Electronics Technology and Robotics III
Structure and Materials 1
(Notes primarily from "Underwater Robotics – Science Design and Fabrication", an excellent book for the design, fabrication, and operation of Remotely Operated Vehicles ROVs)

- **Administration:**
    - Prayer
- **General Introduction:**
    - The frame of an underwater vehicle provides a firm platform for the fixing of the necessary mechanical, electrical, and propulsion components including special tooling such as sonar, cameras, lighting, manipulators, scientific sensor and sampling equipment. ROV frames have been made by lots of different materials from plastic composites to aluminum tubing.
    - In general, the materials used are chosen to give the maximum strength with the minimum weight, since weight has to be offset with buoyancy.
    - The size of the frame is dependent on the following criteria.
        - Weight of the complete ROV unit in air
        - Volume of the onboard equipment
        - Volume of the Sensors and Tooling
        - Volume of the Buoyancy
        - Load bearing criteria of the frame
- **Systems Interaction:**
    - Interactivity between ROV systems causes difficulties in the design and fabrication process.
    - Changing any of the power, navigation, propulsion, ballast, payload, structure, control or tether systems affects the design and construction of the other systems.
    - For instance, a team may find that they have to add another payload tool to their ROV. The frame now must be changed to accommodate the new tool which in turn affects the ballast system and possibly several other subsystems.

- **Three Basic Structure Components of an Underwater Vehicle:**
  - o There are three components in an underwater vehicle's structure, the frame, pressure canisters, and the fairing:
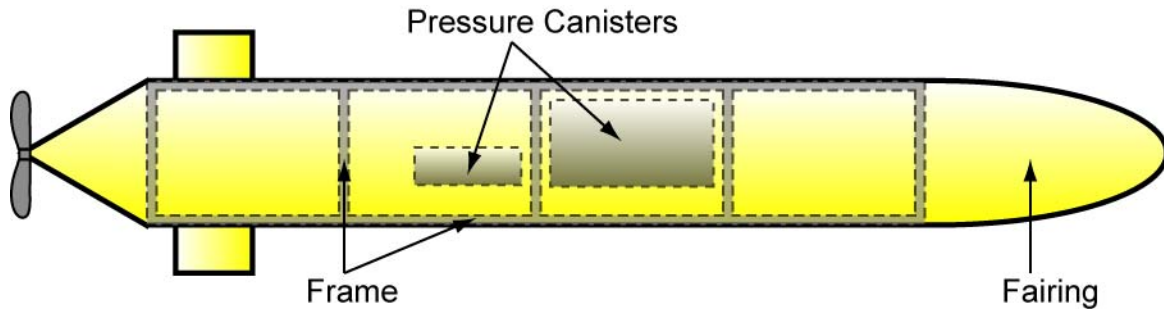
Pressure Canisters

Frame

Fairing

Figure 1: Three Basic Components of an Underwater Vehicle

  - ▪ **Frame** – the internal supporting structure that gives a vehicle its shape
    - It is required to support the weight of the vehicle in and out of the water.
    - It has to distribute concentrated forces such as lifting points.
    - It must resist hydrodynamic forces from currents, waves, and thruster propulsion.
    - All of the other ROV components such as cameras, pressure canisters, and thrusters must be mounted such a way that servicing is convenient.
    - It must withstand the forces from the onboard tools themselves and the additional forces transferred to the frame while the tools are in operation.
    - The frame should guard the underwater vehicle from collisions underwater and rough treatment out of water.
    - It should protect the tether from damage.
  - ▪ **Pressure Canisters** – rigid, watertight containers that protect contents from water and pressure
    - They have to withstand water pressure forces.
    - They must keep the integrity of the watertight seals.
    - They need to provide a way to service their contents.
    - They may include wire penetrations in their outer walls and still maintain water tightness.
    - They must provide a way for mounting to the frame.
  - ▪ **Fairing** – the external surface of a vehicle, such as a submarine, that serves to reduce drag
    - Fairing should minimize the drag the vehicle encounters in the water.
    - It should have a smooth surface so the vehicle does not get caught or entangled in its working environment.
  - o ROVs are normally made without a fairing since they do not travel great distances nor at high speeds.

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- **Structure Basics:**
  - **Strength and Stiffness:**
    - Strength – the power to resist strain or stress without experiencing damage; durability
    - Stiffness – the measure of the resistance offered by a body to deformation.
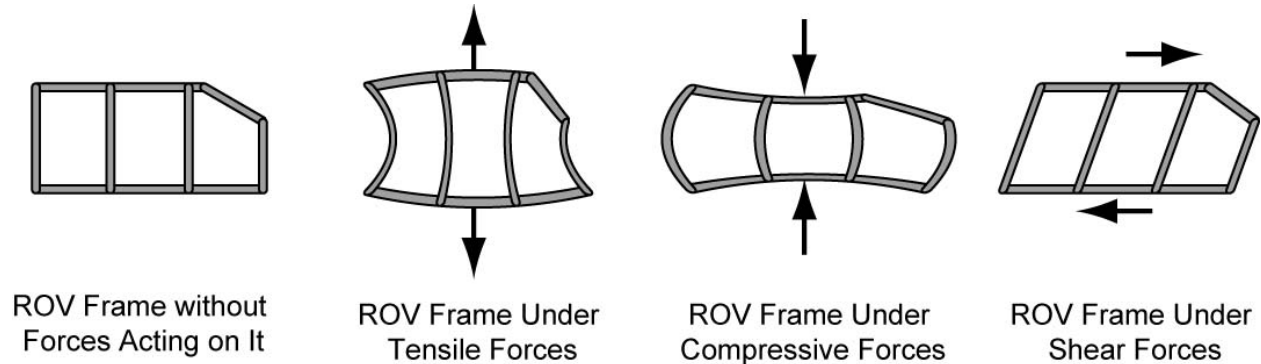

Figure 2: ROV Frame Under Three Basic Structural Forces

    - The strength and stiffness of your ROV is subject to:
      - The strength and stiffness of the individual parts
      - The geometry of the structural members in the vehicle
      - How the parts are fastened to each other
      - Perform Structures and Materials Lab 1 – Strength and Stiffness of Geometric Configurations
  - **Weight** – the force that gravitation exerts upon a body
    - Although buoyancy can be added to compensate for more weight under water, the additional weight encumbers the handling of the vehicle while out of water.
    - In general, less weight is superior than more weight.
    - Factors to consider when putting your underwater vehicle on a "diet":
      - Limit the size of your vehicle
      - Use materials that have higher strength and stiffness for their density
      - Make use of material cross-sections that lend themselves to higher strength and stiffness
  - **Construction and Maintenance:**
    - Keep it simple; simple designs are easier to construct and have fewer things that can malfunction. One of the MATE competition score sheets lists "Components easy to access for maintenance & troubleshooting" as one of their line items.
    - COTS parts – Commercial Off-The-Shelf parts:
      - Parts that are ready-made and commercially available.
      - The final part is normally quicker to purchase than to build the part yourself.

- COTS parts are more reliable and occasionally cheaper than DIY parts.
    - DIY parts – Do-It-Yourself parts:
        - More educational
        - Have a backup part available that can be easily inserted
    - In the MATE competitions, multiple commercial components such as tethers or thrusters are encouraged. Systems designed to perform multiple, complex functions from one "black box" or series of components designed to integrate with each other are discouraged.   An example is the FIRST controller system.
- **Safety:** Safety by design
    - Safety is always the first priority in the design and operation of an underwater vehicle. The standards for manned vehicles are understandably much higher and more rigid than an unmanned vehicle.
    - Partial list of potential hazards for unmanned vehicles:
        - Injury from rollover or shifting during transportation
        - Electrical shock
        - Discharge from stored energy such as hydraulics and pneumatics
        - Lacerations from sharp objects
        - Hazards to divers nearby
        - Injuries during the fabrication process
    - Safety by design is a concept that supports the view that along with quality and cost; safety is determined during the design stage. This proactive approach results in a decrease in accidents and injuries.
    - Code of Practice for the Safe and Efficient Operation of Remotely Operated Vehicles by IMCA: http://www.imca-int.com/documents/divisions/rov/docs/IMCAR004.pdf
    - 2011 MATE safety inspection sheet: See Appendix A or link to http://www.materover.org/rov_competition_files/2011/2011_SafetyInspection.pdf

- **Structural Cross Sections and Geometric Configurations:**
  - o The goal when designing an underwater vehicle frame is to maximize the strength and stiffness with the minimum weight and material.
  - o Connecting and joining the frame elements is a key factor in your material selection.
  - o Structural Cross Sections:
    - ▪ A beam under bending experiences high tension and compression stresses along the outside fibers that are farthest from the neutral axis (see Figure 4). The beam material close to the neutral axis carries little of the load so it should be minimized which eliminates much of the weight. To prevent failure, most of the material in the beam must be located in the outer regions. This observation is the basis of the I-beam cross-section; the neutral axis runs along the center of the web which can be relatively thin and most of the material can be concentrated in the flanges (Figure 3).
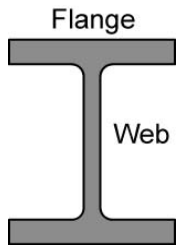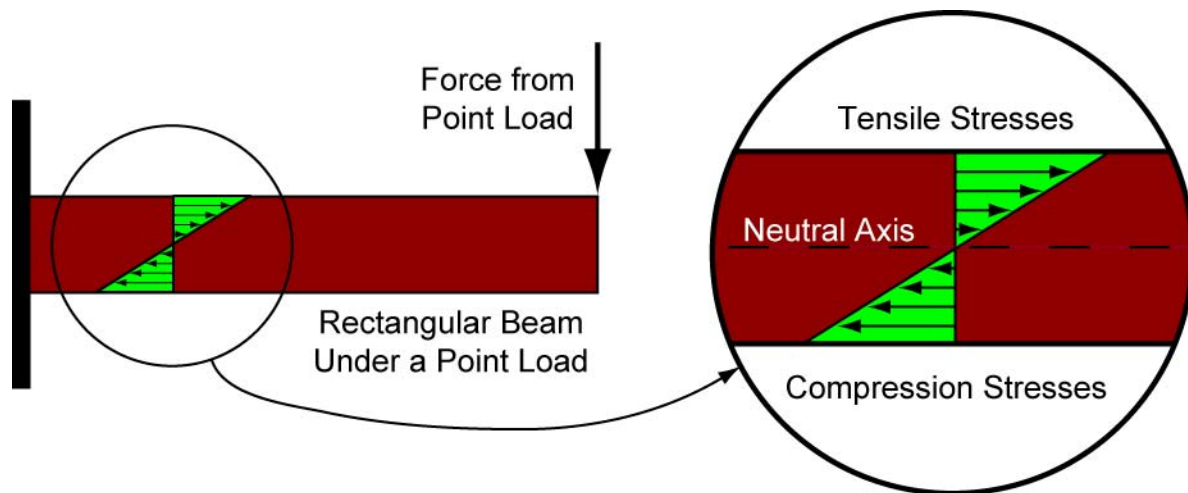
Flange

Web

Figure 3: I-Beam

Figure 4: Beam Under a Point Load and the Related Stresses

- ▪ Good material cross sections for frames:

Tubing   I-Beam   Angle   Square Tubing
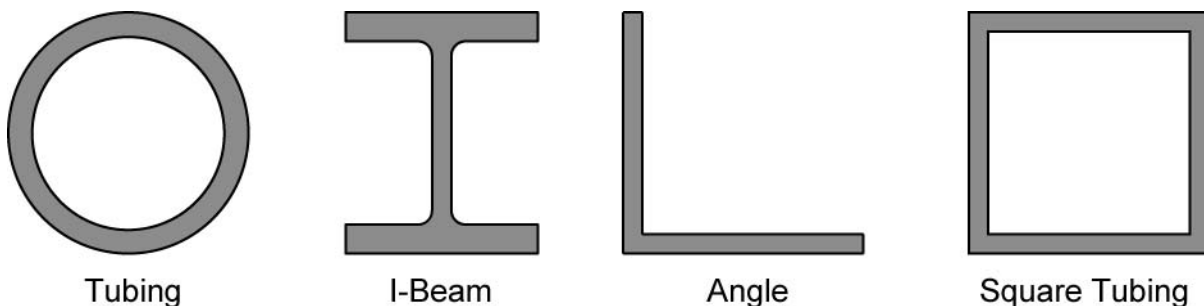
Figure 5: Material Cross Sections with Good Strength and Minimum Weight

- If a compression load is applied on a column, the member may fail either by crushing or by buckling depending on its material, cross section and length. If member is considerably long in comparison to its lateral dimensions it will fail by buckling. If a member shows signs of buckling the member leads to failure with small increase in load.
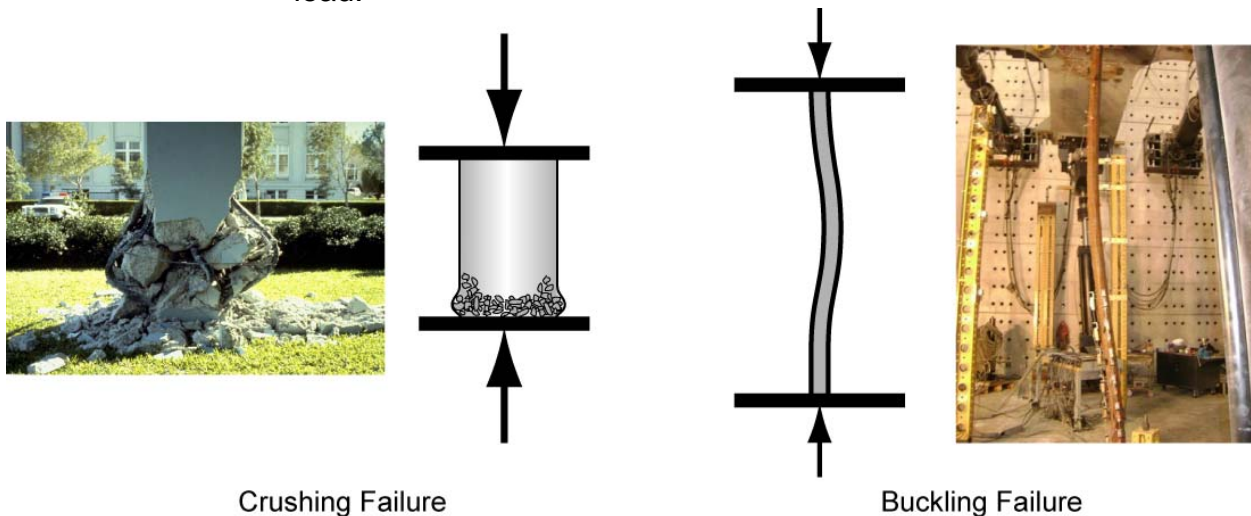

Crushing Failure   Buckling Failure

Figure 6: Types of Column Failures

- Perform Structures and Materials Lab 2 – Crushing and Buckling
- Ways to Make a Rectangle Rigid:
  - A rectangle assembly with pivot joints can distort into a parallelogram without changing the length of any side. This makes the rectangle shape inherently unstable.
  - A triangle will distort only if the length of one or more of its sides changes.
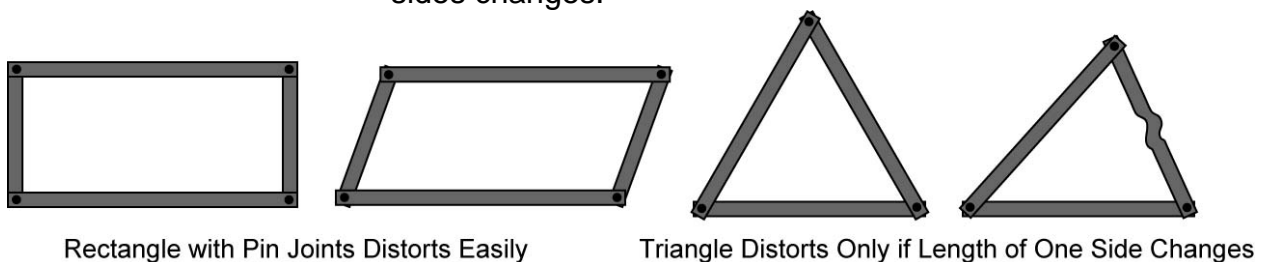

Rectangle with Pin Joints Distorts Easily   Triangle Distorts Only if Length of One Side Changes

Figure 7: Stiffness of a Rectangle and Triangle

- There are several ways to stiffen a rectangle assembly:

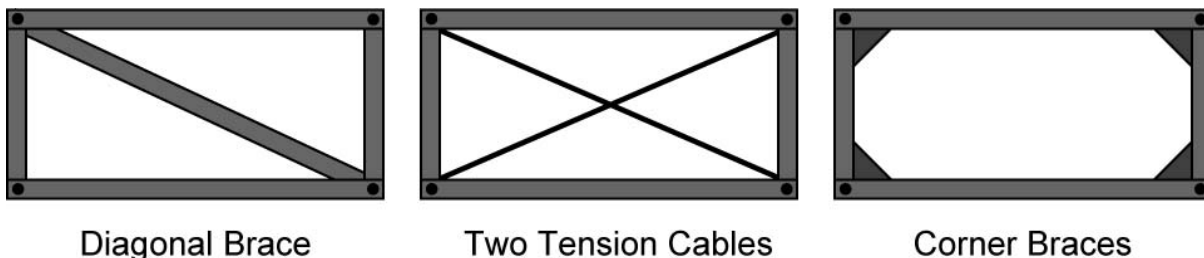Diagonal Brace   Two Tension Cables   Corner Braces

Figure 8: Stiffening Rectangle Assemblies

Cornerstone Electronics Technology and Robotics III
Structures and Materials Lab 1 – Strength and Stiffness of Geometric
Configurations

- **Purpose:** The student tests several structural geometric configurations under load to determine the relative load bearing capacity of each configuration.

- **Apparatus and Materials:**
    - 5 – Popsicle Sticks
    - 6 – #6x32x3/4" Machine Screws
    - 6 – #6x32 Nuts

- **Procedure:**
    - Drill the ends of the Popsicle sticks with a #25 drill bit (creates a loose fit for a #6x32 screw).
    - Connect the ends of 3 Popsicle sticks to form a triangle using the machine screws and nuts. **Do not tighten the machine screws and nuts, but only tighten until they barely touch the wood.** See the illustration below.

    - Apply a force with your finger as shown above and note the stability and the load capacity of the shape.
    - Now construct the Popsicles sticks into the configurations of squares and pentagons. Tighten the screws as before.
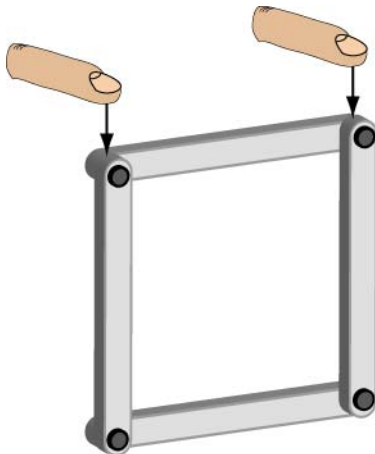
- o Again apply force with your finger(s) as shown above and note the stability and the load capacity of the each shape.
- o Record your results.

- **Results:**
  - o Evaluate the load capacity of each geometric configuration. Make a list from weakest to the strongest geometric configuration.

    - _____

    - _____

    - _____

- **Conclusions:**
  - o Which geometric configuration had the highest load capacity?

From: http://www.atlaso.com/bridge.htm

  - o Explain in your own words why that configuration performed better.

- **Purpose:** The student tests the effect that a material cross section has on strength and stiffness.

- **Apparatus and Materials:**
  - 1 – 10-Ton Hydraulic Bench Press with Pressure Gauge (http://www.northerntool.com/shop/tools/product_200332763_200332763?cm_ite=145208&cm_pla=Metal%20Fabrication%3EShop%20Presses&cm_cat=Shopping&cm_ven=Aggregates)
  - 1 - 0.75" OD x 0.62" ID x 12" Aluminum Tubing – From McMaster Carr: http://www.mcmaster.com/#9056k713/=d99sia
  - 1 – 0.5" x 72" Aluminum Rod – From McMaster Carr: http://www.mcmaster.com/#8974k33/=d99uph
  - 1 – ¾" x 5' PVC Rod – From McMaster Carr: http://www.mcmaster.com/#pvc-rods/=d9fti4
  - Nylon Strap and Hose Clamps

- **Procedure:**
  - **READ, UNDERSTAND, AND APPLY ALL SAFETY INSTRUCTIONS FOR THE HYDRAULIC BENCH PRESS BEFORE USE.**
  - PVC – Crushing and Buckling:
    - Cut 2.5 cm and 30 cm pieces off the PVC rod.
    - Mill both ends of the rods to form a smooth surface that is perpendicular to the rod length.
    - Secure the nylon strap with hose clamps onto all 30 cm pieces used in this lab. Anchor the other end of the strap to a fixed surface.
    - Load the hydraulic bench press with each piece such that the compression force is applied along the length of the rod.
    - Measure the maximum force each can withstand and record your results.
  - Aluminum – Cross Sections:
    - Lathe turn down the entire length of a 30 cm+ rod to a diameter of 10.7 mm.
    - Cut a 30 cm pieces off the 10.7 mm diameter aluminum rod.
    - Mill all of the ends of the tubing and rod. Secure the rod with straps.
    - Load the hydraulic bench press with the ¾" aluminum tubing.
    - Increase the press load until the maximum compression force is reached. Record the maximum force.
    - Repeat the compression test using the 10.7 mm diameter aluminum rod. Record your results.
- **Results:**
  - PVC:

PVC Length	Maximum Applied Force
5 cm	
30 cm	

o Aluminum:

Aluminum Piece	Maximum Applied Force
3/4" Hollow Tubing	
10.7 mm Solid Rod	

- **Conclusions:**
  - o PVC:
    - ▪ Which length of PVC exhibited crushing failure?

    - ▪ Which length of PVC exhibited buckling failure?

    - ▪ The compression strength of PVC pipe is approximately 9,600 psi. The area of the ¾" PVC rod is 0.442 in^2. How do your test results compare to the maximum calculated value?

  - o Aluminum:
    - ▪ Fill in the table below.

Aluminum Piece	OD (in)	ID (in)	Area	Maximum Applied Force	% Increase Max Force
10.7 mm Solid Rod	0.421	-			-
3/4" Hollow Tubing	0.75	0.62			

    - ▪ For experimental purposes, are the two areas equal?

    - ▪ Which shape can carry more compression load?

    - ▪ What does that say about the cross section of the shape that carries the higher load?

Photos of Structures and Materials Lab 2 – Crushing and Buckling
NOTE: RESTRAINING DEVICES AND PROTECTIVE SHIELDS WERE REMOVED TO PHOTOGRAPH TESTS
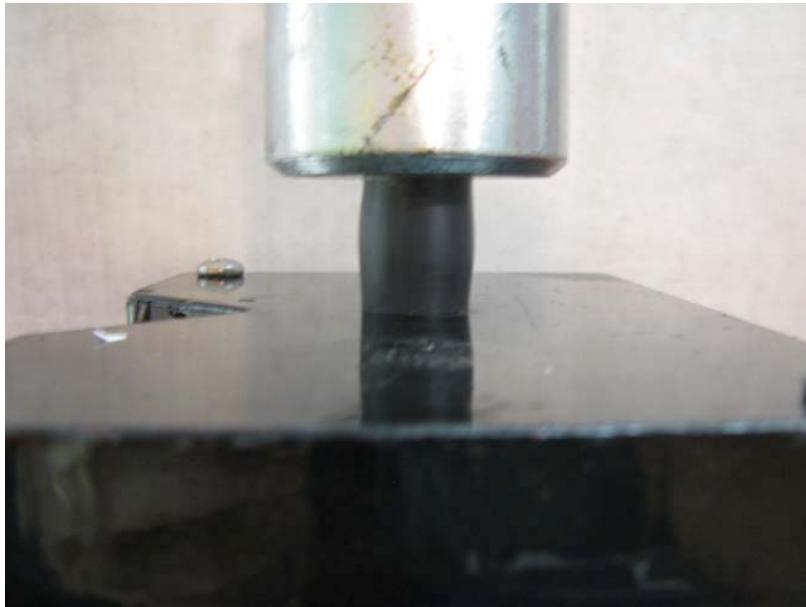
PVC Crushing

PVC Buckling

Hollow Tube Buckling

10.7 mm Rod Buckling

Appendix A

TEAM NAME:_____   TEAM NUMBER:_____

2011 MATE ROV COMPETITION
ROVs and the Offshore Oil & Gas Industry
SAFETY CHECK LIST

The ROV, tether, surface controls and any other item used in the deployment and operation of the ROV will all be inspected as part of the safety check. Companies must bring to the safety inspection all previously mentioned items along with Electrical Schematics or Power Distribution Diagrams, and if used, Pneumatic and Hydraulic Diagrams, Hydraulic Fluid MSDS and specifications for valves and any pressure related items used in the system. A copy of the technical report should also be provided. In the case of team designed pressure accumulators, pressure test results must also be provided.

Documentation	
	Electrical schematics & power distribution diagrams
	Technical report
	Pneumatics diagrams (if used)
	Hydraulic diagrams (if used)
	Hydraulic fluid MSDS (if used)
	Fluid is compatible with the Biodegradable Food-Grade specification. Teams using water do not need to provide an MSDS.
	Pneumatic and/or Hydraulic component documentation as needed.
	Explorer: Wellhead demobilization instruction sheet for divers, laminated and clear.

Physical	
	All items attached to ROV are secure and will not fall off.
	Hazardous items are identified and protection provided.
	No sharp edges or elements of ROV design that could cause injury to personnel or damage to pool surface.
	Explorer: Wellhead Cap poses no safety risk to divers

Electrical	
	Single attachment point to power source.
	Correct connector to power source provided.
	Single Inline fuse or circuit breaker. (25 amp Ranger, 40 amp Explorer)
	No exposed copper or bare wire.
	No exposed motors.
	All wiring securely fastened and properly sealed*.
	Tether is properly secured at surface control point and at ROV.
	Any splices in tether are properly sealed*.
	Surface controls: All wiring and devices properly secured.
	Surface controls: All control elements are mounted with wiring inside an enclosure.
	Explorer: No power conversion before ROV.

Properly sealed means that the wires cannot be exposed to water. Tape only sealing will allow the conduction of electricity through water.
At minimum joints must be soldered, then sealed with silicone sealant and then finally taped. For in water taping, silicone self-vulcanizing tape is preferred over thermoplastic tape.

Pneumatic / Hydraulic (if using)	
	Company is on the list of having passed pneumatics/hydraulics test.
	All pressure lines have minimum pressure rating of 100psi (pneumatic) or 300psi**(hydraulic) stamped on line or verified with specification data.
	Valves meet the minimum pressure of 100 psi or 300 psi**
	Attachment to pressure source is secure.
	Pressure is regulated to 40psi max for pneumatics and 150 psi max for hydraulics.
	Pressure vessels have a stamped pressure rating or verification by specification.
	Pressure vessels have current inspection sticker.
	Pressure vessels can be secured on pool deck.
	Company fabricated pressure accumulator test results are provided (if used).
	No hydraulic fluids are leaking.
	Pneumatics utilize compressed air or inert gas

** 100psi for Pneumatic systems and 300psi for Hydraulic systems. Verification of these items can be done by inspection of printed specification sheets provided by each company.

Corrections needed before entering the water:

Cleared to enter the water:

_____
Signature of competition official