tasks required by the Mission Scope reliably, quickly and effectively, you have been creative and done your design work well!

READ and UNDERSTAND the Mission Scopes thoroughly. Start by asking the question "*What?" must the robot do.*

2. TYPES OF ROBOTS

Underwater Robotics competitions are of two types…..ROV and AUV. These terms are *acronyms* for **R**emotely **O**perated **V**ehicles and **A**utonomous **U**nderwater **V**ehicles. The AUVs are robots which have no remote control mechanism. They are programmed to perform certain tasks independently of direct human control…on their own. Seeing them perform is at best difficult and at worst impossible, so you are staring at the surface of the water until they emerge.

The ROVs are remotely controlled. If you've ever driven a radio controlled toy car or aeroplane you have operated a remotely controlled vehicle. The underwater ROVs however, can't use radio signals to any depth greater than about1 meter….the signals are absorbed by the water. Consequently, the Underwater ROV is controlled by sending signals down a tether which contains electrical wires. Since humans control the ROV, they have to see what they are doing, so underwater video cameras are used for that purpose. Your team will be operating the ROV throughout the whole competition heat. It's more exciting!

3. PERFORMANCE SPECIFICATIONS

Our next step is to extract from the Mission Scope statement the types of tasks which are required of the robot and to define very detailed *Performance Specifications* for the robot…*what precisely it must do!*

For example:,
the depth of the water will determine the length of the tether - the wire that runs from the ROV to the controller and supplies communication and power to the vehicle.
the speed required will determine the power required in the motors required to drive the ROV;
the maneuverability required of the ROV will determine the location and direction that the motors will be mounted on the ROV;
the tasks required of the ROV will define the types of tools required on board - unscrewing a bolt will require a type of wrench and something to turn it;
the need to see what you're doing will demand certain types and positions of the video cameras.

These *Performance Specifications* are often split up into categories, which are appropriate to the type of robot to be designed. An underwater ROV (Remotely Operated Vehicle) normally has the following features which define its performance.

Structural support: What sort of supporting frame is required? What are its limitations in size, shape, weight, form or materials?

Mobility: How must the ROV move: up/down; fast/slow; rotational/turning circle; back/forward; side-to-side? How maneuverable must it be? What must it be able to sense? Light/images; proximity/distance; sound; current velocity; orientation; speed of movement ?

Actions: What must it do to complete each of the mission tasks: What activities must it perform? Are special tools or carrying structures required? Are there time limitations?

Distance: How deep must it go, how far from the deck or floating platform must it range?

Effectiveness: How does the robot score points? Which tasks are most important, or easier to perform? What are some winning tactics or strategies?

Interactions: What are the interactions of your robot with the competition field props or with other ROVs ? What further information or clarification of the mission tasks do you need to fully understand what is required?

Performance Specifications are the outcome of answering these questions. They are often stated in the following form which includes precise terms and in quantities that are measurable.

For example:
"Our ROV must…..be able to move in a forward and reverse direction at a speed of 0.25 meters / second."

"Our ROV must be able to dive to a depth of 5 meters (16')"

"Our ROV must be highly maneuverable and able to turn 360^{o} within its own footprint to conduct the missions."

Answering these questions is easier if you can sort of "put your eyes" in an ROV and form images in your mind about where the ROV must go and what it must do after reading the Mission Scope.

Telepresence
Placing your mind in the ROV as if you were a part of the machine is called *’telepresence’*. If you can do this and create an animated image of the ROV conducting the tasks of the mission scope, in your mind, it will permit you to precisely describe what it must do; how it must act. These descriptions are the Performance Specifications for the ROV.

Knowing the answers to these questions enables us to go to the next phase in the design process – and helps guide that process – to come up with required parts; the shape and design of the ROV.

4. DESIGN SPECIFICATIONS

Your next step flows naturally from the Performance Specifications. You must define more detailed technical data on the types of components which must go into the ROV to enable it to fulfill the Performance Specifications. This is often viewed in several categories of these components, which are similar to the categories of the Performance Specifications:

Performance Category	Design Categories
i. Structure	Frame design, shape and materials – for function
ii. Mobility	Thrusters: number, power, orientation
iii. Sensors	Cameras, lights, sonar, touch sensors, compass, GPS
iv. Tools	Arms, claws, rakes, wrenches, hammers
v. Ranging Distance	Tether length: waterproofing required
vi. Buoyancy/ Ballast	Fixed or variable, location and materials
vii. Controls	RC via wire or signal via fibre optic cable
viii. Other?	Depends on the specific mission

For each of the Performance Categories in the table (above) investigate and attempt to determine the types of components and materials which should go into your ROV. Naturally some research will be required and the methods for research are addressed in the next section. Design specifications are always fluid - in other words, they are not absolutely fixed. They are the best answers until additional research produces better answers or your testing of these designs doesn’t work out.

For example, your design specification for Thrusters may initially state that they should be the same as a very maneuverable ROV you viewed in a video file, e.g. the SeaEye ROV. This unit has five (5) thrusters and is incredibly fast and maneuverable. Sounds logical !

However your subsequent research or information from the research of other team members indicates that there are problems with having 5 thrusters:
a. space limitations in the small robot you will design;
b. unavailability of small enough thrusters to fit your ROV;
c. high huge cost of the commercial thruster motors;
d. difficulties in waterproofing homemade thrusters;
e. the amount of power required by that number of motors which will exceed the amperage capacity of 12V electrical power available.

So…back to the research…. What other methods or materials could work to get the required performance?

You could think of how ROV would operate with fewer motors. Perhaps you would sketch the lay-out of a ROV with only three motors. The next step might be to create a cardboard "mock-up of the design to look at in model form. You could use cardboard box for the sheet materials or structures and the tubes from wrapping paper for the cylindrical components. What is the minimum number of motors/thrusters with which an ROV could operate?

Design Specifications are often formed in statements like this:

"Our ROV will require two water proofed thrusters – one on each side - of 12V and up to 5 A power consumption each, to propel it forward and in reverse at a speed of 0.25 meters / second. The thrusters should be a maximum of 8 cm in diameter to reduce drag."

"The propellers for this unit must be shaped to optimize performance at rotations of about 1000 rpm. This will probably mean a multi-blade prop tapered towards the outside with concave edges"

The propellers must be shrouded or enclosed to prevent them:
injuring the deck crew when handling the ROV;
being damaged by hitting other structures or ROVs and thus not work;
becoming entangled in the mission props "

5. RESEARCH

It is always helpful - in fact essential - to do some research on existing ROV designs and components before you begin defining your design specifications.

Why do research?
Research will provide you with information that can help focus your mission and build a functional ROV to complete the mission. One thing of which you can be sure: the answers are already out there – somewhere.

A design which is close to that required to perform the tasks in your Mission Scope has probably been designed, built and used before!

That's why extensive research can give *YOU* the edge. You will have the valuable answers and ideas that less diligent researchers won't have. Learn from other people's efforts, ideas, designs, experiences and mistakes to form the foundation of your own design.

Once the Performance Specifications of your ROV have been carefully and specifically defined, and you are starting to refine your ideas on the Design Specifications, your research should be intensive and quite detailed.

How to do effective research.
Within your team group, assign certain people to do research and answer the following questions to become knowledgeable in these topics areas. These members will be your team's experts on that topic and guide the rest of the team in developing the Design Specifications for your robot. You should :
check out reference books;
do an Internet search for ROV and their components, etc. ;
visit a firm or agency which actually has a variety of ROV's so you can inspect their designs; and
question ROV experts from industry and educational institutes on the design and operation of their ROVs.

Computer Activity 1. - Instructions
Your early research will consist entirely of two aspects:
i. Internet searches on ROV designs and current models
ii. Industry magazines which describe and advertise the various ROV types and models.

In the table below are the general topics you should use to start your research. The eight questions below should be divided among your complete team and investigated by pairs or trios (etc) from your team, similar to the sort of working groups shown in the table. Individuals can choose which of these topics they would like to investigate. It is suggested that more people should investigate the topic that are the least familiar to the team…sort of more brain power to the difficult topics. These sub-groups will become the resident experts on the topics they choose to investigate. Not everyone will get the topic they want, because we have to keep the groups approximately the same size.

Small Group Research:
As you conduct your research on the www, jot down some notes from the sites as your search produces.
Write down the URL's (website addresses) and save to your "Favorites"

Print a picture and/or copy it onto a disk, if you need to use it to show your team or others.

Large Group Research and Discussion:
After about 45 - 60 minutes into your research, you will join up with the other members of your team and you will all sit together to discuss the things you have learned from your research. Your small group will become your team's resident experts on that subject area.

All the members within the same working group number will now present to the whole team, their findings on each of the questions for which you were responsible. Select a spokesperson or two to report your findings.

Q'no.	Team Member	Question
1	Member 1,2	Find out what are the different shapes of ROV's?
2		Are they different, because the do different tasks?
3	Member 3,4	What materials are used to build ROVs?
4		Has anyone built a ROV to do similar tasks to yours?
5	Member 5,6	How many thrusters do ROVs have? Why?
6		Why are there different thruster designs and locations?
7	Member 7,8, etc.	Will you need special equipment to perform your tasks? Is it readily available? Do you have to modify or design and build a new tool apparatus?
8		What types of underwater video-cameras are out there? Do any of them have the performance features you will require? Could you make one cheaper?

6. DESIGN

OK…… You now have some individual ideas about the design of the ROV you will require. Make some rough sketches of your ideas. This is very important. Words cannot adequately describe ideas whereas illustrations, sketches, images, can! Ever see a patent? It uses both words and detailed drawings.

Don't become wedded to your own ideas. Others members of your team may also have good ideas and the BEST designs come from an objective evaluation of ALL of these ideas. That's why the individual members of your team should independently develop their own ideas for solutions or designs. Only after this is done can the whole team come together to discuss, and attempt to refine and improve on the number of ideas which have been brought forward. We do this through a process of *Brainstorming* in teams.

What is Brainstorming?
Brainstorming is a vital part of the design process. It is a procedure conducted in groups. The basic premise is that a design forged from the ideas of many will inevitably be better than the best design ideas of a single individual. This has been demonstrated time and time again.

STEPS:

1. In groups of 4-10, elect an *animateur* (discussion leader) and a *recorder* (someone who takes notes on what is said or sketched and shown to the group).
2. The group is given responsibility for developing as MANY ideas as possible on how to perform a <u>single task</u> of the ROV mission, or (*for example*) to select the best Thruster design and placement for the ROV.
3. The *animateur* asks the group to sketch or list some ideas individually for 5 -10 minutes. No idea is too crazy – No idea is stupid - No idea will be ridiculed or criticized. All ideas – without limitation - are considered in an atmosphere of tolerance, respect and open-mindedness.
4. The *animateur* ensures that every person's ideas are heard and considered, sketches and clarifications are requested to illustrate the idea when necessary and provides time for the *recorder* to jot down descriptive notes and compile sketches form the person generating the ideas.
5. Finally, the *recorder* presents these ideas to the assembled team, and the person who generated the idea supports this presentation when necessary, with additional comments or clarifications
6. All these ideas are then vetted and discussed by the whole team, suggestions are made, questions asked, opinions voiced in terms of the value or otherwise of the idea. All these are recorded.

There is another process which can be very useful at this stage and it is called the SCAMPER process. It is a method of refining and developing or combining ideas to make them better, and it is described below.

SCAMPER

S	SUBSTIUTE: Replace one component with another (pipe frame w/ Lexan sheet)
C	COMBINE: Merge two or components into one
A	ADAPT: Adapt an existing design to your own purpose (a multi-purpose arm?)
M	MODIFY/MINIMIZE/MAXIMIZE: Change the size or number (e.g. number of teeth in a rake)
P	PUT TO ANOTHER USE: (e.g. use a thruster motor as a suction pump)
E	ELIMINATE: Could you do with less? Keep it Simpler Stupid! (KISS)
R	REVERSE: Turn the design around, upside down, might it work better?

7. Finally, after the ideas have been refined by the SCAMPER process in each category, select the best 2 or 3 ideas for further work and make practical, full –scale prototype mock-up's of the ideas.

7. THE AQUATIC ENVIRONMENT

Moving from building robots to function on land, in air is substantially different than building robots to operate in water. It's a totally different environmental medium.

Water differs from air in the following ways:

AIR	WATER
Air is a fluid	Water is a fluid
Air is a gas	Water is a liquid
Air is light	Water is heavy
Air is not very dense	Water is about 750 x denser than air
Air is compressible	Water is not compressible
Air is a good heat insulator	Water is a great heat sink
Air doesn't conduct electricity well	Salt water conducts electricity well
Air doesn't dissolve things	Water is formed from polar molecules
Air is formed from several gasses	Water is formed from a single molecule

All these things affect the design and other features of the components used in an underwater ROV – sometimes in unexpected ways.

In the next couple of pages, we will examine the affects of water on designing an ROV.

7.1 The Aquatic Environment – Pressure

Think about the depth of the water you're working in and how your structure will handle the increasing pressure with depth.

Discussion questions: Why are the pressure hulls of most submersibles spherical? Spheres are the most pressure-resistant shape. Hulls are pressurized to 1 atmosphere and are made of materials that help to maintain this by withstanding the pressure changes.

Laboratory:
1. Inflate a spherical balloon with air, Tie some string around the balloon's widest circumference. Measure this circumference. Tie a heavy weight to the balloon and lower it gently underwater. What happens to its volume? What happens to the string around its circumference?

Pressure & Depth
Right now you are moving through a sea of air. The column of air over every single square inch of surface weighs 14.7 lbs at sea level. The metric equivalent is 101 KiloPascals (kPa) or 101 millibars. This is called one atmosphere (1 ATM) of pressure.

For every additional 33 feet (10 meters) you descend into the ocean, pressure increases by an additional 14.7 lbs per square inch (101 kPa). – one additional atmosphere (ATM) of pressure

At 33 ft depth (FSW) you only “feel” 14.7 additional lbs per square inch or 2 atmospheres of pressure. Thus, one atmosphere = 14.7lbs/square inch.

Sea level = 1 atmosphere = 101 KiloPascals or 14.7lbs/square inch.
33 feet deep = 2 atmospheres = 202 kPa or 29.5 lbs/square inch of surface area
66 feet deep = 3 atmospheres = 303 kPa or 44.2 lbs/square inch of surface area
100 feet deep = 4 atmospheres =404 kPa or 59 lbs /square inch of surface area

This is thinking in terms of absolute pressure. However, we usually think in terms of gauge pressure. Pressure gauges are set at 0 at sea level, which means they will read 14.7lbs/square inch (101 kPa) at 33 feet deep (10 m).

Example:
If depth = 8,250 ft (2500 m) ; pressure = 3675 lbs/square inch or 250 ATM.

“Feeling” Pressure: Use a large trashcan filled with water and plastic bags. Put your arms in the bags and immerse them into the trashcan. You can “feel” the water pressure as it squeezes in on the bag. If the trashcan is deep enough, you can actually “feel” more pressure on your fingers than on your forearms.

How does pressure affect an underwater robot?

The deeper the ROV goes, the more pressure exerted by the water column on gas filled spaces such as motors and camera casings.
The deeper the ROV, the greater the pressure for water to enter these spaces and to compress anything containing gas – even rigid foam insulation.
If you have a cut in the tether coating and allow water to enter, the water pressure will force water up the tether to the level of the surface.

7.2 The Aquatic Environment - Buoyancy

Buoyancy & Archimedes Principle
The Greek philosopher Archimedes, who lived from 287 to 212 B.C., discovered a law of physics that has become known as Archimedes Principle.

Archimedes Principle states that an object wholly or partially immersed in a liquid is held up by a force (buoyancy) equal to that of the weight of the water it displaces.

Displacing simply means pushing water aside. If you push an empty bucket into a pool, it is pushing water aside – displacing it. Bugger objects obviously push more water aside or displace it. So pushing more water aside means displacing more water. A boat displaces more water than a bucket ……..Doh!

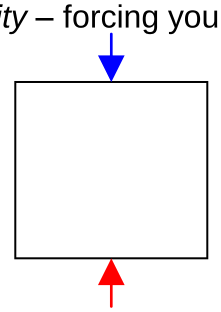
Displacing more water = more buoyant force and more difficult to sink.
Displacing less water = less buoyant force and easier to sink.

Demonstrating Archimedes Principle: Cartesian Diver – see http://www.exploratorium.org/snacks/descartes_diver.html

For more on buoyancy and ballast: Alvin's Ballast Systems (9° North November 18th expedition log) – see http://www.marinetech.org/nine_degrees/expedition.html?phase=log&date=942912000&base=expo942864462&picnum=0

How does buoyancy affect your ROV in water?

Gravity – forcing your ROV down



Buoyancy - lifting the ROV up and

There are two forces acting upon your Remotely Operated Vehicle in water :

Buoyancy is an upward pushing force; Gravity is downward pushing force.
Neutral Buoyancy is achieved when both forces are equal.

There are ‘*imaginary centers*’ where these two forces are concentrated in any object in a fluid called the Center of buoyancy (COB) and Center of Gravity (COG), respectfully. The COB is always above the COG; if not, the vehicle is unstable and will turn over and make sure that this is so.

The distance between COB and COG is called the BG (Buoyancy Gradient). The greater the distance between the COB and the COG, the more stable the vehicle and the more likely it is to remain upright. However, the smaller the BG distance, the less stable but the more maneuverable. (*Think of a jet fighter aircraft.)*

A ROV which has the COB and COG in the same spot is expected to be highly maneuverable, but will turn over quite easily and therefore is rather unstable. So are most fighter planes. Some submersibles are built this way as well. However, having the COB and COG in the same spot requires active control – by the pilot or a computer – to keep it that way.

Discussion questions: Why are ROVs box-shaped? Remember that function drives design. What is the purpose of an ROV? ROVs are made to do work – pick things up, take core samples, etc. You need a stable platform to do this; therefore you need to increase the BG. That’s why ROVs are so tall: a large BG = stability. We don’t necessarily care whether or not the ROV is streamlined because we can overcome the drag of a boxy shape with propulsion devices.

Two Important Physics Rules relating to ROV design

1) Floats must be located above heavier weights. (Stability is the issue here.)

2) An ROV must to float before it can sink (make sure that when finished, the ROV is trimmed to be just a little….a very little…..positively buoyant.

An ROV shouldn’t sink when it’s put in the water – it should float – at least a little. Think of ROVs used by the scientific community or the oil industry. What if they sank immediately upon entering the water? Most scientists and employers don’t want to risk losing a very expensive vehicle.

Also, think about function here. What is it that you want your ROV to do? There are bottom-crawling ROVs that are made to sink because their purpose is to sit and work on the bottom.

In the underwater robot competitions, however, a number of the Mission Tasks are conducted in mid-water. The more your ROV departs from neutral buoyancy (either sinks or floats) , the more problems you will have in maintaining a position and working in mid-water. It will require using thruster energy to simply stay in position. Furthermore, many Mission Tasks require lifting something from the bottom and you’ll need additional buoyancy to aid surfacing. Most of the time you want your ROV to float before it sinks.

Laboratory 2.

1. Take a plastic glass or cup. Make two holes in opposite sides near the open rim of the glass and tie pieces of string about 6” long, through both holes
2. Attach equal weights like old bolts to each of the strings, and keep the string length as short as possible. Insert an seal a small diameter aquarium tubing about 3’0” long into the bottom of the glass and squeeze it shut.
3. Let enough air out of the over-turned cup to permit the cup to go to the bottom of the tank. Adjust the air level to make it neutrally buoyant.
4. Now, try and make it neutrally buoyant with small pieces of Styrofoam.

Which material is easier to achieve neutral buoyancy? Why?

Laboratory 3.

1.. Glue a 35mm photo film canister inside the cup.
2. Melt or drill small holes in the bottom of the canister.
3. Insert an antacid tablet in the canister and re-immerse it in the tank, releasing enough air to make it sink. Sink the cup and see what happens.

Back to Archimedes Principle

By adding ballast in the form of weights, you can in essence make the object weigh more than the water it displaces and in this way help it to sink. Ballast, along with motors and propellers, make Gravity greater than Buoyancy and allow the vehicle to sink.

7.3 Aquatic Environment – Density

Water Density

Density and buoyancy
Related to Archimedes Principle is the concept of *Density*. Why do balloons filled with helium gas float in the air, but those of the same size, which are filled with air, do not?

It relates to how much the different gasses weigh for the same volume of balloon. The balloon filled with helium gas weighs less than the air which it displaces. In other words, it is a lighter gas for the same volume, which is another way of saying it is less DENSE. *Density*, then, of any substance is the weight of a specific volume. – and represented by say… grams / liter or lbs / cubic foot. If wood is less dense than water it will float in the water.

Density and Resistance

You can walk swiftly, even run through air, but have you ever tried walking upright when the water was up to your chest? Really difficult isn't it.. That's because water is so very much denser than air – it's difficult to push aside. It's much easier to swim through it than push the water aside while walking. In the same way, the less surface area of your ROV you try to move through the water, the less resistance the water will exert on it and the less power will be required to make it move faster.

How does Density affect your ROV?

Buoyancy
By adding ballast in the form of weights, you can in essence make your ROV weigh more than the water it displaces and in this way, help it to sink. Ballast is anything which is denser than water ; Flotation is anything which is less dense than water. So ballast can be your motors, propellers, thruster housings, structural frame, electronics, etc. Flotation can be oil, air enclosed in rigir foam or inside a sealed space or can, pieces of wood, etc. If you make Gravity greater than Buoyancy it will allow the vehicle to sink.

Resistance
Making your ROV with a large surface area prevents water from flowing through it readily. It's the same as moving a paddle through the water, it requires such effort that the boat moves instead.

If your ROV is to be efficient, you must be ever mindful of ways to reduce surface area to enable the ROV to move efficiently in all directions – forward/back; up/down; turn left/right. You must think about this when designing the mechanical, frame and tool components of your ROV and when choosing the type of tether to be used.

7.4 Aquatic Environment – Conductivity

Electrical Conductivity of Water

Conductivity
Most ROV's use electrical power; either to drive electromechanical motors for thrusters or to drive an electrical pump motor for hydraulic thrusters. Electricity is also used to power controls, underwater lights, cameras, and motorized tools such as robotic arms, etc.

The electricity for these uses travels down a tether which is a multi-wired cable. In most commercial ROVs the voltage can be between 40 and 600 Volts DC. The high voltage permits a lot of current to be carried down a small wire thereby reducing the weight and drag, of the tether.

This is all great – UNLESS, there is a leak into the electrical or electronic components of the ROV. Water conducts electricity and causes short circuits in the electronic components - making them dysfunction. It's bad enough with fresh water, but salt water in the ocean is several times more conductive than freshwater. Consequently, a leak of water into any electrical or electronic components is a tragedy that may irreparably fry all the electrical components of the ROV. The other concern id safety as divers working in the vicinity of an electrical leak may be in grave danger.

7.5 Aquatic Environment – Electromagnetic barrier and Thermal effects

Electromagnetic barrier properties of Water

Barrier to Radio Waves

Water conducts electricity and causes short circuits in the electronic components - making them dysfunction. It's bad enough with fresh water, but salt water in the ocean is several times more conductive than freshwater. Consequently, a leak of water into any electrical or electronic components is a tragedy that may irreparably fry all the electrical components of the ROV. The other concern is safety as divers working in the vicinity of an electrical leak may be in grave danger.

Alteration of light penetration

Water filters our light to a varying degree depending on the frequency (colour) of the light. If you wore a red T-shirt SCUBA Diving in warm water, it would look muddy brown at about 20 ft depth – even in very clear water. It's colour would change gradually with depth because the shorter wavelength light is filtered first. Blue light from the sun is visible down to 300 ft depth. At 100 meters depth, most of the light from the sun is filtered out and the sea is dark.

Light is also distorted or refracted when it travels from air to water or vice versa. This is called refraction. You can see this if you put a pencil in a class of water and look at it from the side. Water acts as a lens.

This affects the way underwater cameras "see". It reduces the camera's field of view (FOV or horizontal angle) over which it and you can see. For example, a video-camera with a FOV of 105^o in air has only a FOV of 81^o in water, so you have to move the camera back from the object you're viewing to get it all in the picture.

High Specific Heat

Water has a very high specific heat. This means that it can absorb a great amount of heat energy and still be warmed only slightly. While this is bad if you fall overboard in cold water, it is good if you want to dispel heat build-up. Water acts like a very efficient *heat sink*. Because it takes a lot of heat to warm the water. This feature of water is used to keep your working Thruster motors cool so they don't burn up. It is also why you shouldn't operate them in air.

How do these physical features of water affect a ROV?
If you are looking for different coloured objects at depth in the water, particularly those coloured red or orange, the ROV must bring its own light. It will also need lighting if it is inside a structure like a reef or shipwreck or, of course, if it is night.

When light in the water enters the transparent lens of the casing for an underwater camera, if is refracted, and may distort or reduce the range of vision of the camera lens, making the image narrower than you would expect.

When electricity travels down a small wire, there is more resistance which is noticed by the wire becoming heated. When wire conductors are heated, they further reduce the flow amount of electricity which the wire can carry, causing voltage drops and power loss over a length of small gauge wire.

This can also be a worry because, at some point, the wire insulation can melt and cause a short circuit between that wire and adjacent ones.

8. BASIC ENGINEERING PRINCIPLES:

Perhaps the most important principles of engineering design are:

8.1 Ask the right questions:

In so many problems or areas of uncertainty as to the best solutions to a problem, the most important starting point is asking the right questions. For example if the eventual design is to succeed, what are the essential or important things on which you should focus.

For example: If it's a boat you're designing, above all else, it should float and not turn over. If it's a ROV your designing, above all else it must perform well, the task for which it is being designed. It doesn't matter if it's fast, streamlined, powerful, beautiful to behold, an elegant design, if it won't fit through the minimum opening in its holding garage.

8.2 The Many Heads Principle:

This principle states that the more ideas, applied to a question or problem, the better the solution is likely to be. Involve many people in the design process, with different experiences and expertise.

Some of these ideas may be old ideas and readily available from some of the research you will conduct. Some of these ideas might be modifications (even slight changes) of existing mechanism or solutions. (You will find that these types of solutions will most probably be your best options). Finally, totally novel or unique ideas might be required to form a solution to your problem, but this is much less likely because so many solutions already exist.

KISS PRINCIPLE: Keep It Simple, Stupid.!! This principle states that if there are two ways of doing something and one is simpler, choose the simpler alternative. Why? Fewer complications in design, fabrication and maintenance – means that there is less to go wrong.

For example: If you can design a functional robot with only one motor/thruster for propulsion, this is better than an equally functional design with two motors. If you can limit the power consumption to motors which operate peripheral tools or devices, there is more available for other energy demanding tasks, such as movement through water.

9. ROV DESIGN CONSIDERATIONS

The eight (8) topics that you need to consider when designing and building your ROV are:

Function – what the ROV must DO is what drives choices in all that follow.
Structure – what keeps it all together
Flotation – what allows it to float
Ballast – what helps it to sink
Power – what supplies the energy for the vehicle
Propulsion – devices (motors and propellers, also called “thrusters”) that transform electrical energy into motion
Control – directing the vehicle – the human interface with the machine
Navigation and sensors – sonar, video, lights

These items are discussed below in more detail, except when they have been treated above in section 6.

9.1 Function

Function or what the ROV must do to achieve its *Mission Scope* are the focal points of design and building. So, with the expectation that the ROV will have to be built around your tools, the first task is to look at ways or the tools which your ROV will require to achieve the tasks. Otherwise, you may design a beautiful vehicle which is cannot perform the functions you require. It would be like designing a sports car when you need to carry firewood.

Start with function!
Look at the Performance Specifications again. What did your group identify as the important tasks and how did they suggest that these tasks be accomplished – by what

designs or tools? Sketch these ideas and think about how they could be made more efficient or simpler.

For example, can the tools or mechanisms be made smaller, less heavy? Is there some danger that if may be ineffective in some way and can you think of a design change to correct it? Do you need a motor to operate it or can you think of a way to use the movement of the ROV or some other mechanism to achieve the same task.

Test your ideas!
Build functional mock-ups of these tools or mechanisms. You can use cardboard, wood, foam core, plastic – anything which will enable you to test the basic ideas. Consult with your instructor on what you could use to create a mock-up of the tool or mechanism.

Now test it IN WATER! Just because it works in air doesn't at all mean the mechanism will work well in water. Remember, water is a completely different medium or environment than air. It will affect the operation of the tool or mechanism dramatically.

9.2 Structure

Sketch a layout of your design before your start. This should just be a rough outline of where you think the various components of the ROV should be. There should be at least three (3) sketches – TOP; SIDE and FRONT or BACK. These sketches should be drawn at the same scale perhaps ½" on the drawing = 1" of the actual robot. This means that an 18 " robot cube will be drawn in a 9" cube on regular letter paper.

Helpful hint
Remember, the frame structure should NOT drive your thinking about your eventual design. The tools or components required to complete the tasks should!! Let function (what it is you want your vehicle to do) drive the general layout of your ROV (where things should be placed).

Stability
In sketching your rough layout, think about stability. Where should your buoyancy be? Where should you attach the motors and propellers for thrusters and other devices that you may need to complete your mission. Where will you place these components to maintain a stable structure and still allow them to function? Do you want a highly stable ROV or one which can me highly maneuverable and turn somersaults?

9.3 Flotation

We discussed flotation before. Essentially a stable ROV has a large vertical distance between the Centre of Buoyancy (COB) , produced by the flotation and the Centre of Gravity (COG) , produced by all the things that are heavier (denser) than water . Naturally the flotation sits above the COG.

In reality, most ROV's have their flotation in the uppermost level of the structure, and everything else hangs from beneath it. This is particularly true of what is called the "*Work Class*" ROVs which are those used most frequently in industry. They don't need to do somersaults; but they do need to provide stable platforms for their working arms and other tools.

If a ROV tool needs to undo a large bolt underwater, the force applied will also turn the ROV in the opposite direction. (Much like in space.) An unstable ROV will turn considerably more, thus less force can be used to do the work required. So the need for a stable ROB is obvious. Normally the industrial ROV doesn't have to travel any significant distances to do its work, so having a tall box shape, with significantly higher water resistance (*drag*) is not a problem.

The other major class of ROV's are the "*Eyeball Class*" . These ROV's are typically used almost exclusively for inspections and not much active work.

They have to cover larger distances, so they are typically more streamlined , are a lot smaller, and have less drag. They need to be more maneuverable to go up and down in their work, and consequently, may have less stability.

9.4 Ballast

Ballast is anything on the ROV which is denser than water and causes it to sink. It would include the frame, motors, propellers, thruster housings and cowlings, lights, camera, tether, pumps, onboard electronics and any tools needed to do the work. So it would seem that with all this stuff that sinks, it wouldn't be necessary to provide additional heavy material on the ROV. In most cases that's true. The wise location of these sinking items (denser than water) means that no additional ballast is required.

Additional stability in a work class ROV or more maneuverability in an eyeball class ROV might require the addition of ballast, but if that is the case, the following should be kept in mind:

Ballast should be very dense so that it has little surface area and causes minimum drag.

Ballast should be placed carefully only on the finished ROV to provide small refinements in trim or stability. It should NOT be electolytically active with other metals (Copper and Tin) on the ROV and chemical reactions occur between them. (lead is a good option)

9.5 Power

Most ROV's use electrical power as the source of energy to drive its various components. Your power source can be as simple as a 12 VDC (Volts Direct Current) car battery or portable power source. That's what we will use in our student robots.

In reality, the voltage produced by a fully charged car battery is about 13.5 VDC, but that won't hurt your ROV's equipment. Furthermore, the voltage will drop or decrease as it travels along the wires in your tether. The farther it travels, the greater the drop in voltage, so you will have less thruster power on the bottom, that if it was connected right to the battery.

In our case, there will be a pair of small wires (18 gauge - AWG); one positive (+) and one negative (-), for or each motor or other electrical component on your ROV. You will have a maximum power available of about 18-20 amps.

Industrial ROV's often use much higher voltage than we will use – up to 3000V supplied from the surface, but this high voltage is transformed to 48V, 24V or 12 V DC onboard the ROV for use by the motors, pumps, lights and cameras. . There is at least one positive (+) and one negative (-) wire carrying the power inside the tether for an industrial ROV.

The power for ROV's is normally conducted from a surface source to the ROV by a *Tether* cable. Tethers perform several functions:

i. Power transmission: copper wires inside the multi-wire tether act as conductors to bring the electrical power to the ROV and its components.

ii. Signal wires: smaller signal wires on industrial ROVs conduct signals which govern the amount and polarity of power provided to the ROV motors and other components. On our SCOUT ROVs, the 12V DC power is turned off or on by double pole / double throw (DPDT switches on the surface and controls which Thruster(s) get the power needed to maneuver the ROV.

iii. Video (camera) information is sent through a coax cable like on the back of your TV set, which is attached to the outside of your tether cable. It will provide a clear picture of its FOV, on a TV monitor located topside.

iv. Flotation: If the tether sinks it is a drag on the movement of the ROV, so it is normally coated with a light incompressible plastic layer to give it neutral buoyancy. In the scout class, you can use flotation material which will NOT compress in deeper water.

A Brief Lesson on Electricity

Electricity is the energy that is produced by the movement or flow of electrons through a conductor. The measure of the rate of flow is called current and is measured in amps.

Conductors are materials that allow electrons to flow easily through them. Some materials are better conductors of electricity than others. Pure elemental silver is the best conductor. Gold, copper, aluminum, steel – the metals – are also good conductors of electricity.

In supplying power to your ROV, the goal is to pass electricity from its source down the tether to the ROV; therefore, it makes sense to use a good conductor. That's why ROV tethers contain copper wire – a very good conductor.

Insulators are materials which are NOT good conductors of electricity, than it's often a good insulator. An insulator basically prevents or slows down the flow of electrons. Plastic and rubber are good insulators. Insulators wrapped around copper wires allow multiple wires to be bundled together without shorting each other out. The copper wire conductors in ROV tethers are coated with a good insulating material.

An electrical cell a contains a chemical reaction which produces electrical discharge or electrons. You know them as C-cell or D-cell or AA cells. A real battery is a collection of such cells connected so that their Voltage is a sum of the individual cell voltages. Both are examples of a power source.

The cell or battery represents stored potential energy – a stored source of electrons. Volts is the measurement of that potential energy – how much energy is stored in the battery.

A battery has positive and negative terminals or poles; the + and - represent a high (+) or a low (-) charge of electrons. If the two battery poles are not joined by a conductor, there is no flow of electrons between the two poles. The energy is untapped, so to speak. However, as soon as you connect the two poles with a piece of copper wire, you get a flow of electrons from positive pole to negative pole; energy is tapped and released. You've essentially created a circuit or pathway through which electrons can flow.
You may have noticed appliance labels that read, for example, 120v AC , 60 Hertz. This means that the appliance functions using power that is 120 volts of alternating current fluctuating at a rate of 60 times per second. AC current is created by generators.

Motors and propellers represent resistance. Resistance is just that – resistance or impedance to the flow of electrons. The higher the resistance to the flow, the lower the flow or current of electrons, and vice versa; the lower the resistance, the more easily electrons flow and the higher the flow or current. Resistance is measured in ohms. The product of resistance is normally heat. In motors, a build up of heat means the motors are working too hard.

Series versus parallel circuits
Let's say you want to wire electrochemical cells (batteries) in a series circuit. You would join the cells end- to-end (positive to negative in a chain) like in a flashlight. Wiring them this way, the voltage – the potential stored energy – is additive. Therefore, if you have three 12-volt batteries wired in series you have a total of 36 volts. What's the advantage to this? More power, more potential energy, which means your motors will turn faster, which means that your ROV will move faster.

Now, let's say that you want to wire these same batteries in a parallel circuit. In this case, you must connect all the positives ends of the cells to one wire and all the negative ends of the cells to a second wire. In a parallel circuit, the voltages of each battery are not added together. The voltage of the three cells in a parallel circuit is the same as in each individual cell – still 12 Volts.

Why do this? The greater number of cells lets the power supply last longer, your ROV has greater endurance, the motors and other units work much longer..

For more electronics see "The ROV Alvin's Electronics and The Ground Control problem (9^o North, November 17^{th} expedition log)

9.6 Propulsion

What moves the ROV? Motors and propellers, which in combination are called *thrusters*. Thrusters take the electrical energy from the battery and transform it into mechanical energy or motion. Thrusters with cowling on them and specially shaped blades to conform to the inside of the cowling are called Nozzles or 'Kortz Nozzles'.

Trying to decide which is the best size of motor and best shape propeller for your ROV is part science; part art form; part experiment. There is an awful lot of information known about ships motor and propeller design, and there seem to be many different combinations which work well. However there are some basic rules and jargon associated with the topic.

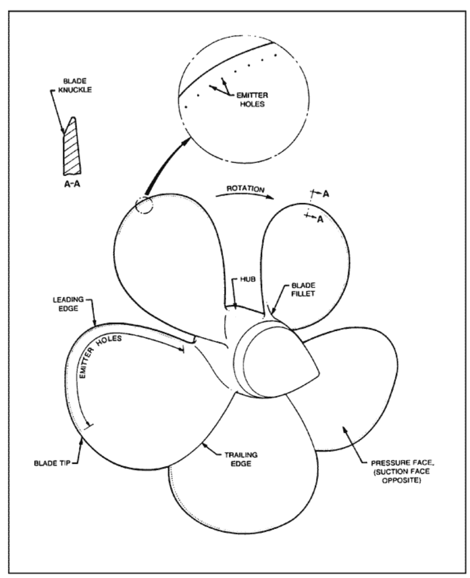


Figure 2-1. Propeller Terminology.

Hub. The center section of the propeller bored for a tapered (interference) fit onto the shaft.

Blade Fillet. The radii defined by the transition of the blade faces into the hub. Also referred to as the blade root.

Pressure Face. The aft face of the propeller blade.

Suction Face. The forward face of the propeller blade.

Leading Edge. The blade edge adjacent to the forward end of the propeller hub.

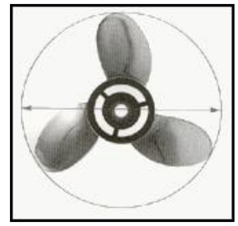
Trailing Edge. The blade edge adjacent to the aft (back) end of the propeller hub. A blade knuckle is a sharp, wedge-shaped trailing edge as illustrated in section A-A

Blade Tip. The blade edge on the outermost radius of the propeller.

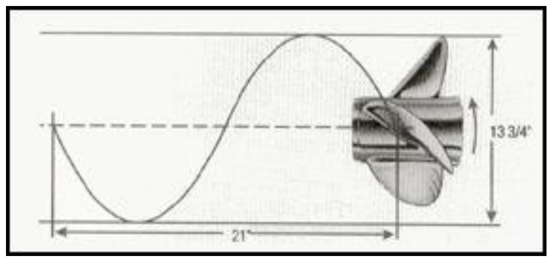
Emitter Holes. Holes drilled into a channel near the leading edge.

Propeller Selection: The size of a propeller is described using two sets of numbers. These correspond to the diameter and pitch. The pitch always follows the diameter when describing a propeller.

Diameter: Diameter is two times the distance from the center of the hub to the tip of the blade. It also can be looked at as the distance across the circle that the propeller would make when rotating. It is the first number listed when describing a propeller.

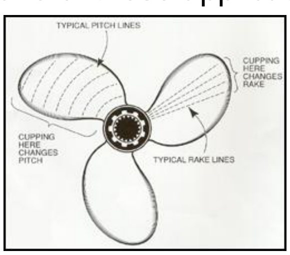


Pitch: Pitch is defined as the theoretical forward movement of a propeller during one revolution -- assuming there is no "slippage" between the propeller blade and the water.



Slippage: For most boats, there <u>is</u> slippage and therefore the distance advanced is less than the design pitch. The amount of slippage varies from boat to boat. Pitch is the second number listed in the propeller description.

Cupping: Many of today's propellers incorporate a cup at the trailing edge of the propeller blade. This curved lip on the propeller allows it to get a better bite on the water. This results in reduced ventilation, slipping, and allows for a better hole shot in many cases. A cupped propeller also works very well where the motor can be trimmed so that the propeller is near the surface of the water. The cup will typically result in higher top end speed on one of these applications.



CUPPING RAKE

Rake: Rake is the degree that the blades slant forward or backwards in relation to the hub. Rake can affect the flow of water through the propeller, and has implications with respect to boat performance.
Aft rake helps to trim the bow of the boat upwards, which often results in less wetted surface area and therefore higher top end speed. Aft rake propellers also typically "bite" better on ventilating type applications.
Forward, or negative rake, helps hold the bow of the boat down. This is

more common in workboat type applications.

Some fundamental rules about selecting propellers and motors:

Choose an electrical motor based on four features:
adequate power output, measured by amps or watts consumed
suitable voltage for your electrical system (12V DC for ours)
ease of waterproofing or possibly already water-proofed.
small diameter on the circular dimension and low the drag

What is adequate power?
The power is merely a function of the output of your motor. If your motor is too big, it may draw sufficient current as to greatly reduce performance and operate at low efficiency. If it is too small, the amount of thrust will be inadequate

Choose a propeller for your electrical motor based on four features:

the diameter which should exceed the motor diameter although the hub can be same size as the motor or transmission.
the pitch of the blade, which depends on the diameter and the rotational speed of the motor in RPM's
the width of the blade , which effects the amount of water it pushes.
the weight or mass of the blade, lighter, thinner blades for higher speed applications

What is the best motor and propeller combination?

This can be determined simply by experimenting! The optimal performance can be tested with a motor and a series of different propellers. The motor can be fixed on either a sliding platform in the water or on a vertical rod which rotates on a horizontal axle. Then a simple spring scale or, for more accuracy, a strain gauge can be connected to the motor and the force of the motor / propeller combination is measured under the peak and reduced Voltage conditions. This is called a *Bollard Pull* test. (see appendix for instructions)

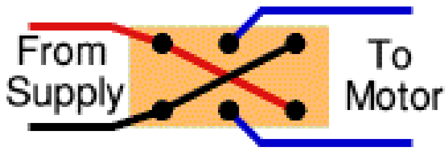
Some additional instructions on selecting the right propeller for your ROV is available at http://www.post1.com/home/oskarlee/propCAD.htm

9.7 Controls

In the final analysis, the pilot is the controller of your vehicle. The skill of the pilot can make a huge difference in the performance of the ROV and thus, it is wise to ensure that pilots get plenty of training to become efficient.

Pilots control the ROV by sending signals down the tether wires to activate the motors which generate the rotational force to turn the propellers. The motors, the propellers, the metal, bullet-shaped hub joining the two, and a shroud which protects the propeller and the fingers of deck hands constitute a "*thruster*".

In the SCOUT class of ROV, the switches used merely permit the motor to be turned on or off, and to reverse its direction. This is achieved through the use of a DPDT switch (described above and shown to the right).



The DPDT switch used permits reversing the polarity of the electrical power, producing the reverse in direction. It is also spring loaded and returns when released to the centre off position. As simple as this switch is, it has controlled provincial winners in the Ranger class of ROV competition for years.

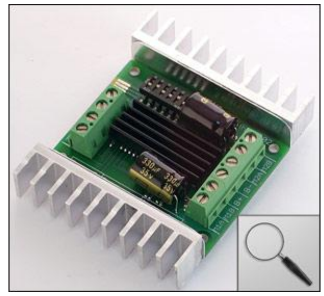
The SCOUT and Ranger teams use a switch control box – one for left or Port thrust, a second for right side or Starboard thrust and another for vertical thrust. Bear in mind that each switch can control the motor in two opposite directions.

Both horizontal switches in forward position pushes the ROV forward, with reverse also being true. The Starboard switch forward sends the ROV in a left arc or circle. Combine that with the Port switch in reverse and the ROV spins on its own footprint. Consistent Ranger class winners have used this simple but effective control apparatus, as do many Regional competition winners at the International Ranger class competitions.

The only drawback of the DPDT switch is that it does not permit proportional control, where a little movement of the switch will produce a slow turning of the propeller and pushing the switch farther results in acceleration. For this feature, a more sophisticated electronics arrangement is required.

Many Ranger class teams use a joystick, attached to a computer and electronic speed controller (ESC) to provide proportional control for their ROVs.
This arrangement permits variable speed control, which provide a range of speeds that is often advantageous when accurate movements are required to accomplish precision

tasks. There are many types of ESCs, and should be selected based on their ability to handle an input of 12 Volts DC and an output amperage (A) which is demanded by your thruster motors. Generally the *Scout* class uses a 500 gph bilge pump motor requiring about 2.5 A at peak load. The *Range*r class uses a 1100 gph bilge pump motor with about a 3.7A peak load.



With the ESC (shown right), if you want the ROV to turn left in a slow arc, you can gradually reduce the speed to the Port thruster and maintain higher speed in the Starboard motor.

If you want the ROV to pivot and spin, the Port thruster motor is full forward and the Starboard thruster motor is in full reverse. Given there is one or more vertical thrusters, pushing water down will cause the ROV to rise and *vice versa*.

Some components benefit from proportional control, such as for a robotic arm to do precision movements to achieve tasks or other tools. These more advanced controller systems use Pulse Width Modulation (PWM) and electronics to control speed and reverse motion of the motors. Some components only need off / on switches, such as for lights, wrench tools or pumps.

Larger ROVs used by scientists and industry have entire rooms, filled with video monitors and pilots operating joysticks, which move manipulator arms, and receive information from sensors.

9.8 Navigation

The navigation for the vehicle is done by the pilot using his or her eyes to steer the vehicle and see where it's going. In most Scout class competitions, the pilot peers over the side of the pool and tries to determine what the ROV is doing by looking through the surface of the water. This is largely due to the cost of a reliable waterproof video camera. In both the Scout and Ranger class competitions in NL, a more realistic underwater video camera must be used.

On your ROV you will need an underwater video camera and this is provided as part of your parts bank. The one you will receive is waterproof and can be used on your ROV as is. All you have to do is attach the coax cable to the ROV's tether with some tape about every 30 cm and plug in the dry end to a TV. You can purchase any number of additional cameras….. even ones that need to be waterproofed. If you want to take on this challenging and vital task, specific instructions can be provided.

It may also be useful to know your orientation such as in direction and depth. There are sensors available by which this information can be viewed on your controller device. With time and money, you could add video and still cameras, sonar, lights, etc.. You could even add an electronic compass which will read on the surface or be seen by the underwater cameras.

Activities in navigation: Ocean Adventure Sound in Seawater – see http://library.thinkquest.org/18828/data/interactivity_5.html.
Pat's Lesson in Navigation (Return to 9° North April 22nd expedition log) – see http://www.marinetech.org/return_nine_degrees/expedition.html?phase=log&date=956386800&base=expo955408611&picnum=0 (this includes geometry concepts!).

10. FABRICATION

Tools and Safety: - SAFETY FIRST
You will be using tools for cutting, which are sharp; tools for drilling holes which are equally capable of drilling you; tools for soldering which can burn, and then there are some power tools which can perform all of these tasks better and faster. You should gain from this ROV fabrication experience,

10.1 SAFETY FIRST!

Safety apparel (PPE):
During all fabrication in which there is any risk of things being pushed, thrown, released or thrust into your eyes, you must wear safety glasses or goggles. This includes, but is not limited to hammering, cutting, sawing, drilling, assembly, sanding, polishing, screwing or soldering, etc. You should also wear closed-toed footwear. Shoes or boots with hardened toes are also a good idea.

If there is any possible risk of a heavy piece of equipment or materials falling on your head or feet, you should use a hard hat and steel-toed footwear.

Tools:
Your instructors will provide you with instruction on the safe use of all tools. If you are not completely comfortable with the use of any tool (hand or power) DON'T use it! Approach an instructor who will be only too happy to demonstrate its use or complete the task on your behalf. We hope you will gain confidence in using these types of tools during the process, but you are also quite welcome to ask another student with more experience in using tools to do so on your behalf.

You will also be sharing some tools which will be loaned from central stores, or found in a tool kit. It's pretty frustrating to have to look around a whole workshop for the one tool which will do the job, so the solution is for everyone to put the tool back where you found it – as soon as you've finished with it. Power tools will be signed out and signed in when you're finished.

Slippery surfaces:

In a fabrication shop for ROV's there will inevitably be some water spilled and possibly some light oils, which may cause the floor to be slippery and thus dangerous. Be on the lookout for the presence of these substances on the floor and i. mark them, ii. cover them and iii. remove them ASAP.

You'll be working around a tank of water with your prototype and around a pool with your finished ROV product. These wet environments are particularly slippery if you are running or have inappropriate footwear. DON'T !!

Skylarking; roughhousing, playing; throwing; swinging:
A workshop is NOT a gymnasium! There are any number of ways in which you can hurt yourself. None of the above is an appropriate activity in a workshop – and you WILL be stopped and disciplined if they occur. The appropriate behaviours in a workshop are those you'd use in <u>Church !</u>

10.2 Sequencing

The next big question is *"What happens next in building the ROV?"* Our best advice is *NOT the ROV*. If you build the vehicle first, you may find that the mission tools you eventually design and fabricate don't fit it.

So, we would recommend you go back to the *Mission Scope* and as a team start reading, researching, creating as <u>many individual</u> ideas and drawings for the tool to complete the first task, as possible. Bring back the individual ideas and drawings to the team and use the brainstorming and SCAMPER methods to refine the design. Create a mock-up and finally build the tool. Test the tool on some mock-up of the Mission Props and see if it works. You may observe that it doesn't work as well as you'd like. Don't stop there! Most inventions require several refinements to do the job properly and the absolute best way to find out if it can do that job is to try it in the conditions it will face in the competition.

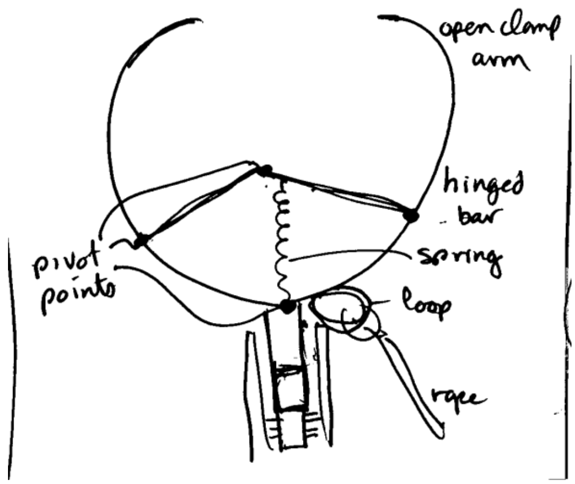
When should you start building the actual ROV? That depends on how many people you have on your team. If there are a large number of students on your team, and you have a second mentor to guide them, you may wish to assign a small group to build the ROV right after the 2nd or 3rd version of the first tool has been tested. Attaching the first tool to the ROV is the most realistic testing situation and it will give your pilots experience in that task.

Now start with the same design, build and test process as above, for the second, third or fourth Mission Task.

10.3 Mock-up and prototype construction

The first mock-ups are called "proof-of-concept" prototypes. After several solid design concepts or ideas are selected, for any task, they must be demonstrated as technically feasible. The concepts which appear to be the most feasible from the detailed drawings and the subsequent brainstorming, SCAMPER and feasibility investigation, must still be demonstrated after they are fabricated in your first prototype. You are cautioned that just because an idea seems great on PAPER doesn't mean that it will actually WORK!!

For example:
The idea:
You have an idea about a mechanism which when attached to an ROV will retrieve a lost "sonar tow fish". The sonar tow fish is a torpedo shaped device which is about 100 cm long and 10 cm in diameter. It has four radiating fins on the back end and a round nose cone. It also has a 10 cm diameter tow-loop (U-bolt) on its shaft about 1/3 the way back from the front end.



Your idea is to have a plastic ½" diameter rod sticking out of the front of your ROV which carries a spring-loaded, self-closing clamp / hook, attached to a rope. The clamp can slide off the rod when it is attached to the tow loop on the "sonar tow fish"..

The sketches:
Your first task is to sketch the clamp or hook, as its working is an essential part of your idea, your sketches should be in great detail. (A rough example is shown to the left.)

It's really easy to change sketches, to move things, to change the size of certain parts, to look at the concept from different perspectives, and it costs little in time and effort or materials. It's smart to sketch the idea very well in some detail and then to scale to see how the parts will fit together. *"To scale"* means that a fixed distance on your drawing equals a larger distance on your actual ROV or tool mock-up. For example Scale: 1 cm = 2 cm means that for every 1 cm on your drawing, will be 2 cm on your tool or ROV.

Keep all your sketches and notes together in your group's binder.

Mock-up Materials:
Keeping with the same example, the next step is to determine what low cost materials are available for you to make a first prototype or "mock-up of this device. Small pieces of acrylic or Lexan© may serve well for the open clamp arms and the hinged bar. It is a

great material for fabrication as it can be heated and bent, easily cut using a band saw into intricate shapes, is very strong and resistant to breakage, is quite light, and is almost transparent in water.

The pivot points can be made by small bolts and nuts positioned through drilled holes; the spring may need to be purchased from a hardware store.

Fabrication:
Now, cut the appropriate shapes in the plastic sheeting, drill the holes and assemble the parts by inserting the fasteners (bolts) and spring.

Testing
Try it around a 10 cm diameter plastic pipe. Will it work to grasp the pipe. Try it in water. Does it still work?

Refinements
How can you improve the mock-up of the spring-loaded clamp? Think of ways to make it more reliable, more solid, lighter, simpler, then refine the mock-up of the clamp.

Entire ROV mock-ups
If you wanted to get an idea of how the various components you wish to have on your ROV would fit together, you could make a mock-up of the whole ROV, to a single scale, with motors, flotation, tools, tether, etc. Only in this way will some difficulties in scale and size be visible.

Generally, mock-ups of entire ROV's, with all components can be made from:
i. two thicknesses of cardboard (single and double)
ii. foam-core board (the stuff useful for mounting posters)
iii. tape : duct tape and fiberglass tape
iv. doweling (round sticks)and square profile sticks of varying thickness
v. pieces of hard plastic sheets or 1/4" plywood
vi. plastic tubes and pipes for column-shaped objects

Tools for mock-up fabrication:
The only tools needed normally are:
i. cutting or utility knives and large scissors
ii. rulers, straight edges, compasses and tape measurers
iii. glue (white wood)
iv. small hammer and some nails
v. some string
vi. a hacksaw and possibly a band saw.

Logistics of Mock-up fabrication:
If there is a team of 4 people, time won't permit everybody to mock-up and test the same component. A division of effort is needed. Perhaps 2 people can form a sub-

group to do different components in the mock-up or even three different ideas about a tool or mechanism to be used to complete a mission task. With a team of 10 students, it's easier to have a division of effort, but the management, mentoring and guiding takes more time.

It doesn't mean the team's groups can't discuss problems or seek solutions from the rest of the team; it's just that the sub-group takes primary responsibility for doing one piece of the work.

The sub-group builds a preliminary model of the design to demonstrate that the design concept will work. The mentors will be guiding and helping you along the way.

There may be a couple of designs tried for each component before the final design is selected, and it selected based on which performs best – which one fulfills the performance specifications. This all takes more time than you will expect, so we have to start the mock-up fabrication very early in the design process – within the second day, at least.

In order to efficiently use time, some of the mock-up fabrication can occur between meetings with your fellow team members, at school or at home. Perhaps a mentor or parent might be able to assist you in developing this prototype which you can then proudly bring back to the working group at the next meeting.

As your ideas are tested, it is not unusual to have the design of your ROV change as new ideas emerge on ways to improve it. It's easy to modify the design at this stage. After testing the mock-ups or prototypes, the fabrication group may discover it simply doesn't work well and therefore goes 'back to the drawing board' or revisits the results of the brainstorming session to look for another design option.

The process of constructing a first prototype will also provide NEW information on feasibility or possible improvements in the original concept. It's possible that you will have NEW ideas emerge just from working with materials and forming the prototype. Be open to new ideas at this stage and innovation to the original design.

Special Materials:
There may also be some special materials such as motors, sliders, rollers, rods, springs etc which must be obtained. Ask a mentor if they are already available to the team or where they might be obtained.

Helpful hint: When fabricating your structure, *"Measure twice, cut once!"*

10.4 Full-scale Construction

Now that you have discovered the effectiveness of most of your ideas through mock-up and prototype construction, it is necessary to build a full-scale ROV

When time is running out and you will have to use your human resources very efficiently. If you rush, there is a greater probability of either:
injury when you are not focused on safe ways of achieving a task, or
mistakes - sometimes critical ones - either in decisions or in pushing too hard to get a task done, you break a fragile part.

10.4.1 Safety:

The first thing to reinforce here is the continued use of good safety practices. When you are in a hurry, it is almost inevitable that you try short cuts to getting your task done. This may literally mean going across an area which has hazards (e.g. slippery), running where you really shouldn't, or not thinking before cutting into a piece of plastic or acrylic which will splinter and shard.

The most important thing as you progress towards the development and fabrication of the final product is to slow down and start thinking. Act smart, rather than fast stupidity. Remember to use safety equipment and procedures.

How can you manage the team for greatest efficiency?

10.4.2 Let's start planning:

i. List the all fabrication and testing tasks to be completed
ii. Assign a realistic length of time to complete these fabrication and testing tasks. You should try and complete the fabrication at least a day before the competitive testing. Will additional time be required?
iii. How many people are required to work on this task? Assign people with the skills required to fabricate any component to that task
iv. Are there any special materials or parts your team will require? List them as critical assets
v. Now you can graph these planning details in a PERT (Project Evaluation and Review Technique) chart, as follows:

Model PERT chart for delivering a ROV Design and Building Camp

TASKS	Sun Nite	Mon	Tue	Wed	Thu	Fri	Sat	People	Materials
Aquatic Environment								Full team	Manual
Investigate Mission								Full team	Internet
Performance Specs								Sub-group	Mission Doc't

Design Specs								Sub-group	Computer
Research								Full team	Internet
Design process								Sub-group	Computer
Engineering Basics								Individuals	Manual
ROV design								Sub-groups	Sketching
Fabrication								Sub-groups	Tools/parts
Testing								Full team	Tank
Competition								Full team	Pool

Your PERT char will probably have core specific sub-tasks like:
Investigate the mission tasks on______________ and summarize the task to the rest of the team.
Develop performance specifications for the ROV’s movement
Research options for thruster type, power and layout to achieve these performance specs.
Develop a series of Design Specifications for the ROV’s movement
Select parts and materials to build the Thrusters and mounting brackets for the ROV
Saw pipe to provide a housing for the Thruster motor
Glue motor into pipe housing
etc.

10.4.3 How can you keep the team on track?

Supervision:
This requires the supervision of an organized person. It could be the person who could contribute least to the mechanical part of the effort. That person could be your “Team Lead”.

Communication:
Just because primary responsibility for certain facets of the design and fabrication are accepted by a small sub-group of the team, doesn’t mean they must do it on their own. If the sub-group encounter’s a problem, they should immediately get the advice of the other team members to solve it. It could be that the tam will have another sub-group stop work on their component of the ROV to help out the subgroup with difficulties – just to ensure that a critical part of the ROV is designed and fabricated to optimum performance standards.

Be prepared to shunt ‘people’ to critical tasks if its progress is behind schedule.

Consultation:

Information is ***GOLD***! Young people don't recognize that an enormous amount of knowledge arises from experience…..because they have so little of it. Experience teaches - it gives the experienced person an edge in problem solving and an informed intuition to make smarter decisions ! Far from older people knowing "nothing", smart designers use the experience of the instructors to arrive at more effective solutions. The expertise is there for you to use…use it!

Some regional competition organizers distribute a list of willing mentors to the teams. These mentors may only be available periodically or when called, to maximize the benefits of their presence, when they arrive. Have questions or tasks ready in which they can advise or assist.

Team member recruiting and use:

Can you attract to the team, other students who have been involved in building robots, and particularly ROVs before? If so go the extra distance to involve them and let the less experienced team members know that they are willing to share their insights and knowledge.

Your ROV team is committed to such a spread of requirements in the competition that it is wise to involve students with DIFFERENT skills as opposed to drawing them all from a single class of say…woodworking or Physics. These characteristics seldom reside in one of even three individuals, so the larger sized teams have an advantage in the range of skills they contain well as the depth of abilities and just raw "horse-power" to get things done!! These useful skills include:

Technical:	**Communication and management:**
Mechanical	Teamwork Skills
Fabrication	Work ethic
Materials	Organization
Electronics	Good Speaker and Writer
Experimentation	Diplomatic
Physics	Methodical and Entrepreneurial

10.5 Full-scale Construction Instructions:

10.5.1 Frame:

What materials should I use?

There are any number of frame materials which would work on your ROV. Most of the early Ranger class teams started out with 1/2" ID PVC pipes and "T" and 90^{o} elbow fittings and make their frame (chassis) from those materials. Most move to a form of sheet plastic which is cut and bent to shape to form their frames within 2-3 years, as there are advantages. Some of the materials we have observed being used in student-built ROVs at competitions include:

Pipes:
½”- 2” PVC water pipe
½” -2”PVC electrical conduit
1-14” ABS drain water pipe

Sheet plastic with sections cut out:
Polyethylene plastic sheet with SPG <1.0 (floating)
Acrylic sheet
Polycarbonate (Lexan™) sheet

The simplest material to use is ½” ID PVC pipe. (ID is Internal Diameter and PVC is Polyvinyl Chloride) Its ea of cutting and joining, changing shapes and sizes an w some little work, its internal buoyancy, combined with its low cost make it a terrific starter kit frame. One type of ROV frame using PVC pipe is illustrated at right. The advantages of other frame types vary.

One example of a ROV PVC pipe frame

If the pipe is sealed, it can contain air and therefore provide buoyancy, removing the need for additional foam buoyancy which will provide additional drag (friction) in moving through the water. That said, it must be completely sealed or it won’t work well at all. That’s quite difficult as you have to penetrate the pipe to attach….well…everything else.
Some teams have stuffed their pipe frames with a buoyant building insulation foam material, and that has worked pretty well.

Pipe’s only real disadvantage is that a ½” ID pipe is about ¾” in outside diameter (OD) and therefore inherently has more drag itself, so you should keep the number of pipes; particularly pipes which are in a perpendicular orientation to the main axis of the ROV’s forward moment, to a minimum.

Furthermore, having buoyancy near the bottom of the ROV reduces stability, so you may have to be careful where you locate the other heavier components like the thrusters and tools, to maintain that stability needed to do mission tasks.
What ever material you choose, use cheaper mock-up materials first. Then in the next phase, cut materials to size but DON‟ T glue them as you may well need to pull them apart again to adjust the size or fit some of the tools needed in the mission.

Your SCOUT Class ROV materials includes a 2 ft. x 4 ft. rectangle of 3/16” thick Lexan™ (polycarbonate). It is a superb structural fabrication material, as it:

i. Has a density just a little heavier than water and thus doesn’t require much buoyancy to make it neutral;
ii. Is incredibly easy to work with, to cut, to bend, to mold, to drill and to join other components;
iii. It’s transparent and doesn’t form an optical barrier;

iv. It's almost indestructible and can take knocks and abuse without damage.

When you design the size and cut-outs of your Lexan™ frame, you'll be able to cut it into shape and bend it to form your ROV chassis

10.5.2 How big should your frame be?

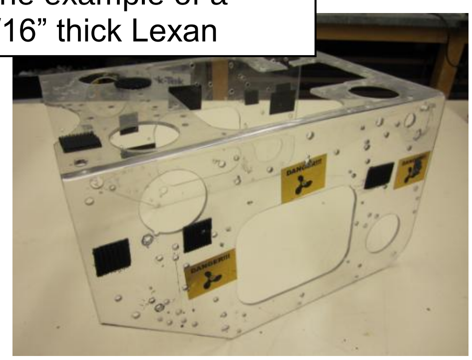
There is no easy answer. It obviously can't be bigger than any hole or space that it must enter or exit. Such limitations have occasionally been part of previous Mission Scopes.

It must be big enough to hold the tools and operate them, which may be difficult for a very small ROV. Bigger means more drag and slower.
The real answer is "as small as is practical". That's why it's a good thing to concentrate on tool design first. Then you have a good sense of how big is necessary.

10.5.3 What design of ROV should you make?

You can look at a variety of ROV designs by searching various websites. You will notice two different types. The first is a box of some shape. The second is a sleeker, more streamlined design. Any idea why?

One example of a 3/16" thick Lexan



The answer relates to the different types of mission of these two types. The first is called a ***"Work Class"*** ROV (WC) aptly named because it s designed, not for speed, but for working ability. It is a proven design. Depart from it at your peril. It is designed as a stable platform for its tools. As you can probably guess, it's also slower moving – even though some of the smaller WC ROVs have speeds in water of over 3 knots (about 4.7 km/hr or about 1.2 meters / second (ms-1) That's still ***cruisin'*** for a WC ROV, but they are using high voltage power and large thrusters.

The more streamlined designed ROV normally doesn't have any tools aboard. It's merely a survey tool – a video camera is its only payload.. This is called an "***EyeBall***" (EB) class ROV. It has lower stability but higher maneuverability, and (depending on the power and thrusters), slightly higher speed.

You will choose one design type or the other, or perhaps combine features of both types in your ROV. The important thing is to **TEST IT**. Make sure your ROV performs at the level you require…….. or change it.

10.5.4 Construction using ½” PVC water pipe or Lexan™ plastic sheet

STEP 1. Drawing

First of all, draw the frame you want, to scale, on paper. Use the information above to modify the frame design drawing to fit your need. You should think of:

- Dimensions
- Materials
- Buoyancy
- Drag
- Stability
- Location of thrusters
- Location of required tools
- Location of camera and tether attachments

Draw your frame to Scale: 1 cm = 2 cm. This means that 1 centimeter on the paper is actually 2 centimeters on the real ROV. On a standard piece of letter-sized paper, you can draw a ROV which will be up to 50 cm long when it’s built…that’s certainly on the upper extreme limit that you will need.

Draw your ROV from at least two, ideally three (3) perspectives:

i. Plan view (looking down on the ROV from above)
ii. Side elevation (looking at the ROV from the side), and possibly
i. Front elevation (looking at the ROV from the front)

Put dimensions (cm) on the REAL ROV over each piece of piping or sheet plastic material in the drawings. Obviously the same pieces on either side of the ROV will be the same length. This makes it easier for when you’re doing the cutting and forming.

If you are using PVC pipe, show in thicker pencil, ink or marker, where the joins or fittings between the pieces of pipe, will go. The frame pipes are joined with the use of two different types of fittings:

i. 90^{o} elbows (**L**) which lets you make a corner
ii. “T” fittings (**T**) which lets you make a ……well a “T” shape

If you’re going to use the Lexan™ plastic sheet for your ROV frame, you should draw your frame from three (3) perspectives: side, top and front or back. Draw to a scale. Use solid lines to indicate edges or lines to be cut and dashed lines to indicate fold or bending lines.

CAD: If your local high school is teaching a Design and Fabrication course, it likely has some expertise in the use of software for 3-D drawing. In NL the software distributed to schools is ***Solidworks*** . Why not contact them and see if they will show your ROV team students how to use it to draw frame (chassis) and possibly cut it on the school’s CNC router. It does a fabulous job.

Insert the location of thrusters, tools and cameras on the drawing to see how they fit. It's normal that you may have to draw and re-draw the frame design a few times to get it just right. Our advice is make it no bigger than the mission and onboard equipment or gear require.   After all…the bigger the slower !!

STEP 2. Cut the pieces.
OK, now using the finished diagram as your guide, cut the pieces.

If you're using ½" ID PVC pipe, it can be cut using any number of tools, including

i. pipe cutter with deeper roller blade for plastic
ii. hacksaw
iii. band saw
iv. Dremel (high speed rotary) cutter

Effective operation of each of these tools requires a little skill. You'll become more efficient in their use with practice, but do you really want to cut precious materials which are in limited supply first…NO…Develop your skills on less valuable materials.

The preferred tool for cutting ½" ID PVC pipe, for safety and clean, absolutely straight cuts is the pipe cutter with a wider diameter roller blade for cutting plastic.   It's a matter of inserting the pipe, tightening the screw holder and then rotating the cutter around the pipe, tightening the screw ¼ turn each rotation. Within seconds the pipe is cut…and each cut is perfectly perpendicular to the length of the pipe. Before you cut new, long lengths of pipe, try shorter bits from the collection in your workshop….cut from longer lengths only as a last resort.
You'll probably need to cut two or four of each pipe length, as your ROV is "*bilaterally symmetrical*"….. like you are.

If you're using the Lexan™ sheet, cutting is normally done with power tools, for which you'll need training.   Use a band saw for the outside edges and a scrolling Jigsaw saw with reciprocating blade for the inside cuts. The resulting edges tend to be rather rough, so you'll have to use a file to smooth them out and finish with a sanding block. Don't scratch the Lexan™ surface just smooth the edge.

This will only give you the flat sheet of plastic. Now you need to bend it to make a frame shape. The normal way is to bend the long Lexan™ sheet across the shortest dimension (width)….twice. This results in a box shape with no bottom, just the sides and top (see illustration above).

Bending the 3/16" thick (3.572 mm) Lexan™ sheet is made easier if it is *"scored"* along the bend line. "Scoring" is making a shallow cut in the thickness of the sheet along the bend line at about 20% of the thickness of the material. For the ~3.6 mm thick sheet, that means a cut *about* 0.7 of a millimeter deep, normally achieved with a table saw. Getting the right depth is not an easy task. Try out different heights of the table saw blade on scraps of the Lexan™ with the same thickness, before you score your large frame sheet. The scoring should be on the side of the plastic sheet towards the inside of the bend. Your scoring cuts will be on the same side of the Lexan™ sheet.

Bending the plastic sheet requires a heated "strip" bender. Here are some instructions in its use. There are some tricks you should know.

i. Set up blocks or plates to bend around
ii. Medium low heat.
ii. Keep watching during the heating process.
ii. Check frequently to see if the plastic is bendable/

Bubbles in the plastic are a *No-No!!*….they weaken the bend.

http://www.technologystudent.com/joints/desk17.htm

STEP 3. Assembling the frame

If you're using the Lexan™ sheet…you're already done! Move on to STEP 5.

However, if you're using the ½" ID PVC pipe to construct your frame, the cut pieces are now ready to be joined using 90^o *elbows* and "*T*"s. Fit all the pieces of pipe together using these fittings, just like in your diagrams or design plan. Be sure to use force to insert the pipes as far as they will go into the fittings. DO NOT GLUE (You‟ ll see why a little later on !!)

Do they all fit? Does the frame shape look symmetrical and sit flat on a table? If not, push the pipes in further into the fittings. If the frame is still not symmetrical, you've got problems. Perhaps you have put a couple of pipes in the wrong location. Otherwise, you've probably cut them the wrong length and you will have to adjust that length or cut a new piece. Make your modifications, until you're happy with the product. . DO NOT GLUE …at least yet. Once you do, the frame won't come apart, and you may wish to change the shape after you start fitting other components such as thrusters, tools, cameras, buoyancy, etc. In fact we recommend after all the other assembly is complete, to attach the fittings to each pipe using a small 1/2" long, #6 stainless steel Robertson, pan-head screw.

10.4.5 Thrusters:

STEP 4. Fabricating the Thrusters

The choices of which thruster to use and where they are attached to your ROV is really about how you want your ROV to perform. What are the relative vertical and horizontal distances it must travel? What loads must it carry? Thrusters are merely electrically powered motors with propellers on them. We've discussed how to determine which combinations of motor and propeller is most efficient, before. The thruster motors can be of any size, shape, model, brand or design.
Normally for small ROVs, it is easy to salvage a waterproof motor from a "bilge pump" used to pump extra water from the "bilge" (space between the hull and the floor in small to medium size boats.

The most frequently used brands of bilge pumps are Rule -ITT, Attwood, and Mayfair-Johnson. They come in a variety of pumping capacities, typically measured in "gph" (gallons per hour). The pumping capacity is an imprecise measure of motor power, as gains in pumping capacity can be achieved by small changes in the pump housing design or enlarged outflow pipe. The number of amps (A) used at the same voltage is a more revealing measure.

SCOUT:
You will have four (4) Thrusters motors for the SCOUT Class, which uses bilge pump motors that are rated at 500 gph (gallons per hour) and require 3A under load at 12VDC. The reason you can't use more motors is that their power requirements will exceed the 15A limit imposed on each SCOUT Class ROV by the in-line fuse required in the competition rules.

Ranger:
The Ranger class will have six or more (6+) thrusters each using bilge pump motors that are rated at 1000 – 1200 gph (gallons per hour) and require 4.5A under load at 12V. Ranger ROVs have a 25A limit at 12VDC.

Removing the pump housing
The Rule and Attwood brand pumps need a bit of careful cutting to remove the unnecessary bits of plastic which makes it a pump. The Johnson pump motors are almost ready to use, just by unscrewing the motor cartridge from its housing. A bilge pump with waterproofed motor cartridge removed is shown to the right.

<u>Remove the impeller</u>
The next thing you'll want to do is remove the pump "impeller". This is the plastic toothed object on the motor's drive shaft. It must be done carefully so as not to move the shaft sideways, thereby damaging the waterproof seal. Put two flat head screwdrivers or two table knife blades under opposing sides of the "impeller" and lift it evenly off the shaft.

<u>Paring off unnecessary bits</u>
When cutting, sawing or grinding excess pump material off the waterproof motor housing, you have to be VERY careful as it's all too easy to penetrate the waterproof housing for the motor. Then, you'll have to plug it up with an ABS cement/glue.. The Johnson bilge pump cartridges require very little modification. You may wish to carefully remove the wings on the end of the cartridge farthest from the drive shaft, to streamline them a little. Don't cut into the thick section of the wing.

STEP 5. Fabricating the protective propeller cowling

A protective cowling or shroud for the propellers is an essential next step. It is a safety measure for the deck crew handling the ROV and a method of keeping the propeller from damaging itself or whatever it's hitting and avoiding getting the prop fouled from other materials like your tether or lines and competition structures. Here's how!

You need:
i. a 2" to 1-½" ID ABS pipe reducer coupling
ii. a short length of 1-½" ID ABS pipe

Generally you have to cut two sections out of each of these parts such that the remaining prongs overlap.

Cut the reducer coupling by mounting in on a piece of 2: pipe and then in a moveable vice such as used on a drill press. Push the small end ring (1-½") of the reducer into the band saw blade. The blade must bisect the small ring (across its diameter) and penetrate into the cone shape until it reaches the larger ring (2") then STOP.

Now rotate the whole pipe about 20 degrees (2.5 cm) in either direction, and position it exactly as above. Repeat the cut across the diameter of the smaller ring. Now you have four cut slots into the smaller ring. It leaves two segments of the arc much larger than the other two.

Rotate the whole vice 90^{o} horizontally, such that the 2" pipe and the reducer coupling are now perpendicular to the band saw blade. Now you're going to cut down the plane of the large ring, where it meets the cone section of the adapter….but only through the larger arc segment. You must be very careful NOT to cut the smaller arc segments.

Once this is done, the large arc segment can be pulled from the reducer. Do the same thing on the opposite side of the reducer. The piece on the left (above) is what you have left. You're 2/3's done.

Now take a 20-30cm length of 1-½" ID ABS pipe and mount it is in the drill press vice. Measure off a 4.5 cm from the end and mark it with a scratch or a white grease pencil. Point the end of the pipe at the band saw blade position it such that the blade will cut across the maximum width (the diameter) of the pipe. (Looking through the near end of the pipe at the blade will guide this positioning.)

Exactly as with the reducer, you'll make a cut across the diameter into the end of the pipe, rotate it about 20^{o} and then make another cut. The end of the pipe will now have four cuts which define four segments of the circumference. Two opposite segments will be about 2.0 cm long. These are the segments which will remain after the next cuts.

Again, like the reducer, rotate the whole vice 90^{o} horizontally, such that the 1-½" ABS is now perpendicular to the band saw blade. Cut out the two longer arc segments at about 4.5 cm from the end, being careful not to cut the smaller arc segments. The piece on the right (in the photo above) is what you have left. Almost done!

Now you can join the two parts of the thruster cowling together. (see photo right) The bilge pump motor cartridge fits tightly into the 1-½" ABS pipe. The propeller and brass hub can now be installed on the motor's drive shaft and the whole unit can be glued together with "transition" cement (ABS to PVC). The finished product looks like this:

STEP 6. Mounting the Thruster

Once you have the bilge pump motor in the waterproof housing, and the propeller cowling attached, it's still necessary to mount it on the ROV.

This is achieved by using a standard 1-½" plastic conduit clamp. The conduit clamp fits over the 1-½" diameter section of the ABS pipe on the thruster cowling, and is used to attach the thruster to either a PVC pipe frame or a Lexan™ frame.

You may need to secure the bilge pump motor with the attached cowling, in the conduit clamp bracket. Drill a small hole about 11/64th" through the conduit clamp, perpendicular to the axis direction of the motor housing and shaft. Force screw a ½" long, 10-24 SST screw (preferably Robertson pan head) into this hole enlarging it and producing threads in the conduit clamp. This 10-24 SST "set" screw may be tightened GENTLY, once the thruster is mounted on the frame. Insert

When mounted on a Lexan™ frame, the thruster cowling is wider than the largest diameter of the bilge pump motor, so you may have to cut away a section of the frame to accommodate it. If you know where your thruster will be mounted, this can be done before the frame is bent. Alternately, you can place a rubber or HDPE spacer between the motor and the frame to move it outside the plane of the frame.

"*Vectored*" Thrusters

If you mount the thrusters on a vertical pipe or other surface, you can change the horizontal direction of the thrust simply by rotating the pipe. By tilting the edge of the HDPE spacer which is in contact with the thruster, on a Lexan™ frame, you can achieve the same result. If you turn the thruster direction either inward or outward, it is called "*torqueing*" the thruster. A "*vectored"* thruster points at a different direction than the forward or vertical axis of motion.

Why would you do this? Two thrusters which point inwards towards one another and towards the centreline of the ROV by…. say…. 30^{o} will enable the ROV to turn more responsively. There is a downside, however. These vectored thrusters will push less water behind the ROV when they are both pushing in the same direction. Consequently the ROV may be 20-30% slower moving in line with its axis, than if the thrusters were pointed straight backwards. This shouldn't be an issue. The vast majority of the time you'll be operating this small ROV it will require slow, gentle, measured movements to complete the Mission tasks.

Now you're ready to attach the conduit clamp to the ROV. On a pipe or Lexan™ frame, hold the bracket next to the surface on which it is to be mounted. Mark through the two holes in the conduit clamp, the points where you'll need to drill holes for the mounting bolts.

It is critical that you keep these two holes in the same plane or parallel direction, so the bracket can be mounted straight; not twisted !

The hole size needed to insert the 10-24 bolts is 13/16”. Use a ½” to ¾” screw on Lexan™. A little longer through pipe about 1-¼“ long. It needs to be long enough to go through the conduit clamp, the frame material and still have enough thread to attach a nylon insert **lock-nut** on the other end. Do the same thing on the other end of the bracket.

STEP 7. Mounting the propellers in the thruster.

The propeller you are going to use is a 60mm diameter 3 or 4 blade plastic prop made by Graupner. It has a 4 mm thread inside its hub or centre. This female thread fits over the 4mm male thread on the brass coupling that joins the propeller to the bilge pump motor. On the other end of the brass coupling is a 1/8” ID hole which accommodates the drive shaft of the bilge pump motor.

Mounting the propeller is accomplished merely by pushing the coupling over the bilge pump motor drive shaft, ensuring the flat portion of the drive shaft is aligned with the small #8 stainless steel (S/S) set screw in the side of the brass coupling and tightening the set screw using an Allen wrench.

If you want something different, you have to produce your own couplings.

Our current favorite prop, to match the Johnson 500 to 1200 gph bilge pump motors is a 3-blade, 60 mm diameter, ~35mm pitch plastic prop with 4 mm brass insert female thread. The reason is that it has tested efficiency using Bollard Pull experiments and adapts nicely to the protective cowling we have designed for it (described more fully below). The local retail cost is about $12.95/unit.

You can look through the variety of props available by also consulting the web. “*Choose wisely*!” Some manufacturers are Graupner, Billings, Dumas.
A source of props is Signal Hobbies in St. John’s, NL; Great Hobbies in PEI (www.greathobbies.com) and Hobby-Lobby in Tennasee (www.hobby-lobby.com). Look at their websites and see if there’s anything you like.

For each thruster, we supply a bullet-shaped connector / coupling , lathed from a ½ “ brass solid rod, which accepts the bilge pump motor shaft on one end on the propeller end is tapped for a 4mm threaded bolt. This 4mm brass threaded rod precisely fits the same female thread size inside the hub of the propellers.

Repeat for all thrusters. You now have a mobile ROV.

10.4.6 Buoyancy:

STEP 8. Buoyancy

Pipe frames:
Remember we said earlier DON'T GLUE the pipe frame together. The reason is that we have to take some of the joints apart. One of the best ways to achieve buoyancy in a pipe-framed ROV is to let the pipes contain buoyancy. This reduces the additional drag of an additional chunk of solid foam attached to the ROV. There are two ways to do that:

i. seal the pipes and fittings by gluing them together and making them completely watertight, or

ii. inserting non-compressible flotation material inside the pipes and then simply fastening the pipe ends inside the fittings with a small stainless steel screw.

In our ROV camps and courses where the piping and materials are recycled from one event to another, we DO NOT glue the elbow and 'T' fittings to the pipe.

Consequently, it's not waterproof and leaks, so the buoyancy is lost. We offset this lack of air buoyancy this by creating small ½" diameter plugs from 2" thick sheets of high density foam, by use of using a heated wire foam cutter, and inserting them inside the pipes before joining them to fittings by fastening them with small (# 6) stainless steel sheet metal screws. The screws should be located about ¼" from the open end of the fitting.

If the pipes on the bottom of the ROV are also made buoyant by either of these two methods, the additional flotation lowers the Centre of Buoyancy (COB) dramatically, and may cause stability problems for the working ROV.
It is wise to experiment with the buoyancy and stability in any ROV to ensure it will perform the mission tasks as the builders had hoped.

Your ROV should be neutrally or slightly positively buoyant in the liquid in which it is operating.

If the frame material has no inherent buoyancy, student-built ROVs need to have buoyancy located at the **top** of the ROV structure. Ideally this flotation is attached to the top of the pipe or Lexan™ structural frame and shaped and streamlined as much as possible to present a small profile to the water when moving forward, and minimize drag. A suitable foam is a rigid building foam such as Styrofoam SM with the highest rigidity possible. The recommended type is used to insulate under floors or concrete floors, but it's difficult to find. It's called H100 and is a specialist material, not often used in construction.

10.4.7 Electrical Controls and Tether:

STEP 9. Controls and tether
Power:

Now you have your ROV almost ready to enter the water. All you need is power. This is supplied by a 12Volt Direct Current (VDC) power supply or battery (they actually produce13.5 V when fully charged). A fully charged car battery will serve well as a power source.

The SCOUT class ROVs are limited to a 12 Volt, 18 Amp maximum by an inline fuse from the positive side of the battery. The Ranger class ROVs are limited to a 12 Volt 25 Amp maximum. These voltage and power limits are defined for safety purposes and ease of finding components. As there are so many 12 V electrical parts and actuators, it's easier to find what you're looking for.

The down side to 12 V power is that this is not a large voltage potential, and therefore voltage drops over longer lengths of tether. The voltage drops more along a tether with small wires. So the solution is to have bigger wires, right? Yes, BUT the heavier the gauge or thickness of the wire, the more it weighs and the more extra buoyancy your tether must contain to make it ***neutrally buoyant***. (*Neutrally buoyant simply means the tether neither sinks or floats, but kind of lays there in mid-water*.)

The larger the size and number of wires inside the tether the more buoyancy it must have to keep it neutrally buoyant. More buoyancy means a larger diameter tether and possibly more flotation material attached to the outside. The bigger the cable…the greater the drag….the harder the motors have to work to pull it…the slower the ROV can move to complete the mission tasks. It's always a compromise!.

<u>Tether – General information:</u>
The MATE rules and regulations specify that your ROV cannot carry power (such as batteries) on board, except for lights and powering sensors…..not to provide more thrust. The ROV gets electrical power from the surface to the thrusters, motors, actuators, instruments, cameras and sensors on the ROV underwater by means of electrical wire (stranded copper) conductors inside a single protective waterproof jacket. Collectively this is called a "***Tether***". The types and number of wires in a tether is a function of how many items must be powered. You need a pair of wires (+ and -) for every actuator (thruster, motor, camera, solenoid , solenoid valve) used n the ROV. The size of gauge of the wires depends on the amount of current required by the motor, actuator, sensor that it powers.
High school (Ranger class) ROVs typically operate in water no deeper than 14 ft (4 meters), so the voltage drop along the relatively short length of tether required to operate at that depth is lower.

Now, the other factor is how far from the dockside or dockside that the mission tasks are located in the water body. So the <u>minimum required length</u> of tether is the *hypotenuse* of the triangle with depth (Y) on the vertical side and distance of the most distant mission task from dockside (X) on the horizontal side. The length of tether is calculated as this hypotenuse the + an allowance for drooping tether + the distance across the deck to the control shack where the ROV operator is stationed. We have used 40' (foot) (12m) lengths for most applications of 12 V powered ROVs.

Over the tether lengths expected above, AWG 18 copper wire is typically adequate for most small bilge pump motors of the 1000 gph (gallons per hour) designation. Smaller items such as cameras require only AWG 22 wire as they require less power, to operate efficiently.

The ideal flotation for a tether makes it neutrally buoyant in the water in which it will be used. That way it preserves the stability of a neutrally buoyant ROV. Keep in mind that salt water is denser than fresh water. You need more buoyancy in fresh water than in salt water. If you make your ROV or tether neutrally buoyant in fresh water, you'll need to add more ballast (maybe lead) attached to the bottom of the frame, when you put it in salt water.

For a ROV which has the normal complement of motors and a camera, here's the sort of wires you need in the tether cable. We are assuming a 45' cable will be adequate for most Robotics course or camp applications and for any Ranger Class competitive use. The higher the AWG (American Wire Gauge) number, the smaller the diameter of the wire, and the smaller the current it can carry without heating up.

Stranded wire (as in lamp cords) is better than the solid wire (that you'd use in house construction) because it's more flexible. With AWG number higher than the ideal specified (smaller diameter than the ideal), you will have reduced speed, but this may actually be an advantage when performing some precise mission tasks.

Table 1. Normal wire specifications for your 45' long tether cable

Load (quantity)	**No wires/unit**	**AWG (ideal)**	**AWG (OK)**	**No wires total**
12V thrusters (4)	2	18	20-22	8
12V Video Camera	4	22 shielded	22-24	4
		TOTALS		***12***
Alternate arrangement if 3 pairs used for thrusters: 1 pair for both verticals; not 2				
12 V tool motor (1)	2	18	20-22	2

TWELVE wires !! Actually that's not quite correct as two of the vertical thrusters (controlling up and down movement) can be in the same wire. Also, the video wire cable containing a (+) and (-) electrical power conductor and two shielded wires for the video signal, can be strung outside the power cable.

For the SCOUT class ROVs, a home-made tether cable can, however, be made out of communication cable. The cable we use contains eight (8) AWG 22 wires in four, twisted pairs, each pair being shielded by a metal foil wrap. It isheavy, but it was small (about 3/8" diameter).

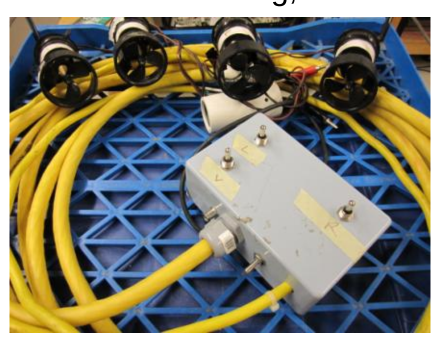
The video camera provided for the SCOUT class has its own cable which can be attached to the power cable to fulfill all your needs. There weren't enough wires for our purposes so we had to run an additional coax cable outside the communications cable to carry our video camera signal. Here's how we connected it.

Table 2. Compromise home-made tether specifications

Load (quantity)	**No wires/ total**	**AWG**	**No. power wires**	**No wires total**
POWER CABLE (8 WIRES)				
12V vertical thrusters (2)	2/4	22	2	2
12V left side thruster (1)	2/2	22	2	2
12V right side thruster (1)	2/2	22	2	2
12 V tool (motor (0- 1)				-
VIDEO CABLE (4 WIRES)				
12VDC to Video Camera	2	22	2	2
Video signal shielded. (external)	2	22	0	2
TOTALS				9

This fabricated tether will require some additional buoyancy to make it neutrally buoyant. We have used seine floats. These are torpedo-shaped, hollow plastic, fish-net floats that can have the 8-wire power cable of the tether strung through them, and then they are fixed in position by either tape or some fine string, on either end.

Another alternative is to make your own tether using the exact gauges you feel are necessary to obtain the required performance from your ROV. We have seen cables made simply from multiple lengths of the desired gauge wires, wrapped together by tape or cable ties. There is also some floating, polyethylene net mesh tubing which can be used for that purpose, and provides some buoyancy, but also a lot of drag, because it's bulky.



A significant step up is to buy commercially-made tether which will suit your specific purpose. When we went shopping for this type of tether for the Ranger class ROVs, there was simply nothing available which was suitable for use with 12VDC. So, with the large number of Ranger class teams participating, a year later, we contracted a company to produce commercial quantities of tether cable specifically designed for the Ranger class ROVs. This may also be the way to go in with the SCOUT class in a year or so. This is a photo of the Ranger class tether currently in use.

STEP 9. Electrical / electronic Controls.

As with the tether, you can go from very simple to relatively sophisticated. In most cases the simpler, cheaper methods are inevitably better as well. We've seen a large number of beautifully crafted and lavishly equipped ROVs that could not do the mission tasks well.

Switches:
The simplest route for topside control is to use switches for the motors. If you tried the same thing with land-based robots, if just wouldn't work, because your power would be full-on or full-off, and the robot would be very difficult to control. In water, it's completely different. The immensely greater density of water prevents rapid starts in boats, ships or ROVs – there is a lot of inertia. Even with full power, it takes a while to get up to full speed, and then the speed is dramatically reduced because water is so thick. Our land-based robots move at a top speed of about 1.5 m/sec or 5.4 km/hr. Our fastest 12V underwater robots move at about 0.5 m/sec or 1.8 Km/hr.

The key here is to select the best switches. You don't want to have your motors continue to run in one direction even when you have taken your hand off the switch, so it has to be spring-loaded. This is called a "***momentary***" switch and it returns to the neutral or off position unless you are pushing on it – much like in a video game. It's also reversing, so if you push forward the motor it controls pushes the ROV forward; when you pull the toggle back, the motor of the thruster, reverses direction and so does the ROV.

These spring-loaded switches are called: DPDT (**D**ouble **P**ole/ **D**ouble **T**hrow - Momentary switches. The better types have the reversing polarity already imbedded in the switch. The cheaper ones you have to do this wiring yourself. These switches are illustrated in the photo above. Look at the wiring diagram in the Appendices for details.

Rheostats:
Rheostats control the amount of current flowing to a motor or other load and their use can control the amount of power flowing to a motor. The household equivalent is an older style dimmer switch (not the digital ones sometimes now used. These types of power controls were also used in model aircraft for accelerating the power to the engines.

These "potentiometers" work by changing the amount of resistance imposed on the current flow to any motor or other load. Increased electrical resistance means increased heat…(that's what causes heating elements in an electric home heater to warm up) .. so you are really using the same amount of power, just preventing it from reaching the thruster motor. This is inefficient, but it works. These rheostat units often use slider controls or wheel (dial) controls, but we've never used ones which are spring-loaded and return to zero power in any direction. They tend to have *"jerky"* control of motors due to their friction-type movement.

Electronic speed controls:
This is the type of unit now used in the more sophisticated model aircraft, model land vehicles, model boats and ROVs. The advantages are:
i. they have infinitely variable control of speed for precise movements.
ii. they do not waste energy in applying resistance to control current.

They operate by a process known as "pulse-width modulation" (PWM) essentially cutting the power sine wave into 256 sections and permitting only a proportion of these power segments from 0-256 to enter the motor, thereby varying power and motor speed.

The disadvantage is that they tend to be expensive. Starting at about $90 US/unit for a single-direction electronic speed controller, to $300 / unit for a high amperage reversing polarity ESC which controls one motor. So, if you have a minimum of three thrusters or groups thereof, the cost is $210-900 US + tax and S&H. Some sources are below:
http://www.robotshop.ca/
http://www.vantec.com/products.htm
http://www.rpelectronics.com

Programmable Electronic Speed controls:
This is the ultimate in proportional speed control and signal channeling for ROVs. These units enable control of all circuits by programming the EPROM chips inside the unit. The unit also enables power of different voltages to enter smaller loads like cameras, and permits electronic switching of additional actuators (loads). The cost for 4 motor control, PWM and some switched is of the nature of $1500 CDN. (www.ifirobotics.com) It should be noted that the successful use of these multi-component ESCs in 2005, prompted the MATE Centre to discourage their use a they were perceived as being (in their words) *"plug and play"*. This is an inappropriate designation as the IFI components have to be knowledgeably and wisely chosen and programmed….much like an industrial ROV manufacturer would do.

10.4.9 Underwater video-cameras:

STEP 9 Video-cameras
Again, there are several alternatives, depending on fends available and the need for extra quality, however some quite reasonable waterproof video-cameras can be produced in a school workshops, using off-the-shelf components.
Select on the following features:
- Colour or B/W (what would you need? B/W is cheaper and lower light)
- Size of CCD: ¼" to 1/3 "
- Resolution (300 up to 500 lines of resolution)
- Field of view (narrow or wide: depends on your need)

- Cost

Home made – potted.
Pick out a board (CMOS) camera from the wide variety available, from either your local electronics shop or the internet. http://www.supercircuits.com
Once you have made your selection and have received it, you now have to waterproof it. Before you do, plug it into the appropriate voltage power source, being certain of the correct polarity and:
i. adjust the focus to be best in the distance range you will use (ignore this step if you are using a fixed focus pinhole unit)
ii. mark on the camera with a spot of paint or nail polish, the exact point at which the image is vertical.

Waterproofing can take two forms:
i. building a waterproof housing, or
ii. ***potting*** the camera in epoxy which will harden to make it waterproof

Potting is achieved by:
i. making an appropriate mould from silicone caulking or another material.
ii. attaching a clear glass or polycarbonate lens over the lens of the camera with a super-glue.
iii. gluing around this lens to attach it to the mould and prevent the epoxy from coating the lens – thereby making the image fuzzy.
iv. mix and pour the epoxy into the mould, ensuring that the cables from the camera emerge from the mould at a suitable location, and
v. let set and cure for 24 hrs +

This process is tricky so you might want to try it once without the camera, to make sure you're doing it right. Consult this website for additional details and pictures.
http://www.videoray.com/MATE.Camera/Mate%20camera.htm

Home waterproofed video-cameras
Waterproof encasement is achieved by building a small container using plastic plumbing parts such as 1-½" PVC pipe, end cap and screw-down union in which to secure the clear lens. There is a stepwise description of this simple process on the MATE Centre website. (www.marinetech.org)

Purchased underwater cameras.
There are some very good, small underwater video cameras available, in either colour or B&W …but they tend to be VERY expensive. One lead is the Electronics Centre, St. John's, NL which sells a professionally encased small but heavy U/W B&W video-camera for the price of ~$350 CDN.

Commercially available waterproof video-cameras
The source for cameras to used by the Ranger class ROVs has discontinued their least expensive camera line…the one which was ideal for that function.

We searched for an alternative have found two:

i. last year's SCOUT Class ROVs were equipped with a B/W video-camera waterproofed to about 30 m, combined with a 12V small battery-operated TV. They worked well. These units were not available this year in time to distribute them to the new 2011 SCOUT class teams so a replacement camera is provided.

ii. This year's U/W video-camera is a colour camera water proof to 70 ft or 20 m, but without the small TV. It appears to be slightly clearer, but the team must supply a small TV to use it effectively.

Both cameras have LED lights inside the waterproof case for use in low light conditions. There is a photo of this unit to the right.

On the highest end of the scale is the miniature pan/tilt, high resolution colour, *"CrystalCam"* model video cameras from Inuktun Services, Nanaimo, BC which sell for about $8000 (CDN). The resolution and clarity with these very expensive underwater video cameras is indeed impressive, however, there is more than satisfactory performance to be obtained from your own home-made one. www.inuktun.com .

10.4.10 Electrical wiring for your SCOUT Class ROV

Rules and Regulations

Here are the regulations and rules relating to electrical power in the SCOUT class.
A 12-volt "car" battery or power source with a 7.5-amp fuse will be provided. You will connect to this power source via banana jacks (female ends will be provided; you must provide the male ends). Your ROV must operate below 7.5 amps when underwater.

Cameras and monitors are permitted. However, the cameras(s) and monitor(s) must operate off of a separate DC battery (12-volt maximum) that your team provides. Only the camera(s) and monitor(s) are permitted to operate off of this battery; your vehicle's motors and all other associated equipment (manipulators, etc.) must be powered off of the 12-volt battery provided by the contest organizers.

NO AC POWER IS PERMITTED WHATSOEVER.

Introduction:

For those whose involvement with electricity is limited to plugging in a TV, the wiring of thrusters on a small ROV may seem daunting, but after the first time you'll realize it is fairly simple.
Let's trace the electricity from the start (a 12V battery) to finish (a motor).
Battery:

You'll use a 12V battery, similar to that which you'd use in a car or a motorcycle. This will be necessary only for you to practice, because the 12VDC power will be supplied at the competition. You will, however, need to bring a small 12VDC battery into which you can plug the underwater video camera. This must be brought to the competition.

Main Power Switch or Circuit Breaker Switch:

The power to your ROV first comes from the battery into a control box via two heavy 12-Gauge, insulated wires. One of these wires is the positive side (+) and it is usually insulated with a white plastic coating. The other side is the negative (- , or ground) wire, and normally has a black plastic insulation. One of these wires (+) the white one, should first connect with a simple ON /OFF switch which turns all the power going into the control box. This is a safety device.

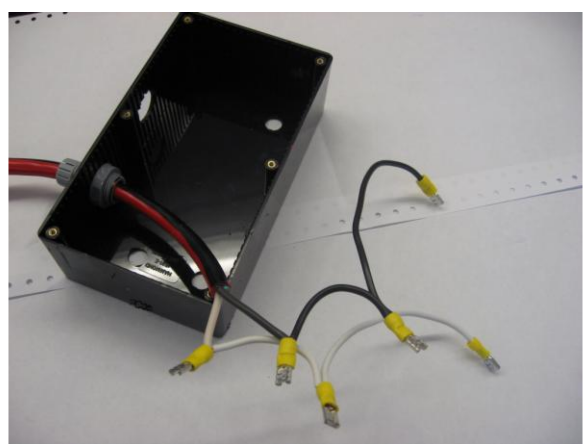
Ideally this switch should be a circuit breaker switch…one which will automatically turn OFF if there is a problem in your wiring or some leaking occurs in your wiring connections. This circuit breaker switch is rated at 20 Amps, which is the limit permitted in the SCOUT competition. We recommend you purchase one of these circuit breaker switches fom your local hardware store (CTC, Rona, Kent, Home Hardware, etc.)

In fact , even if you don't have a circuit breaker switch, the power which will be supplied to you at the SCOUT competition WILL have a 20 Amp fuse that performs the same function.

Powering the Motor Switches:

First Motor Switch:

The wire from this safety switch, also with white insulation, will go to the positive side of the first motor switch. On the switches supplied with your ROV, this white wire will go to the male blade connector on one side of the first motor switch. On the other side of this first motor switch the black wire (-) from the main power cord will be connected. You'll need female blade connectors on the wire to connect with the male blade connectors on the switch.



BTW: This switch is more complex in function than the main power switch. It's toggle moves from a central off position forward to provide to power to the motor . When you pull the toggle switch back towards you, this switch has the capacity to switch the poles of the current in the wires going to the motor. This means that the motor can go in reverse when the switch toggle is pulled in the other direction.

Second Motor Switch:
The white insulated power wire (+) from the first motor switch jumps to the second motor switch in the same male blade location as on the first. This is also true of the black insulated ground wire (-)
Third Motor Switch:
This pattern continues to the third motor switch. (see the photo above for the powr wiring harness for the control box. (Missing is the main power switch.)
Now you have powered all the switches. The next step is attaching the wires from the tether cable to these switches, so the power can flow into the ROV thrusters.

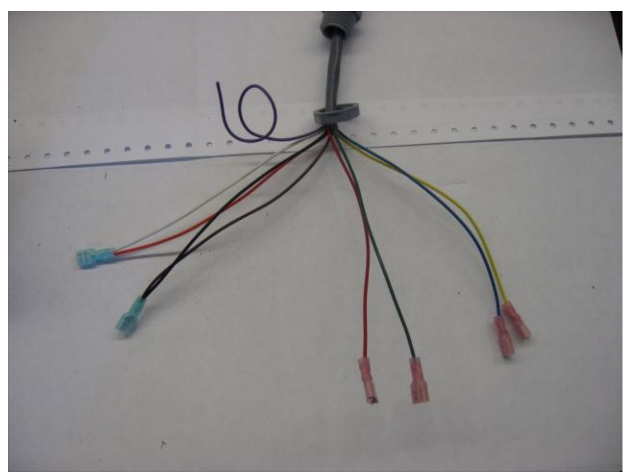
10.4.11 Powering the Thrusters:

The Control box end of the tether has to have the grey insulation removed for a distance of about 8” (eight inches; about 20 cm) from the end.
The ROV end of the tether has to have the grey insulation cover removed from about 2” (two inches; 5 cm) from the end.

Then you have to strip off about 1-1.5 cm of the coloured insulation from the end of all the wires.
On both ends, separate the 9 wires into pairs, with one light colour and one dark colour wire in the pair. E.g.

Positive wire (+)	Negative (ground) wire (-)
White	Black
Orange	Brown
Yellow	Blue
Red	Green

and there is one left over (Purple)

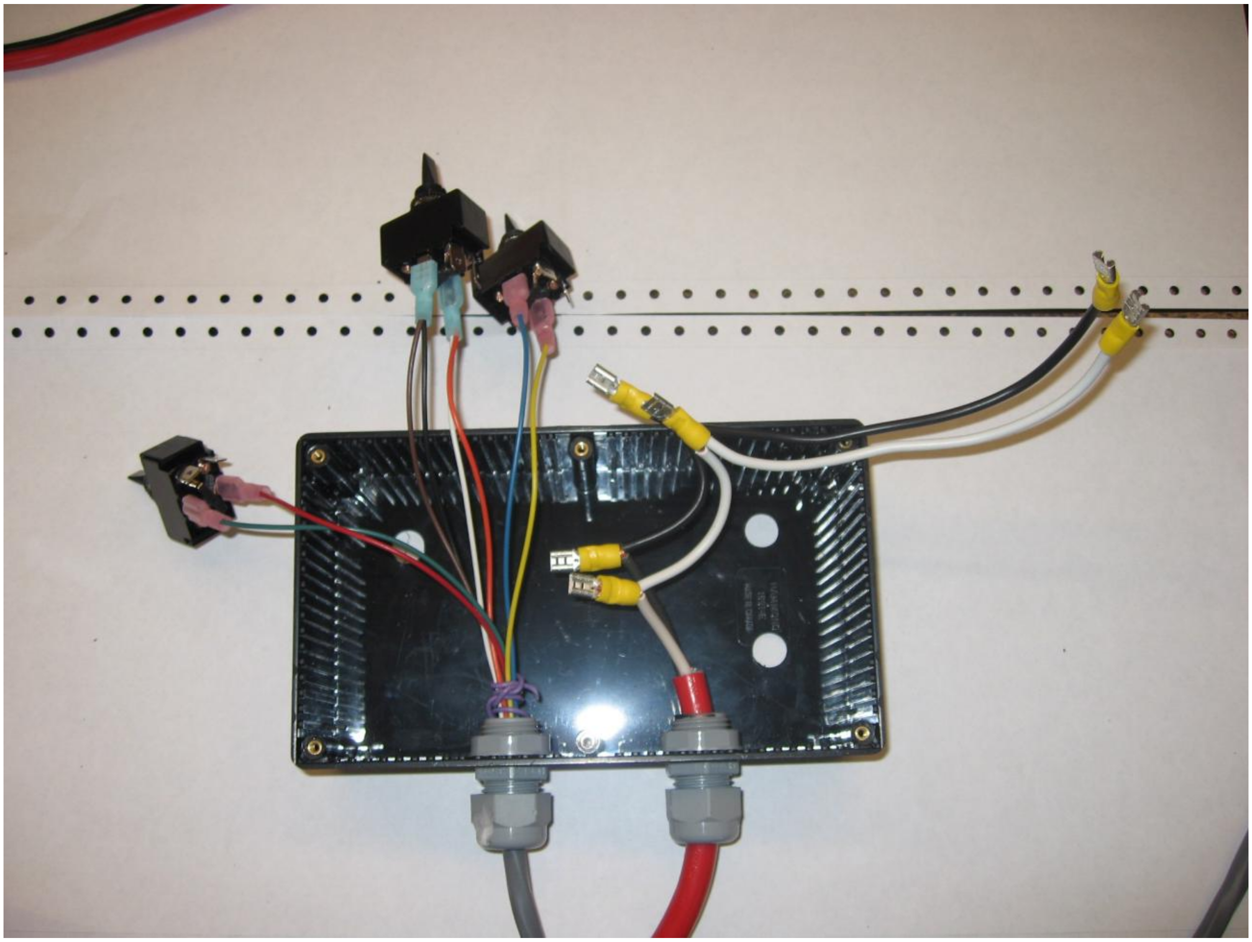


On the Control Box end:

Crimp on the female blade connectors on the end of each of the 4 pairs of wires (but not the one solitary wire) . You will probably use a pink coloured female connector cover on the following wires.
They should be crimped as follows:
Horizontal Thrusters
Insert one wire end of the following colours into their individual female blade connectors.
Black – White
Brown – Orange

That will result in 4 connectors, one for each individual wire of these colours. These four connectors will be plugged into the two switches controlling the horizontal thrusters (for forward and reverse motion).

Vertical Thrusters



The remaining four wires will all plug into one DPDT motor switch , Before doing so they must also be crimped into the female spade connectors. The difference is that the Blue and Green will be crimped in the same connector and the red and the yellow will be crimped together in a second connector. You will probably need to use the female connectors with the blue coloured plastic cover, to hold the larger bulk of the two wires. They will be connected as in the same blade connector, as follows:
Blue and Green….one blade connector (both negative / ground)
Yellow and Red……a second blade connector (both positive +)
Now plug them into the DPDT plugs as shown below.

10.4.12 ROV End

On the ROV end, you have to join the ends with the tether to the wires on the thruster motors. These motors have a black (negative [-]) wire and a brown (positive [+] wire. They will need to be connected to the motors as follows:

Tether wires

Wire from Thruster (+)	Positive wire (+) in Tether	Negative (ground) wire (-) in Tether	Wire from Thruster (-)
Right Horizontal	White	Black	Right Horizontal
Left Horizontal	Orange	Brown	Left Horizontal
Left & Right Vertical Thruater (+)	Yellow	Blue	Left and Right Vertical Thruster (-)
	Red	Green	

and there is one left over (Purple)

The method of connecting these wires at the ROV end needs special attention, as it's the end which is submerged. It must be secure and waterproof.

Here's the process:

STEP 1.

Solder the wire ends from the tether to the thruster motors. This includes :

Wiping flux onto the bare wire ends of the tether and heating the wire end with a soldering iron.

Touch some flux core solder onto each heated wire end and have the melted solder flow into the strands of the wire ends.

This is already done for the wires from the thruster motors, as you can see by their silvery look.

Push some heat shrink insulation over the ROV thruster wires and push it well back to their origin….so they don't get heated in the next operations.

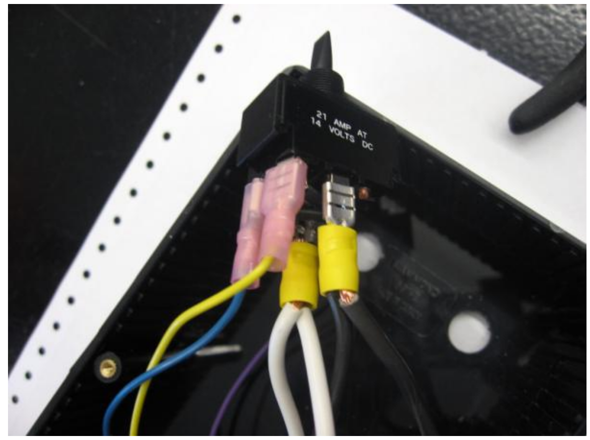
Push a 3" (10 cm) long piece of ½: bore PVC pipe over the tether end and move it back from the end.

Join the tether wires to the thruster motor wires by soldering the two wires to be joined (see table above).

Pull the heat shrink back over the cooled solder join for each set of wires.

Push the ½" bore PVC pipe length over all the joins of the wire.

Wrap tape around one end of the PVC pipe and locate the open end of the small pipe length upwards.



Pour 60-minute hardening epoxy liquid into the upright pipe. Wait for the epoxy so solidify. Top up either end of the pipe if there are holes or incomplete filling.

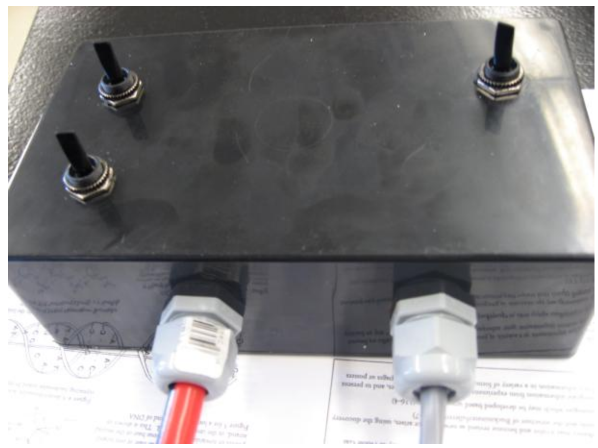
STEP 2. Installing the switches

Drill three ½" diameter holes in the top of the control box to accept the three DPDT switches. They should be easily accessible by young hands. (See illustration below.)

Insert the DPDT switches into the control box in pre-drilled 1/2" diameter holes .

Be VERY careful NOT to strip the threads on the shaft of the DPDT switch.

Test out the switches by attaching it to a 12V battery, to ensure they operate correctly.



10.4.13 Tool design and building:

STEP 10: Tool design and fabrication

This is not really the last step. In fact, the common wisdom is that designing and building the mission tools should be started when you start STEP 1 in the fabrication, or even before that. It is a matter of starting the design process immediately upon knowing what the mission tasks are. If anything, the development of the tools takes longer than the production of the ROV because there are so many unknowns and so many alternative ideas to be tested. Some teams start with the tool designs and actually build the ROV around the tools, after the first tool prototypes are built.

Because the mission tasks are so varied in their requirements, it's difficult to provide prescriptive instructions on how to make a range of tools. The brainstorming, research, design, building, testing and refinement cycle is used.

An <u>*example*</u> is provided below:

The mission statement says *"Collect a water sample of 500 ml from 10 cm above the bottom at 6 m depth in a pond and a wharf at the ocean."* The first step is fully understanding the details of the task. That comes from reading the Mission statement, carefully and creating an image or drawing of exactly WHAT is required. There are a number of things to consider in the ROV design as well as the tools.

<u>Environmental things like:</u>

- What is the bottom really like…muddy, sand, rock, coral lumps?

- What is the clarityof the water..can I see what I'm doing?
- Is there going to be a current…should I collect at slack tide?
- Do I need extra tether to reach from a high wharf to the surface?

See the following website for a discussion of the environmental factors ROVs encounter.
http://www.gvsu.edu/wri/education/manual/monitoring.htm

Tool design requirements like:

- How much water do I need to collect to get 500 ml to the surface?
- Should the container be open or closed on the way down…what are the consequences of each method?
- How to I either just close or open and close the container at the bottom?
- Do I need to use a motor or are there other options?
- What resources or environmental factors can I use to my advantage?
- Can I be sure that my design will work EVERY time …reliably?

With these things in mind, you must now research existing designs of mechanisms to do this task. It has to have been done before. There must be a broad range of apparatus which has been designed to complete water sampling at remote depths and locations.

"The truth is out there"

----Fox Mulder, ***The X –Files*** (2002)

How to start the research?

What groups or industries would routinely collect water samples? Well, *oceanographers, hydrologists, freshwater limnologists or biologists, people doing environmental monitoring*, etc.

What are you looking for: *water sampler, water collection, water bottle, water sampling methods, bottom water sampling* ?

So these are the search key words you would use to start either an internet or library search.

Our internet research identifies a number of sites with water samplers, but most are far too complex for us to make. We need a simple device that we can easily fabricate from available materials and is a size which can fit on a small ROV. Use the word "simple" or "student-built" in the search for the sampling method.

After some dead ends, we discover "Tools of the oceanographer-Equipment" at http://www.biosbcc.net/ocean/bio124project/ and scanning down the website on water sampling tools we encounter a number of designs. Which is the most simple and easy to build?

Can you see how they work? Not really, so searching on "using the sampler", we stumble across the following web site which explains how it works.
http://www.gvsu.edu/wri/education/manual/water_sampling.htm

These instruments all are designed to be hung on a cable in the water column and use a messenger (metal weight), which triggers their closing when it is sent down the wire. We won't need a cable, because our delivery method is the ROV you are building. We may not need a messenger, because we have the bottom as a surface which can operate the trigger release.

Now, the design becomes a lot simpler. The Van Dorn sampler is essentially a piece of pipe with removable plugs on either end. They are joined by a small length of elastic material (surgical tubing or bungee cord). It's completely open as it travels to whatever depth the ROV goes and is triggered by …what? Well that's up to you, but the one fact which can help you is that it is going to be triggered near the bottom. Where can you get the components for your own Van Dorn water sampler?

Component	Possible Sources	Est. Cost
2" pipe	Plumbing supply, hardware	$4.00
plugs	Kitchen supply or made from foam or 1/2 of a street hockey ball	$3.00
Bungee cord or surgical rubber	Outdoor sports or medical supplier	$4.00
Total Cost		$11.00

Here are some mechanisms designed by students to achieve that task. Yours may be even simpler and more effective. Remember the steps to success: research…...use your imagination….. …draw……build……test…...improve.
The process for researching and designing other tools is the same.

Good luck and have fun!