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ALEXANDRIA, EGYPT

VORTEX

IN THRUST WE TRUST

ALEXANDRIA, EGYPT

MATE
MARINE
ADVANCED
TECHNOLOGY
EDUCATION
CENTER

V-RAY
CAD MODEL

WE DIVE DEEP

COMPANY MEMBERS: *ELECTRO-MECHANICS CLASS 2017*

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I. Abstract

V-ray, the latest product by Vortex Company comes as a response to the RFP (Request for proposal) issued by the Port of Long Beach for a Remotely Operated Vehicle to assist install a Hyperloop system, conduct maintenance on the port's water and light show, identify and collect samples of contamination and identify the contents of fallen containers and mapping them.

VorteX, an eight-person company (Figure 1) founded in 2015 by engineering students in Alexandria University in the field of electromechanical engineering, utilizes its capabilities, experience and machining facilities to come out with best quality ROVs demonstrated through its previous products. As a company dedicated to the advancement of the field of marine and underwater robotics and with its integrated specialized departments and technical experience, VorteX demonstrates its latest product *V-ray* in this technical documentation.

V-ray is the summary of wide experience mixed with continuous efforts by the company departments to come out with the best quality product capable of performing the assigned missions. Meeting the size and weight constraints, *V-ray* is designed elegantly to minimize drag forces and manipulate efficiently under the precarious conditions of the port. *V-ray*'s vision system compromises of two high quality cameras and lightning system helping the pilot to view both of the equipped manipulators actuated by pneumatic system.

This technical report is a documentation of detailed technical aspects of *V-ray* describing the product evolution, designing phase, our manufacturing methods, company's safety measures, obstacles that faced VorteX and how they were successfully solved.

Figure 1 : VorteX team photo with V-ray after local competition
Left to right (standing): Abdelrahman Abou-Klila, Abdelrahman ElMaradny, Mahmoud Assem and Hesham Said.
Left to right (sitting): Amr Essam, Mohammed Tarek, Ibrahim Youssry and Abdelrahman Hussien

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II. Safety

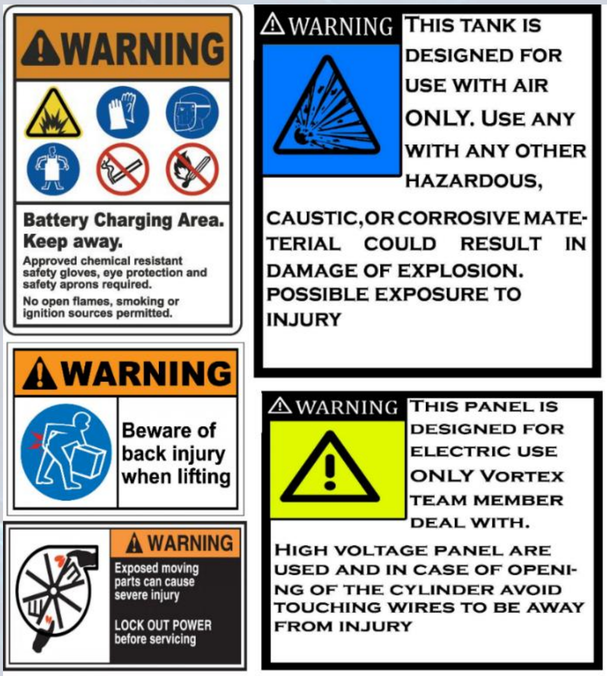

Figure 2: Various safety stickers on V-ray

VorteX Company pays the greatest attention concerning all safety aspects. Safety is a priority for all VorteX engineers since any injury is considered a failure for our team in handling our own product. Risk was decreased as low as possible during designing, manufacturing, handling, transporting or testing *V-ray*.

During designing process, due attention was payed while designing the main body to avoid the presence of any sharp edges that could cause injury. Concerning our sealing techniques, we take safety factors to prevent any chance for water leakage in our electronic units onboard. While testing our water tightness of electronic housings we take factor of safety before issuing the rated permissible depth. Water detector sensor alarms the operators in case of leakage and trips the power immediately.

A 20 ampere DC fuse (section 10) is placed as a measure of protection to trip the power supplied in case of electric overcurrent. A custom 3D printed (Figure 3) enclosure was made to hold the fuse and protect against environmental conditions.

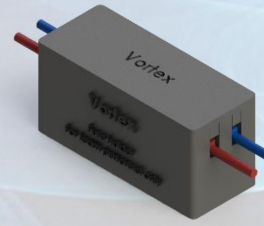

Figure 3: 3D printed fuse holder

Assembling and other machining processes are performed in our various working stations according to a strict safety protocol. A fire extinguisher availability is a must in case of any hazard.

While our personnel perform machining process, several safety measures are always taken and any violation to these measures penalize the violating member even if no accident happens. Protective glasses wearing during all processes is a must. While dealing with drilling process protective gloves are worn, and two members at least must be involved in the drilling process to avoid injury of any of them.

Figure 4: Laser warning sticker

Figure 5: Safety measures taken during dealing with pneumatic components in our workshop

One of the team members is assigned the responsibility of safety measures always maintains a Safety Checklist (Appendix 5) during launching phase, the measures tether-man must follow, post departure measures and measures to be taken in case of leak detection.

During dry testing, a considerable distance must be kept between the company personnel and the vehicle. Electric components are labeled with stickers, thrusters are well shrouded and labeled with stickers, Pneumatic system is labeled as pressurized air hazard, Laser is shielded with a black screen and when the shield is removed, and all testing members wear their protective glasses.

Two Laser shields, black colored, are placed in a distance less than 30 cm to protect the eyes of the surrounding personnel.

III. Project budget and timing

Before starting our project, VorteX decided to schedule a project timing to follow (Figure 6). During the Research and Data collection phase, our CFO estimated an average budget of **2,198.4 $** as a price for manufacturing *V-ray* as a product and estimated another **9,050 $** as extra expenses for MATE competition and travel (Table 1). The final market value of *V-ray* is **2,281.87 $** (Appendix 4) after assembling all parts needed and ready for prototype testing and selling.

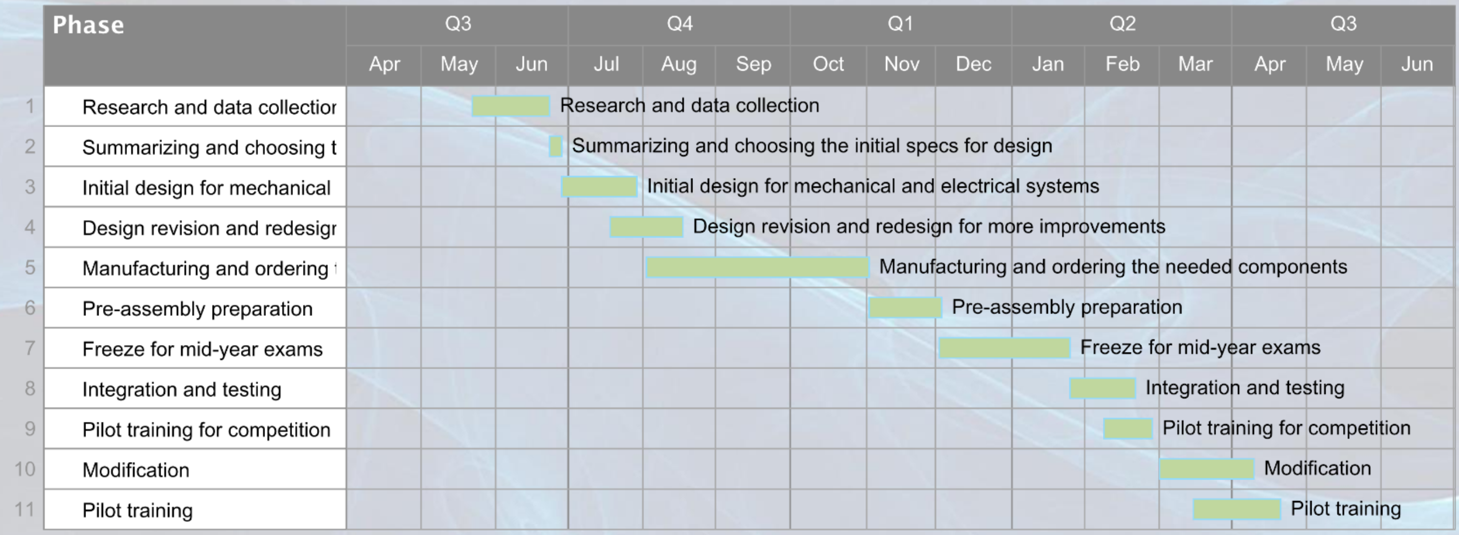

Figure 6: Project timing (Gantt chart)

Subject	Estimated cost[1]	Measures to follow the estimation
Materials for frame and housing	250 $	Choosing materials for body and frame among a list of available materials on the basis of many factors out of which the cost is one of the main factors.
Machining	125 $	During design phase, we take into consideration adopting cheaper manufacturing techniques
Tether	50 $	Shielding our own custom tether according to the required number of cores.
Electrical system	275 $	Manufacturing our own custom electric boards.
Vision system	90 $	Using fixed angle cameras instead of moving cameras. Tilt angles where preciously calculated to give best view for pilot.
Propulsion system	1088.4 $	Buying trusted thrusters to save the money for manufacturing and testing thrusters
Pneumatic system	170 $	Eliminate sealing problem, pneumatic is more powerful relative to electric motor.
Sensors	150 $	
Total (Technical)	**2198.4 $**	
Vehicle shipping	750 $	
Travel budget	6000 $	
Accommodation and transportation (for 10 days)	2100 $	
Marketing	200 $	
Total	**11248.4 $**	

Table 1: Estimated budget and measures to follow it

[1] Egyptian pound was converted as follows 1$=20 LE on the date of budget issuing.

IV. Design Rationale

1. Mechanical design criteria

Design process in VorteX design team passes through some steps before producing preliminary designs to compare among. At first all the design requirements were listed as well as all the constraining factors. The design's main purpose is to encompass all of the vehicle's components in an integrated manner allowing ease of assembly and disassembly for maintenance purposes.

Figure 7: Photo of completed V-ray

A simple scaled hand sketch (Figure 8) was drawn to imagine the design with the main components configuration. A reverse philosophy was adopted in designing *V-ray* to design components from inside-out. Starting from designing the inclusive housing (section 9) and the internal structure for the components, then designing the rest of the frame with the housing as corner stone to build upon.

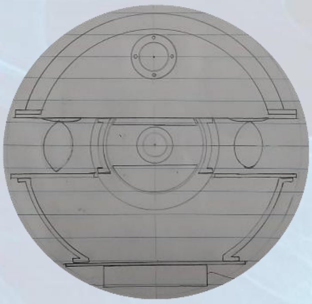

Figure 8: A simple hand sketch in the first steps of design

Several CAD models were generated using SolidWorks software by different team members. The designs were merged to obtain an optimum design with the advantages of all the proposed designs. This optimum design passed through many modifications to reach our final design of *V-ray*.

Figure 9: V-ray design evolution

2. Design Constraints

The main constraints represented mainly in the size and weight imposing an extra challenge on the design team besides other constraints such as cost and machinability. As a result, a mass budget (Table 2) was made for all the vehicle's components assigning specific mass estimation to each component not to exceed. In case of exceeding the assigned mass budget for a component a redesign process is conducted to match the assigned weight.

Component	Estimated Mass (gm)
Frame	2200
Housing components (pneumatic and electronics system)	4000
Housing with 2 covers	2250
Cover	700
Tether (25m)	4000
Thrusters	1770
Main arm	1100
Rotary arm	600
Eagle eye camera case	100
Total	**16720**

Table 2: Mass budget

Another constraint was the size constraint to fit the vehicle in a 58 cm circle. *V-ray* was designed in a sphere-like style to utilize the maximum volume fitting the largest number of components. This is demonstrated through the drawing (Figure 10) showing that *V-ray's* top, elevation and side views are almost circular designed.

Gaining from the experience designing *V-ray's* predecessor (*V-drax*), the design team followed strictly the size and weight constraints decreasing *V-ray*'s size by 32% compared to *V-drax* and its size to 36% only of *V-drax's* weight.

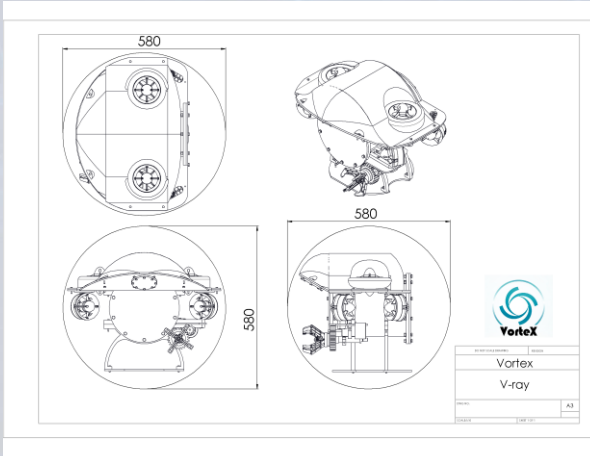

Figure 10: V-ray sphere-like design fitting in 580 mm circle

Figure 11: V-ray and V-drax CAD models

	V-drax	V-ray	Reduction percentage
Size (Circular fit)	850 mm	580 mm	31.76%
Weight	47 kg	16.85 kg	64.14%

Table 3: V-ray vs V-drax in size and weight

3. Frame

VorteX design team adopted a simplicity concept for designing the frame with each and every component serving a specific function to adapt to the previously referred constraints. The frame material is composed of polyethylene of two thicknesses (5mm and 12 mm).

Figure 12: V-ray assembled frame

Poly-ethylene (PE) was chosen over other materials after comparing the following factors; density, mechanical properties, cost and machinability.

Aluminum and stainless steel were proposed options, they were eliminated from the choosing list due to high density, relatively high cost and difficulty of machining.

Figure 13: V-ray machined frame

PMMA (Poly methyl methacrylate), commercially known as acrylic, was also eliminated because of its density (1117-1200 kg/m^3 which is higher than water), its brittle nature and its high cost.

PE (Poly-ethylene) was finally chosen for its density nearly equals 910-960 kg/m^3 which is almost equal to the density of the water making the body acquire zero buoyancy, its high durability and impact strength. PE has also low absorbing capacity to water.

Another factor was its smooth machining by 2-axis CNC milling machine.

The base and main arm holder (1) serves as the stand for supporting the vehicle. It is also the platform of the main manipulator, balancing weight and the mapping camera. The rotary arm holder (2) carries the actuators of the rotary arm. The thruster base (3) is where the vertical and horizontal thruster are mounted according to the specified configuration in (6). All of the previous parts are attached to each other and to the cylinder by means of two cylinder lower holders (5) and 4 cylinder upper holders (6). These holders have the same curvature of the outer diameter of the cylinder.

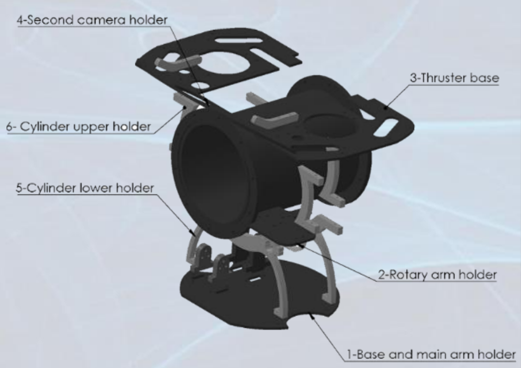

Figure 14: Exploded view of V-ray

The second camera holder (4) holding the eagle eye camera case is adjusted with a tilt angle to view the manipulators clearly. The calculation of the tilt angle will be specified later in (section 11.2).

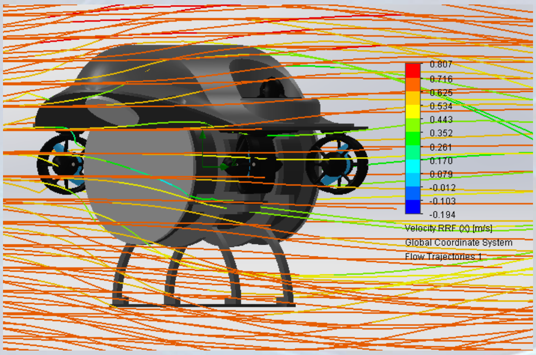

Figure 15: Flow streamlines simulated over V-ray

4. Cover

The design of V-ray's cover was inspired by the stingray fish. The streamlined design of the cover helps minimize the drag force and reduce eddies. The cover was manufactured using 3D printing techniques and painted with a layer of fiberglass.

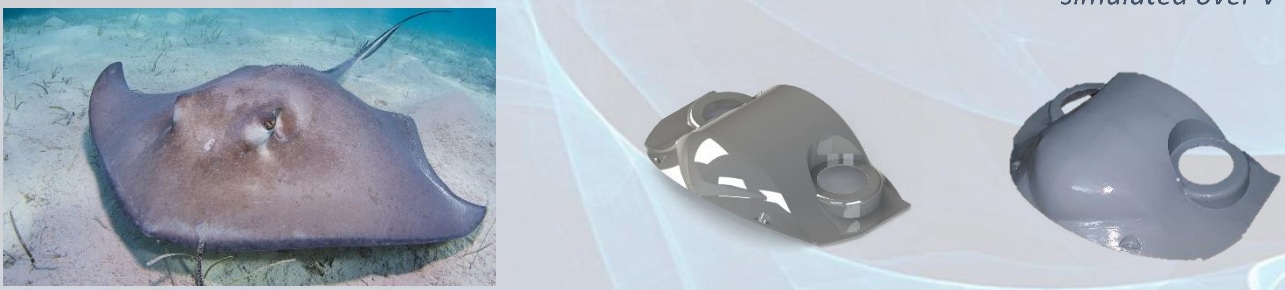

Figure 16: Stingray fish inspiring the cover design, the CAD model of the cover and a real photo of the cover

5. Buoyancy

After listing the buoyancy of all V-ray's components, it was found that 61% of the buoyancy is concentrated in the inclusive housing. The volume of the housing is large enough relative to the weight of their components boosting the total buoyant force of *V-ray*. There was no need to use external buoyancy since the housing's buoyant force overcomes the total weight of *V-ray*.

In fact, we needed to increase the weight of *V-ray*, to make it neutral in water, by hanging bar weights on the lower side of the base. The bar weights used are metal plates covered with rubber for safety and scratching resistance.

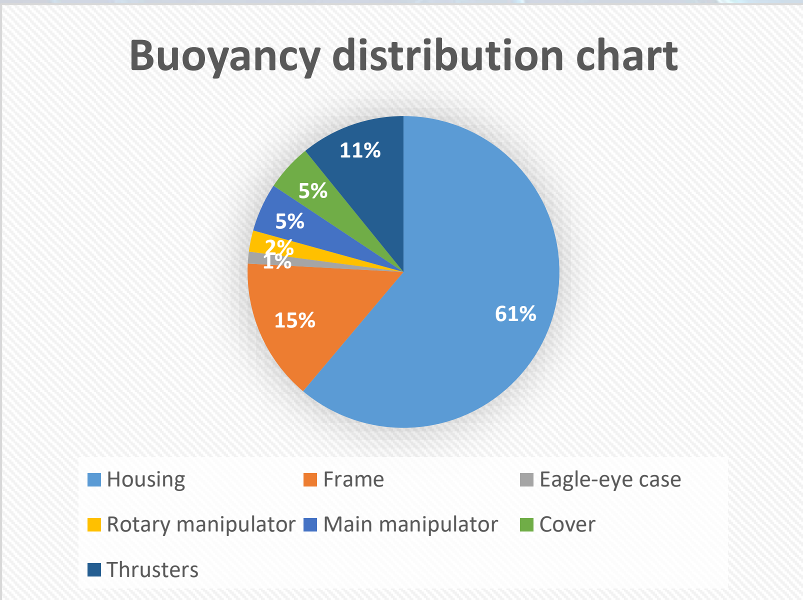

Figure 17: Buoyancy distribution chart (According to volume)

To ensure the stability of *V-ray* we placed the weights in the base of the body while the housing is placed in the center of the vehicle. This makes sure that the center of buoyancy is always above the center of gravity.

6. Propulsion

V-ray propulsion system is composed of 6 commercial T-100 thrusters manufactured by BlueRobotics and was shipped to our company's residence country.

T-100 thrusters are capable of producing thrust up to 23.14N in forward operation and 18.14N in the reverse operation. T-100 thrusters can be fed with supply voltage ranging from 6-16 Volts with maximum current of 12.5 A.

Figure 18: T-100 thrusters

Two Vertical thrusters are placed on the center line of the *V-ray* symmetrically to provide stability and balance for the ROV while propelling upwards or downwards. The 4 horizontal thrusters are aligned with an angle of 30º providing a variety of maneuvering options in all directions with a good combination of speeds. Horizontal maneuvering towards any lateral direction; forward, backward, right or left can be performed with 2 thrusters in forward operation during normal speed maneuvering or can be increased by using the 4 thrusters out of which 2 are forward operated and the other 2 reverse operated.

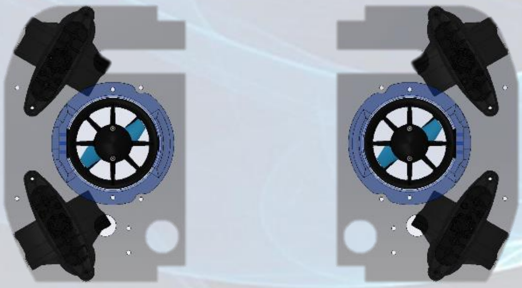

Figure 19: Thrusters configuration

The angle 30º was selected to give the highest thrust component in the forward-backward direction rather than the lateral movement, since it is used more often and needs higher speed.

This alignment of thrusters also enables *V-ray* to rotate clockwise or anti-clockwise using 2 or 4 thrusters in the same way used for lateral movements.

Alongside with this combination of thrusters *V-ray* speed can be altered using our control system to give the best suiting speed for any specific mission or task.

To facilitate the pilot's missions, a mode was created to fix the vertical level of *V-ray* using feedback control from pressure sensor. Using PID controller vertical thrusters get signals to overcome the slightly positive or negative buoyancy fixing the level of *V-ray* at a preset depth, we called this mode as *"auto-depth"* mode which helps to accomplish missions easily.

7. Pneumatic system

When we first thought about using electric motors or actuators for the manipulators, we found that the load that can be lifted is limited and requires high current. Besides, the sealing of such motors and actuators will be complicated and causes increase in its size.

When we considered fluid power systems option, we realized that the pneumatic components' water tightness can endure high depths and withstand high loads depending on the pressure inside it. Although hydraulic systems' rated pressure are higher and use incompressible fluids, we chose pneumatic systems because its components are lighter, cheaper and smaller in size.

Figure 20: Pneumatic system under test

The air is supplied from the station to *V-ray* through a pneumatic hose attached to the tether and then distributed to the two directional control valves after entering the rear cover of the inclusive housing.
Solenoid directional control valve of the type 5/3 is used for the arm cylinder, in order to have the three positions: opening, closing and fixed at any point along the stroke, and the type 5/2 for the grippers cylinders as there is no need for the middle position. (Appendix 2 – pneumatic SID)

Figure 21: Mechanical type pneumatic fitting

Throttle valves are placed in pneumatic circuit on the exhaust of the 5/3 direction control valve in order to control arm cylinder's speed by throttling the exhaust air flow rate.

The pneumatic fittings attached to the cylinders are mechanical type, not quick-connect type (lip type), to withstand high pressure in both directions (air and water sides).

8. Manipulators and missions

8.1. Main manipulator

After studying the missions required, our design team designed a pneumatic actuated manipulator to perform them successfully. The actuator is a pneumatic cylinder (bore 25 mm and stroke 50mm). It depends on the parallel link mechanism to convert linear motion of the cylinder to gripping action. The jaws of the gripper were designed specially for the missions.

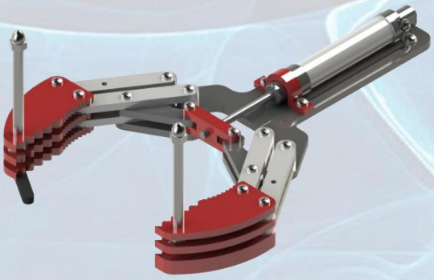

Figure 22: CAD model of the main manipulator

Gripper features for missions :

- Manufactured from transparent acrylic (PMMA – Poly Meta Methyl Acrylate) which doesn't block the view of the pilot.
- 4 layers of jaws maximizing contact with the gripped object to 24 mm
- Radius of curvature specially designed to grip the fountain.
- Vertical rods to disengage and re-engage the locking mechanism.
- Rebar rods engravement to ensure the vertical positioning of the rebar all time.

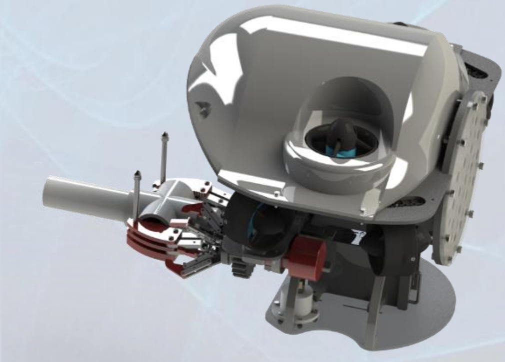

Figure 23: CAD model of V-ray holding the connector

- A Supporting link to prevent the falling of the cap.
- Capable of actuating the sediment collecting claw mechanism (section 8.3).
- Gripper dimensions suitable for disconnecting and reconnecting the power cable
- Removing the pin to release the chains holding the frame.

8.2.Rotary manipulator

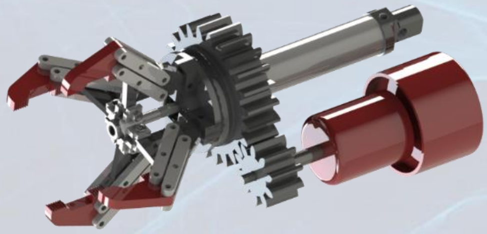

Figure 24: CAD model of the rotary manipulator

The rotary arm is an electro-pneumatic arm composed of a pneumatic cylinder is responsible for opening and closing the gripper while an electric motor rotates it.

The gripper rotates continuously in both directions with an electronic controlled speed. The motor is coupled to the gripper by a custom made gear with teeth ratio to increase the torque of rotation performed by the gripper. The design contains bearings to facilitate the rotation of the gripper by minimizing frictional torque between moving parts.

Figure 25: Fingers of the gripper specifically designed to grip the knob of the valve

The rotary motion gives us the ability to turn the valve in both directions to either stop or restore the flow of water to the platform. The fingers of the gripper where specially designed to grab the valve from its knob.

8.3.Sediment collecting claw

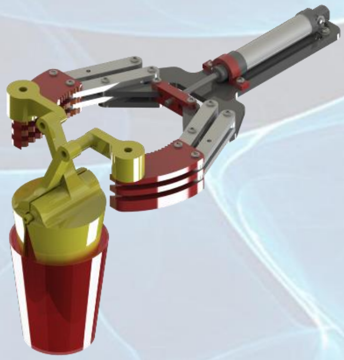

Figure 26: Sediment collecting claw inside a beer cup

The mechanism is composed of two mirrored scissor-like claws hinged from a point to open and close like a scissors. The claw shape sweeps the sediment inside it and hold it in an internal bucket.

The volume of the internal bucket is calculated to be more than the requested sediment sample. The 3D printed claw dimensions were specially designed for the beer cup size.

The whole mechanism is detachable from the vehicle and attached when the mission is conducted. The claw is fixed to the main manipulator gripper using two bolts attached to it.

8.4.Simulated Raman spectrometer

Figure 27: Raman spectrometer laser

A red light laser of wavelength 650nm is placed in the eagle-eye camera case with a titled angle. This laser simulates the Raman spectrometer to determine if contaminants are present.

8.5.Activating each container's Radio Frequency Identification (RFID)

Figure 28: RFID activation laser

Another laser horizontally oriented is placed in the inclusive housing in order to activate the light sensors in the black painted PVC pipe.

8.6.Bluetooth module

An HC-05 Bluetooth in slave mode is required to receive the 7-digit identification number. The received identification number is sent to the control unit to be processed by the co-pilot according to the container manifest handbook.

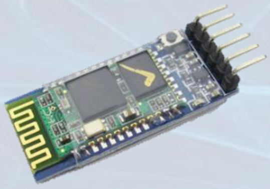

Figure 29: HC-05 bluetooth module

8.7.Pressure sensor

A pressure sensor is used to measure the depth of the vehicle. It also acts as feedback sensor for the auto-depth feature specified in (section 6).

Figure 30: Pressure sensor

8.8.Image processing (mapping camera)

Our company can do this by connecting the camera to the laptop, in this case the co-pilot can take images from the camera and by image processing he can measure the distance easily in addition to draw the map easily.

9. Inclusive housing

Last year we used PMMA (acrylic) cylinder tubes to be our watertight enclosures. As a result of that we faced several problems. The nature of PMMA material is brittle, so 2 cylinders were broken during the test before the last year's regional competition. Another problem concerning the enclosures last year was the large number of cylinders containing the power conversion system, electronic components, pneumatic system and camera. This number of enclosures required a large size to fit in which increased vehicle size.

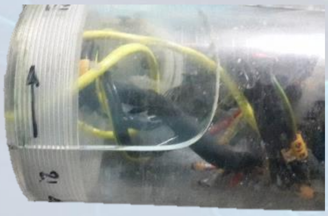

Figure 31: Last year tube fracture

V-ray's inclusive lathe-machined cylindrical housing is made of polyamide (PA nylon 6) with an integrated flange. The material was selected due to its durability, machinability and shock resistance. Dimensions for the face seal O-ring was calculated according to the *Parker sealing Handbook*. The design of face sealing using flange and cover facilitates opening and closing of the housing and ensures the same O-ring compression every time.

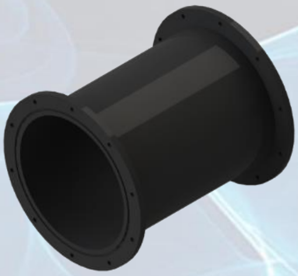

Figure 32: Inclusive lathe-machined cylindrical housing

The covers of the enclosure are made of transparent PMMA (acrylic) in order to allow camera vision, observe the on/off lights of the electronic components and check the compression of the face seal O-ring.

All the electronic components, power conversion system, pneumatic system and main camera are held inside the inclusive housing using an internal structure. The structure is composed of laser-cut (2D) acrylic parts assembled together in a creative way to form several sections. During opening the housing for any modifications, the whole structure is pulled out from the rear side in an easy manner.

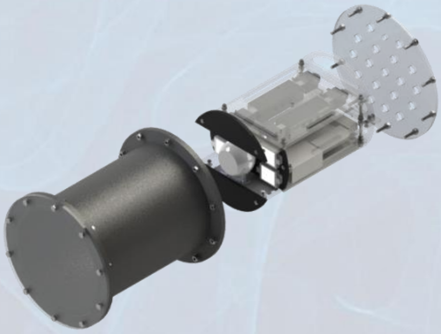

Figure 33: Exploded view of housing with internal structure

During designing the rear cover of the housing in which the cable glands are inserted, wrench analysis was studied. It was to be taken in consideration the possibility of fastening the glands. The wrench used was CAD modeled and the spacing between the glands was optimized to give maximum number of glands with the wrench having the access to all of them.

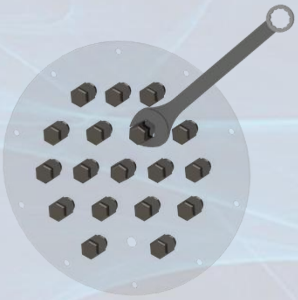

Figure 34: Wrench analysis on rear cover

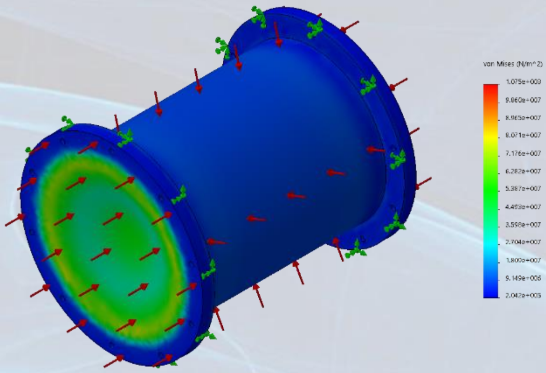

Figure 36: Stress analysis performed on the inclusive housing

Figure 35: Internal structure of inclusive housing with the components

10. Power system

The design of our power system takes into consideration protective measures to avoid electrical faults in our components or the main power supply.

The 48 V feeding *V-ray* passes through a 20 Ampere fuse going to the main terminal box; which distributes the current to the 3 DC converters named as CONV1, CONV2, CONV3. The rating of CONV 1 and CONV 2 is 200W, while the rating of CONV3's rating is 240W. All the converters are 48 to 12 V buck converters.

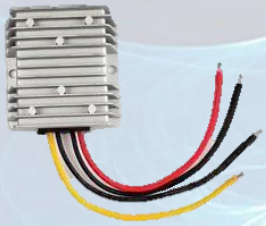

Figure 37: DC converter (CONV3) 240W

Component	Rating of each (W)	Total (W)
6 x T-100 thrusters	120	720
7 x LEDs	10	70
1 x bilge pump	24	24
Pneumatic DCV coils	5	5
3 x Cameras	2.4	7.2
2 x Laser	5 (mW)	10 (mW)
Fathom-s (communication board)	3	3
Total		**829.21 W**

Table 4: Power consumption

CONV 1 and CONV 2 are used to supply power to the propulsion system. Both CONV1 and CONV2 are connected in parallel to avoid tripping of propulsion system if a fault occurs to one of them increasing the redundancy of the electric system.

Figure 38: DC converter (CONV1 & CONV 2) 200W

Total Maximum power consumption = 829.21W. (never reached as we apply software interlocks)
Continuous normal operation = 535 W.
Maximum current drawn = 17.27 A.
Normal current operation = 11.14 A.
Factor of safety multiplied = 1.5.
Used Fuse = 20 A.

We distributed our 6 thrusters symmetrically on these two converters. Each converter is loaded with 2 lateral thrusters and a vertical one. While testing *V-ray*, it was found that at full load, each thruster consumes 120 watts approximately.

Figure 39: 48V Power supply used by Vortex for testing and training

A software interlock is coded to prevent the operation of 3 thrusters on the same converter once at a time.

The maximum ampere drawn from the DC converter during lateral maximum speed movement is 18 amperes which is within the range of the converter's capacity rating.

CONV3 supplies the power only to the Arduino Due, fathom-s Tether ROV interface, the two cameras, the relay modules controlling the pneumatic solenoid valves and other auxiliaries such as lighting system and the lasers.

VorteX uses a power supply of 48 Volt to simulate the MATE power supply.

11. Vision and lighting system

VorteX decided this year to modify the camera and lighting system used in the previous year. This modification will help decrease the volume consumed, weight, complexity of the system and the drawn amperes. The decrease in the volume comes as a result of changing the camera enclosure types and orientation of the cameras.

Figure 40: Light and vision system

11.1. Main camera

The main camera used is a CCTV type camera (a commercial camera manufactured by HIKIVISION) horizontally oriented in the inclusive enclosure giving the view ahead of the vehicle. It has a wide angle with lens (2.8 mm) giving the pilot a perfect view for *V-ray* target. This camera is fixed inside the inclusive housing.

Figure 41: V-ray's main camera

The camera is equipped with night vision system which turns on when the light intensity is dim. Beside the camera we placed the RFID activation laser which is used in the missions as mentioned in the (section 8.5).

11.2. Eagle-eye camera

Figure 43: Eagle-eye camera perspective

The eagle-eye camera used is a low-light analog which best suits the vision system. With a 2.1mm lens, it has a wide-angle field of view of 128 degrees horizontally and 96 degrees vertically. Giving the perfect view of the vehicle's manipulators and seabed. The camera holder as mentioned in (section 3) is tilted by an angle of 60º from vertical in order to view the manipulators. The coverage angles of the camera were CAD modeled to adjust the best tilt angle that views the manipulators.

Figure 42: Low-light analog camera used as eagle-eye

The eagle-eye camera wide angle along with the appropriate tilt angle calculated helped dispense the use of a camera-rotating mechanism reducing the complexity, size and weight of the vision system. Above the eagle-eye camera, the Raman spectrometer laser is placed, which is used in the mission accomplishment (section 8.5).

11.3. Mapping camera

Figure 44: mapping camera inside its water-tight enclosure

Our company aims to achieve the most comfortable vision facilities for the pilot and the co-pilot to accomplish their missions, we added one more digital camera with a wide angel with a lens (2.8 mm) fixed inside an enclosure at the bottom of V-ray, vertically oriented to view beneath the vehicle.

This camera is designed especially for the mission 4 “SAFETY: RISK MITIGATION” which is mainly for measuring the distance from the highest-risk container to the other three containers using Image processing tools (section 8.8).

Cameras connections:

To receive the best video signal, double twisted pair of cores are used for each camera to decrease the resistance of CAT6 type cable used. CAT6 transmits the main camera signal passing through a video balun (video transceiver) to the DVR (placed in control unit - section 12.1). CAT6 transmits the camera signal of the eagle-eye camera and the mapping camera to an Easy-Cap used to display the video on the monitor (Control unit section 12.1). The used transmission technique using Video balun has the ability to transmit video signal through 1500 m cables.

11.4. Lighting system

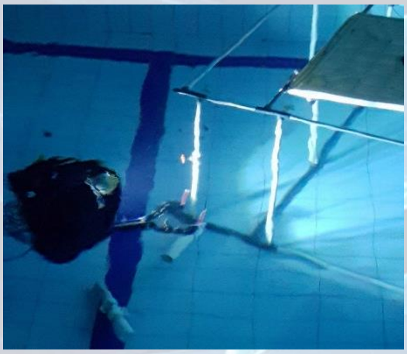

Figure 45: V-ray in dark using lighting system

V-ray can perform missions at dim light because of its highly-equipped lighting system. The lighting system consists of 6 LEDs (Each rated 10W,12V). The lighting construction for *V-ray* is adjusted to give optimum lightning for the main and eagle-eye cameras.

12. Control system

12.1. On-board hardware

V-ray’s control system is an integrated advanced system designed for the perfect maneuvering control of the vehicle. *V-drax* (*V-ray*’s predecessor) was very difficult to troubleshoot in case of problem occurring, due to the use of two onboard microcontrollers (Arduino UNO R3 and Arduino MEGA 2560). To overcome last year’s problems, the function of the distributed control system was assigned to a single main controller board.

Figure 46: Arduino Due used as V-ray’s microcontroller

Arduino Due was chosen as *V-ray*’s on-board micro-controller. Arduino Due is the first Arduino board based on Atmel SAM3X8E ARM Cortex-M3 CPU. It is also the first Arduino board based on a 32-bit ARM core microcontroller. With 54 digital input/output pins, 12 analog inputs.

The Arduino Due is responsible for sending control signals to all the ESCs of the thrusters, relays of the solenoid valves of the manipulators, laser and lighting systems. It also receives the sensor signals, process it and sends it to the topside control station to be displayed by the pilot and copilot.

12.2. Topside control station

Our control station is composed of 5 units which is an integrated station easy for transportation:

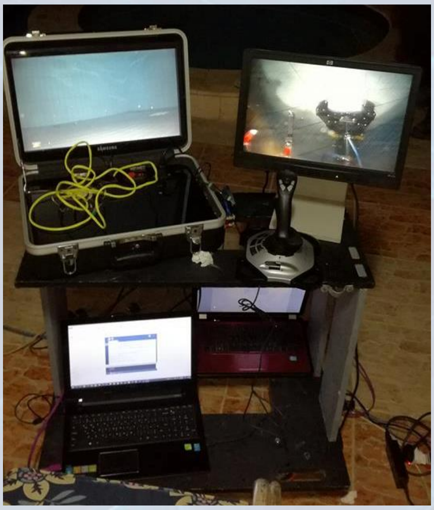

Figure 47: Top-side Control station

- The main laptop (Pilot laptop) on which the processing GUI (Graphical User Interface) program is installed. The program acts as a port for the pilot to give commands to the vehicle. It receives the status of the vehicle, its position and the telemetry data that helps the pilot better control and handle the vehicle.
- The secondary laptop (co-pilot laptop) which receives the eagle-eye camera signal that has a perfect view for the grippers.
- LED (HP) monitor (17inch) connected to the secondary laptop to display the eagle-eye camera signal.
- The control joy-stick which controls the vehicle.
- The main control case which in turn contains the follows:
  - Fathom-s tether interface top-side board (Communication board section 12.4)
  - DVR (digital video recorder) (Hikvision-HD) 4 channels.
  - LED (Samsung) monitor (18inch) which displays the main camera

12.3. Software

V-ray software system was programed to be as simple and robust as possible for the pilot. Software programs are based on Arduino IDE and Processing (based on Java language).

Topside software

A GUI software was programmed using Processing (A Java based programming language). It is installed on the main laptop controlling the vehicle's commands through EXTREME 3D PRO JOYSTICK and displaying the telemetry data from the vehicle's sensors.

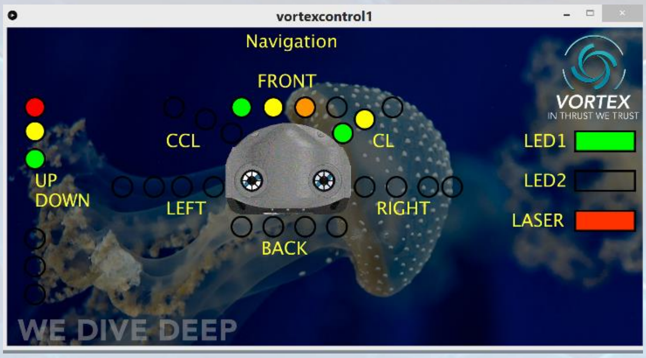

Figure 48: Control system components

Onboard software

The Arduino controlling code is coded as simple as possible to ensure the code is clean, robust, fast and away from complexity. The algorithm of the code is mentioned in the flow chart (Appendix 3). The thrusters can be controlled with different speeds in both directions giving variety of moving and maneuvering options to the pilot. "auto-depth" (section 6) is coded using PID control to stabilize the vertical level of *V-ray*.

12.4. Communication

V-ray uses the Fathom-S Tether Interface Board Set as a communication board which is based on RS-422 communication protocol. This board is a full duplex communication protocol with a very fast response to commands sent to the vehicle and data received from the sensors.

Figure 49: Fathom-S tether Interface board

13. Tether

Our tether consists of three main sections:

1. Electric power transmission
2. Fluid transmission (pneumatic)
3. Communication between ROV side and TOP side.

The cable types chosen were based on certain criteria for every section of the tether as follows:

Power transmission criteria

Some specs were taken into consideration before choosing a cable such that allowable voltage drop permissible can never exceed 5% so that the DC converters get stable DC voltage higher than its threshold converting voltage whatever the load is. The tether must Withstand a continuous current of 12A. So as to decrease the drag force generated from the tether we needed the least possible cross-section area that met the above criteria. After meeting all the criteria our electrical design department settled on choosing the 12AWG as our power cable.

Fluid transmission criteria

The hose for pneumatic must provide smooth air flow and must withstand a pressure of 3 X 10^5 Pa (3 Bar) at least which is more than our operating pressure. The used hose has inner diameter of 5.5 mm and outer diameter of 8 mm which withstands 10 X 10^5 Pa (10 bars).

Signal communication criteria

The signal is transmitted through 16 core; 6 cores for the RS422 communication protocol and 10 cores for the camera signal. The cables cores are CAT6 which can provide serial communication with speed up to 250 Kbps.

We also took in consideration the physical and mechanical properties of the tether so we covered our tether with standard jacket to keep it protected from any harm.

We also wrap our tether with some foam sheets to keep neutral in the water to ease the motion of our vehicle in the water.

V. Challenges

1. Technical challenges

1.1. Testing of water-tightness

Before proceeding with manufacturing processes we had to test several things. One of the most things that was needed to be tested and is vital for our vehicle's safety is to test the water-tightness of our electronic enclosures. As we cannot reach a pressurized water for this test, we created another way for testing. The electronic enclosure is placed inside a water chamber and a hose is connected to the enclosure transmitting pressure to the inside of the cylinder from a compressor.

Figure 50: Testing the water-tightness of our enclosures

If there were no air bubbles formed from the enclosure to the water then the enclosure is water-tight.

1.2.Pneumatic Actuation

Another challenge faced during the design phase was using pneumatic actuation system. We could place our Directional-Control valves on deck but this could cause the enlargement of our tether diameter. So we had to place the Direction-Control valves on board of the vehicle making it more difficult dealing with the size and weight constraint.

2. Non-technical challenges

The company personnel covered the cost of manufacturing our product completely. Due to the high cost of electrical components, pneumatic system and 3D manufacturing of main body, the company faced serious financial problems especially that our company consists of a small number of engineers (8 members).

Our small number of members in VorteX resulted also in another problem imposing high load of work on each member. This affected the hours our members used to sleep which were reduced drastically to be able to complete the assigned work. We faced huge stresses during our journey building *V-ray*.

VI. Lessons learned and skills gained

To come up with a good applicable project like our product, we didn’t rely only on our college studies but we had to do a lot of self-studying in many fields. We had to learn CAD modelling programs such as SolidWorks and Inventor to facilitate our designing processes.

As our Company didn’t include Computer science engineers our Company personnel learned programming to code a GUI (Graphical User Interface) for our product.

Using pneumatic system was a challenge since our fluid power studies in college were theoretical and didn’t imply how to select and purchase the needed components.

We gained experience by searching and asking experienced people in this field. The sealing challenge taught us to design and successfully implement our designs of water-tightening improving our innovative and creational thinking as engineers.

Our electric department became experts in designing and producing our PCBs needed for our electronic systems.

Working on V-ray not only highly enriched our company members improving their technical skills, but more important was a reason to increase our interpersonal and non-technical skills. Working in a large product taught us how to work in a team, and how our sub teams and departments could cooperate together with a sequence of work especially during the brainstorming phases.

The high load of work made it a must for us to well organize our work according to specific schedules highlighting practically the importance of time management in our project. Not only this project had impact on our skills as engineers but it also affected our own life-styles as better persons devoting the values of time commitments, obstacles tackling and persistence to be always better.

VII. Future improvement

- Increasing the efficiency of *V-ray* making it capable of performing more missions, but with smaller and lighter design.
- Mounting an IMU sensor (Figure 51) to help in stabilizing the vehicle automatically in water using our thrusters.
- TMS (Tether Management System) can be made to serve the vehicle's need of the tether length automatically by an electrically motorized system.
- Using ultrasonic sensors to map the see bed.

Figure 51: IMU sensor

VIII. Reflections on experience

"AT FIRST WHEN WE JOINED VORTEX, WE HAD THE THOUGHT THAT IT WOULD BE A TEMPORARY CHECKPOINT FROM WHICH WE COULD EARN SOME EXPERIENCE, THEN PROCEED OUR LIVES WITH NO SUCH GREAT IMPACT CONSIDERED. AS ONE YEAR PASSES, AND AFTER REVIEWING JOIN-ING VORTEX, I FOUND THAT THE TWO PROJECTS WE WORKED ON (V-DRAX AND V-RAY) LEFT A RE-MARKABLE FINGERPRINT IN MY LIFE."

"I LEARNT TO BE STUBBORN TO ACHIEVE MY GOALS AND TO BE PATIENT TO SEE MY DREAM BECOME REAL. ALL THROUGH MY ENTIRE LIFE, I'LL NEVER FORGET THE DAYS I WORKED WITH VORTEX."

"V-RAY WASN'T LIKE ANY OTHER PROJECT I WORKED ON. WORKING IN VORTEX TEAM HAD A DIFFERENT TASTE THAT CHANGED MY ENTIRE MENTALITY AND LIFESTYLE"

"BESIDES GAINING A LOT OF TECHNICAL EXPERIENCE, WORKING WITH SUCH A GREAT TEAM TAUGHT ME A LOT OF TRAITS I COULD'VE NEVER LEARNED IF I DIDN'T JOIN VORTEX. I WORKED UNDER STRESS, FACED A LOT OF OBSTACLES AND EVEN HAD A LOT OF DISPUTES WITH MY COLLEAGUES AS RESULT OF HUGE STRESS-ES IMPOSED ON US. HOWEVER BITTER WERE THESE DISPUTES, RECONCILING WITH EACH OTHER AND RE-SOLVING THE DISPUTES WAS SUCH A GREAT FUN.

IX. Acknowledgement

Our company would like to give credit to those who helped us in our road to success.

- MATE “Marine Advanced Technology Education”
- ROV Egypt Competition – organizing the regional competition
- Oxy-dive training center – sponsoring our regional expenses
- Hadath Egypt – Organizing the regional competition
- AASTMT Arab Academy for Science Technology & Maritime Transport - Organizing the regional competition
- ASY “Alexandria Shipyard” – technical support and free manufacturing processes
- Solidworks for providing free student version for CAD modelling
- Eng. Ahmed Gamal – for technical support
- Our former competitors and colleagues from Aquaphoton team for support and help
- Dean of faculty of engineering Alexandria University
- Our Mentor Prof. Dr. Mohammed Abdelwahed for technical help and support
- Air Technology Company – pneumatic components with discount
- Our beloved families and friends for support .

X. References:

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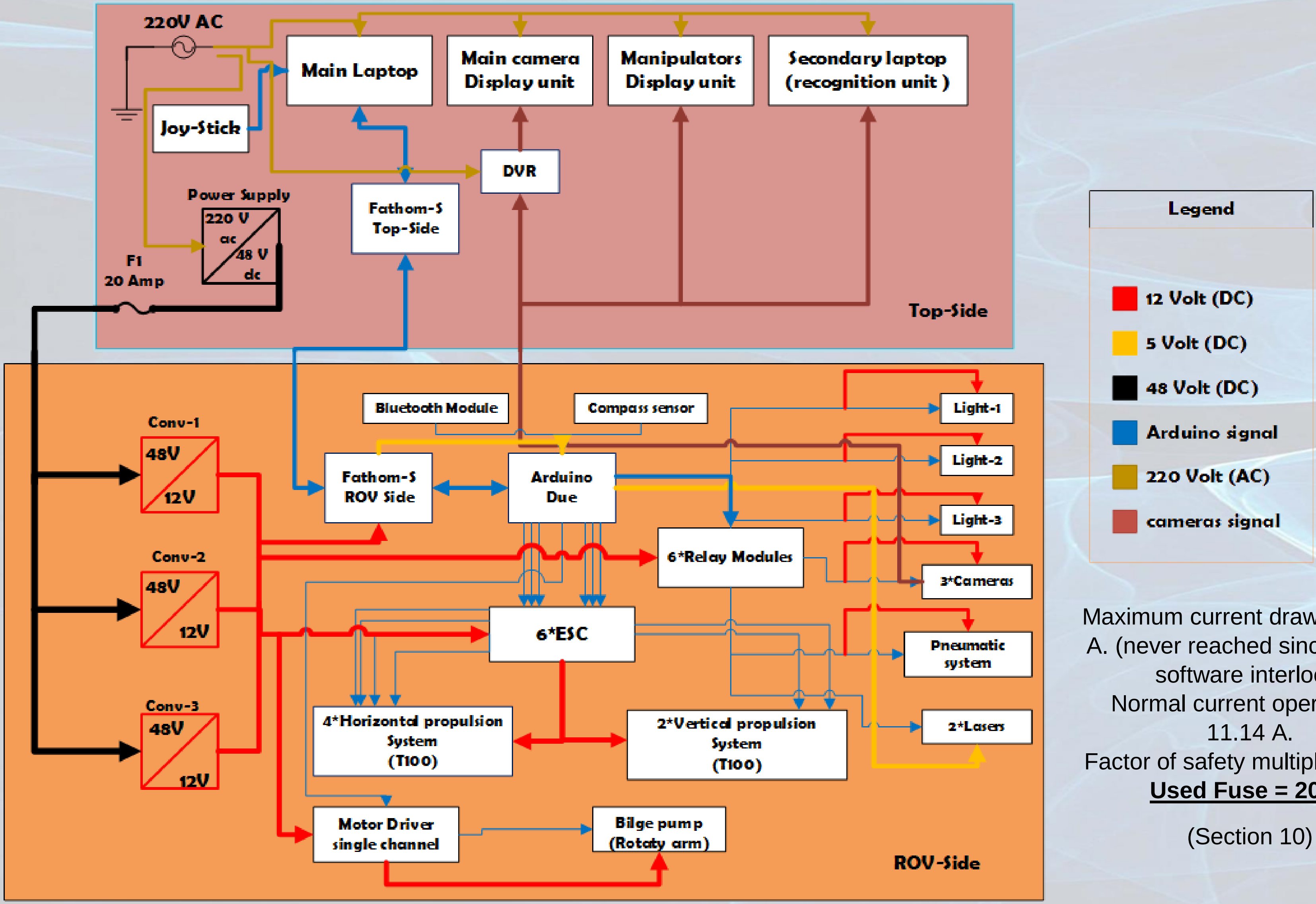
- Budynas, R. G., Nisbett, J. K., & Shigley, J. E. (2011). Shigley's Mechanical Engineering Design. New York: McGraw-Hill.
- Underwater Robotics: Science, Design & Fabrication by Steven W. Moore, Harry Bohm Thrusters
- HSE Employee Handbook, Oceaneering International, Houston, Texas, 2012
- 2017 EXPLORER COMPETITION MANUAL
- https://www.arduino.cc
- General catalogue, components for pneumatic automation -PNEUMAX
- Parker sealing handbook

XI. Appendices

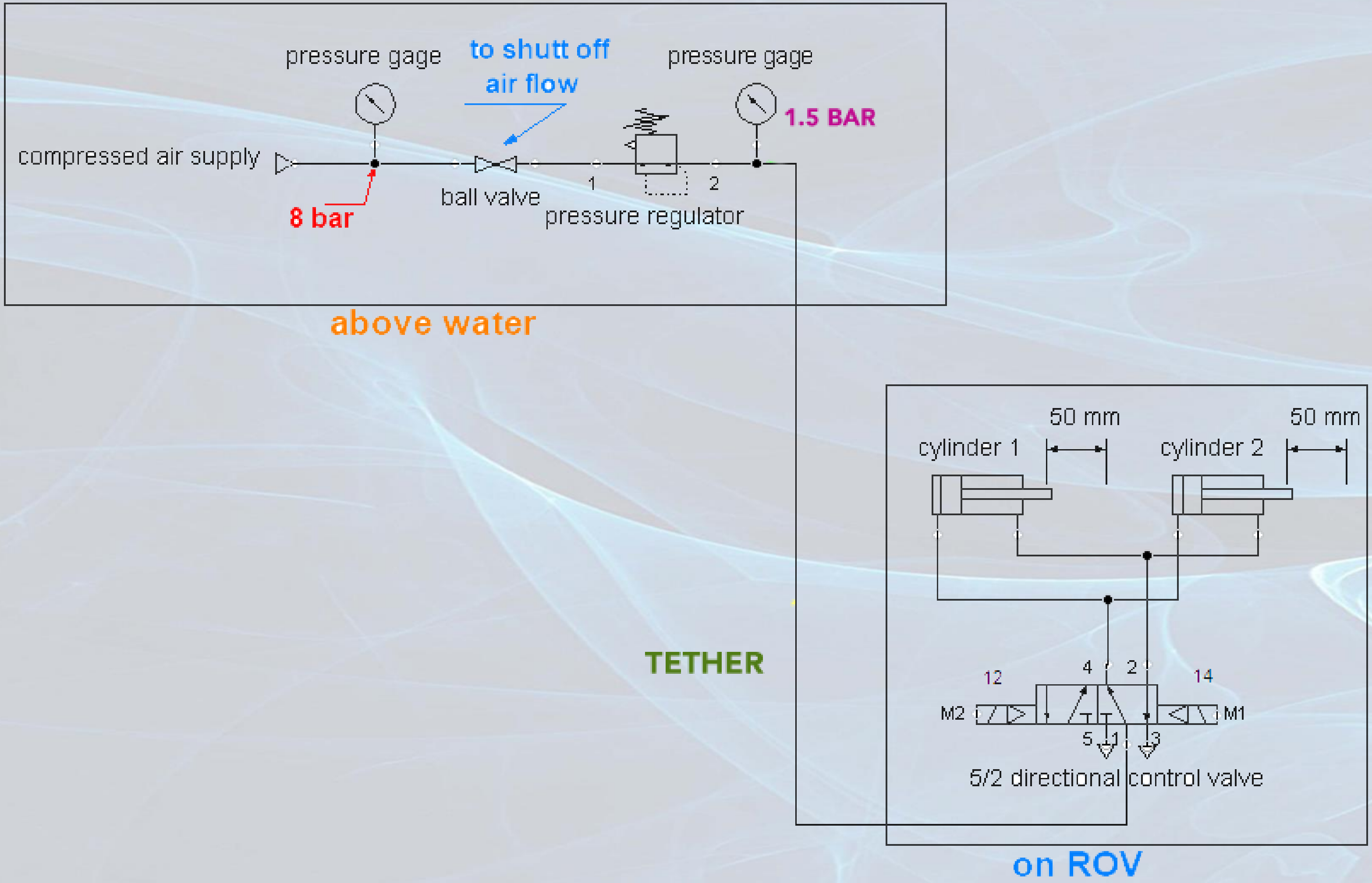
1. System Interconnection Diagram



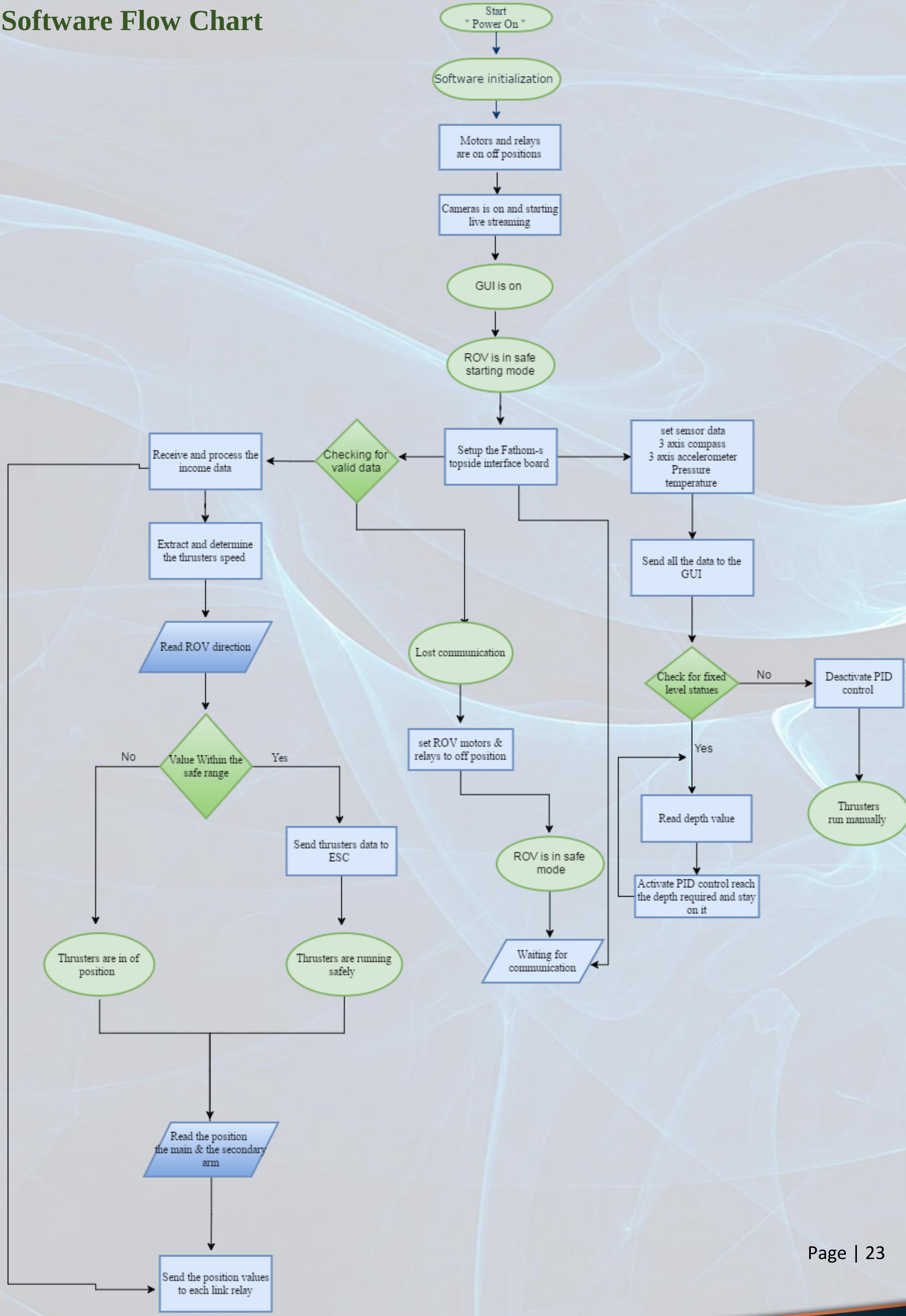
Maximum current drawn = 17.27 A. (never reached since we use software interlock)
Normal current operation = 11.14 A.
Factor of safety multiplied = 1.5.
Used Fuse = 20 A.

(Section 10)

2. Pneumatic SID



3. Software Flow Chart



4. Project cost

Category	Component	Description	Quantity	Price/unit	Total	Type
ROV's parts	Polyethylene cylinders	19 cm inner diameter , 5mm thickness ,28 cm long	1	$86.00	$86.00	purchased
	Acrylic Sheet for control pannel	30cm * 42cm * 4mm thickness	1	$7.25	$7.25	purchased
	Acrylic Sheet for main Arm	black 6 mm and white 4 mm	N/A	N/A	$5.00	purchased
	O-ring	203 * 2.5mm thickness	4	$1.25	$5.00	purchased
	Acrylic face	Material	N/A	N/A	$7.50	purchased
	Acrylic face	Machining	N/A	N/A	$5.00	purchased
	Glands	stainless IP68	20	$1.25	$25.00	purchased
	Second Arm (Mechanical)	Material and new gripper	1	$7.50	$7.50	purchased
	Gears	3D printing	2	$7.50	$15.00	purchased
	Sediment collecting claw	3D printing	1	$18.00	$18.00	purchased
	Bilge pump	1100 GPM	1	$37.50	$37.50	Reused
	Thruster T100 With basic ESC	12Vdc brushless motor	6	$181	$1,088.40	Reused
Body	polyethylene	120 cm * 75 cm * 6mm thickness	8 Kg	$1.90	$15.20	purchased
	Cover	3mm thickness	1 Kg	$135.00	$135.00	purchased
	other materials	bolts , painting	N/A	N/A	$43.50	purchased
	Machining	2D cutting	N/A	N/A	$22.50	purchased
Fluid power system (Pneumatic)	Tank	1 liter , max.pressure 10 bar	1	$25.00	$25.00	Reused
	Battery	Car battery 12V 50A	1	$17.50	$17.50	Reused
	Compressor	Double piston , 12Vdc	1	$12.50	$12.50	Reused
	Main Arm (pneumatic component)	Pistons, Flow controls , regulator , fitting	N/A	$133.20	$133.20	purchased
	Directional Control valve	5/2 single coil, spring return	1	$15.00	$15.00	Reused
	Rotary Arm (Pneumatic)	Piston, Flow control , regulator	N/A	$28.80	$28.80	purchased
Tether management system	Power cable	stranded copper 12 AWG	22 m	$0.18	$3.85	purchased
	Signal and data	Cat-5e	22 m	$0.25	$5.50	purchased
	Pneumatic hose	5.5*8 mm	25 m	$0.25	$6.25	Reused
	Shield hose		20 m	$0.20	$4.00	purchased
Vision and Light system	Main Camera	hikvision cctv protocol	1	$35	$35.00	Reused
	Eagle-eye camera	Low-Light Analog Camera PAL	1	$38	$38.00	purchased
	3rd Camera		1	$7.25	$7.25	purchased
	Monitor	18.5 inch	1	$25.00	$25.00	Reused
	second monitor	17 inch	1	$32.50	$32.50	purchased
	DVR		1	$32.50	$32.50	Reused
	LED	12 Vdc 10 watt	7	$1.25	$8.75	purchased
	Power swtich	on/off wwith led indicator	1	$2.50	$2.50	Reused
	Video Balone	Applification for Camera signal	2	$2.00	$4.00	Reused
	Connection cable	USB, DC-barrel, Power cable , Network	N/A	N/A	$15.00	Reused
	Laser		2	$0.75	$1.50	Reused
	Case for control unit		1	$45.00	$45.00	Reused
Sensors	Bluetooth module		1	$4.50	$4.50	purchased
	Compass Sensor		1	$12.00	$12.00	purchased
Power	Dc-converter	Step down 48Vdc to 12Vdc 200W	1	$36.85	$36.85	Reused
	Dc-Converter	Sstep down 48Vdc with variable O/P 200w	2	$10.97	$21.94	Reused
	Cables	3/4 mm2	10 m	$0.35	$3.50	Reused
	Fuse	20 A	1	$0.05	$0.05	Reused
	Fuse holder		1	$4.25	$4.25	purchased
	Bus bar		6	$0.50	$3.00	Reused
Control	Arduino	Due	1	$49.95	$49.95	purchased
	Relay	12Vdc 10A	1	$10.00	$10.00	purchased
	Motor Driver	single channel	1	$13.50	$13.50	Reused
	S-Fathom	RS-422	1	$91.00	$91.00	purchased
	Sockets		12	$0.50	$6.00	Reused
	Other PCBs	coman, wire to pin header	N/A	N/A	$1.88	purchased
	Jumbers		60	$0.03	$1.50	Reused
	$ 1.00 = 20 LE at May-2017			Total	$2,281.87	
Travel	Flight Tickets		8	$800.00	$6,400.00	sponsored
	Shipping		N/A	N/A	$1,000.00	sponsored
	Accommodation		8	$262.50	$2,100.00	sponsored
	Transportation		8	$56.25	$450.00	purchased
	$ 1.00 = 20 LE at May-2017			Total	$12,231.87	

5. Safety checklist

- **Launching phase**
  - ✓ Check the fuse
  - ✓ Team members wearing closed toe shoes
  - ✓ Wearing eye protection glasses when needed (especially when dealing with laser)
  - ✓ No electronic wires are exposed
  - ✓ Housing is properly sealed
  - ✓ Pneumatic gauge readings are within safe limits
  - ✓ No leakage in pneumatic paths
  - ✓ Power switches are all OFF
  - ✓ All bolts are well tight
  - ✓ Team members take considerable distance from *V-ray*
  - ✓ Thrusters respond to control
  - ✓ Pneumatic path is made sure no to be blocked
  - ✓ Two members ready to launch *V-ray* in water
  - ✓ Check for bubbles
- **Tether-man checklist**
  - ✓ Check all connections
  - ✓ Vehicle is neutrally buoyant
  - ✓ Tether is untangled and secure
- **Post departure phase**
  - ✓ Two members to get the vehicle out of water
  - ✓ No leakage in housing
  - ✓ Pneumatic system de-energized
  - ✓ Control unit shut down
  - ✓ Power switches OFF
- **Leak detection**
  - ✓ Shut OFF power
  - ✓ Detect leakage (if found)
  - ✓ Check for sealing malfunction