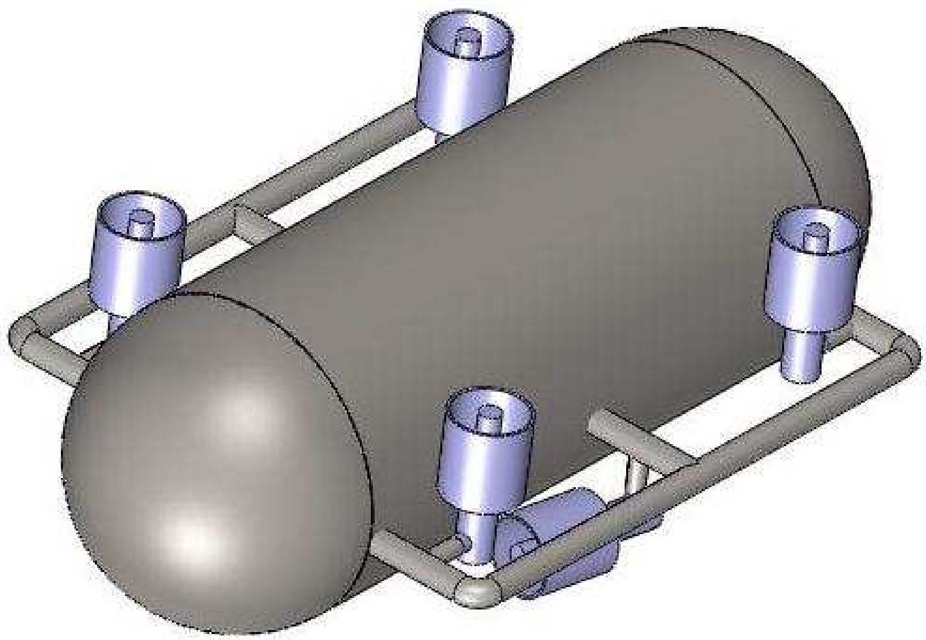

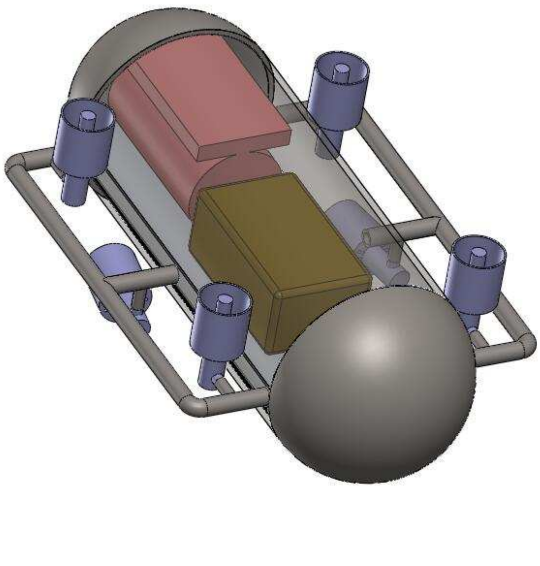

ME 401 ENGINEERING ECONOMICS and DESIGN

MINE DETECTOR UNDERWATER VEHICLE DESIGN PROJECT

Submitted by:

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1. ABSTRACT

Throughout the history, people encountered lots of wars which affected economical, industrial and technological development of countries. These terms are all related to each other. Developed countries obtained industrial and technological development faster. That resulted in designing different kinds of vehicles, machines and so on in order to be used in the war. Ships can be stated as a good example for the case. Ships used in the war could throw torpedoes, transport soldiers and such kind of attacking options. After these were happened, defense industry started to be developed. Mines were designed in order to damage ships and submerge them. Hence, a need emerge for ships, which cost lots of money to design and manufacture. This need was to detect mines underwater. There are two system known which are used for detecting mine underwater. One is AUV (Autonomous Underwater Vehicle) and the other is ROV (Remotely Operated Vehicle). AUV systems are mostly used for detecting underwater. In these systems, sonar is used for detecting mines. Nowadays, people are trying to develop these systems by increasing working depth, detecting range, decreasing mass and dimensions and such kind of parameters. There might be no war from now on, but people are still trying to develop these systems because technological development can be expressed as a proof of power of a country whatever the subject is.

Key words: *MINE, AUV, ROV, DETECTING, DEFENSE SYSTEM, SONAR*

2. INTRODUCTION

In this report, mines detecting technology is intend to be mentioned. There are two systems, which are named AUV and ROV, used for detecting mine underwater. Our aim is focused on designing AUV vehicle. The vehicle will be able to submerge by itself since it is designed with a density of more than water. It can stay in balance underwater by means of four propellers assembled on it. There are 2 propellers which work moving forwards the vehicles well. Forward propellers which utilize to move forward the vehicle as well are assembled with 10^o angle in terms of forward moving line. It will provide turning left and right.

Control system of the vehicle is a great importance on our design. Vehicle will be able to turn left or right by controlling the left and right propeller's working speed. Besides, control systems will give the coordinates where the vehicle move and come back to zero coordinates.

The vehicle can detect mines by sonar. It is located to the front of the vehicle. Since it is located inside, sonar will detect the vehicle first. In order not to memorize more information, sonar system can be adjusted by neglecting the quicker responses.

The vehicle has to stay a certain time interval underwater. That is because of batter life.

All in all, the design is expected to detect mine for a certain time interval.

3. BACKGROUND

Before beginning explain the work that we done in this project, we should have to define the terms of ROV and AUV.

Remotely Operated Vehicle (ROV) is a robot that works underwater, contains a camera in waterproof enclosed, moves with *thrusters* and sometimes has *manipulators* that depends on the operation. ROV is attached to a cable that allows a human operator to control the vehicle’s movements from ocean surface. The vehicle provides the power which needs via this cable, called as *tether*. It also sends video signals to the surface by this tether. They are used in scientific operations for example, observing, researching and examining the conditions of deep ocean.

The first Remotely Operated Vehicle was produced in 1953 by Dimitri Rebikoff, named *POODLE*. However it was used for archeological research and it affected the ROV history very minimal; but it was a start.

Then US Navy took the first real step for using ROVs in operation undersea to find torpedoes that were lost on the seafloor with *CURV* and *CURV II* (Figure 1.).

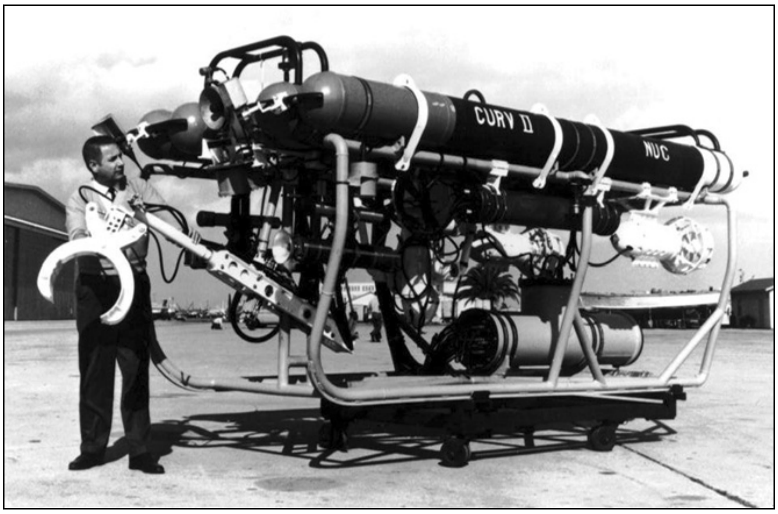

Figure 1. The Navy’s *CURVE II*

In 1974, only 20 robots were constructed and 17 of them were funded by various governments include; France (*ERIC*), Finland (*PHOCAS*), Norway (*SNURRE*), United Kingdom (*BAC-1*), Soviet Union (*CRAB-4000*). By the end of 1982 the number of vehicles were increased sharply and reached to about 500. From 1974 to 1982 private industries were funded and helped for constructing or bought 96 percent of the 350 vehicles.

With the ROV beginning to be accepted by the offshore industry other vehicles began to emerge [1]:

- USA: – Hydro Products *(RCV 125 , TORTUGA , ANTHRO)*
  – Straza Division, San Diego *(SCORPIO)*
  – Perry Offshore, Florida *(RECON)*
- Canada: – International Submarine Engineering *(DART, TREC)*
- France: – Comex Industries *(TOM-300)*
  – C.G. Doris *(OBSERVER, DL-1)*
- Italy: – Gay Underwater Instruments *(FILIPPO)*
- The Netherlands: – Skadoc Submersible Systems *(SMIT SUB, SOP)*
- Norway: – Mayers Verksted *(SPIDER)*
- Sweden: – Saab-Scandia *(SAAB-SUB)*
- Japan: – Mitsui Ocean Development and Engineering Co. *(MURS-100)*
- UK: – Design Diving Systems *(SEA-VEYOR)*
  – Sub Sea Offshore *(MMIM)*
  – Underwater and Marine Equipment Ltd. *(SEASPY)*
- Germany: – Preussag Meerestechnik *(FUGE)* etc.

Nowadays, there are over 450 builders and developers of ROVs (including AUVs) and 150 operators of about 5000 different types of vehicles in the world that we could investigate.

Figure 2. Seabotix Inc.’s *LBV600XL*

Some underwater robots can be controlled by built-in computers and can be operated without any connection to the surface; they are supposed to be completely autonomous. These vehicles are called as Autonomous Underwater Vehicle (AUV). An autonomous underwater vehicle is a robotic device that is driven through the water by thrust system, controlled and routed by a computer; moveable in three dimensions. This level of control, affected by environmental conditions, allows the vehicle to follow desired trajectories wherever and whenever required. The difference between the AUV and the ROV is the presence (or absence) of direct hard-wire communication between the vehicle and the surface. However, Autonomous Underwater Vehicles can also be linked to the surface for direct communication through an acoustic modem, or via a radio frequency or optical link.

In 1866, the first Torpedo, named after the torpedo fish, which was designed and built by Robert Whitehead achieved a speed of over 3 m/s and ran for 700m. It can be considered the first AUV that driving by compressed air and carrying an explosive charge.

The first, true AUV have been developed to obtain oceanographic data in 1950's in the Applied Physics Laboratory of the University of Washington by Stan Murphy, Bob Francois and later Terry Ewart. Their work was named as The Self Propelled Underwater Research Vehicle (*SPURV*). *SPURV I* achieved 2.2 m/s of velocity for 5.5 hours at 3000m depth. The vehicle was acoustically controlled from the surface and could autonomously run at a constant pressure, sea saw between two depths, or climb and dive at up to 50 degrees. [2]

The Naval Ocean System Center developed *Advanced Unmanned Search System (AUSS)* in 1973 and IFREMER constructed *EPULARD* in 1980, they marked a new era in AUV history with containing an acoustic communication system that transmitted video images through the water and supplying their power from silver-zinc batteries. During the 90's there was a rekindling of interest in Autonomous Underwater Vehicles in academic research between the scientists and the number of constructing AUVs is sharply increased after these years. [3]

For instance, The Massachusetts Institute of Technology's Sea Grant AUV lab developed vehicles which could operate at 1.5 m/s for 6 hours to 6 km during the early 90's. These vehicles, were named *Odyssey*, were ran under ice for three hours depth of 1.4 km in 1995. [4]

Autonomous Benthic Explorer (ABE) of WHOI was also constructed in 1994, whose mass was 680 kg and also could be controlled for 34 hours to 5000m depths, because it was traveling with 0.75 m/s velocity. [5]

Theseus was another vehicle which was designed in the early 90's for United States and Canadian military expenditure. It was developed by International Submarines Engineering Ltd. which could operate at 2 m/s for a hundred hours at 1km depth. This device had laid successfully 190 km of fiber optic cable under ice in 500 m of water for 50 hours. [6]

In the beginning of this century, AUV has become a commercial product to observe deep water survey. Kongsberg Simrad of Norway designed a new vehicle called as *HUGIN 3000* AUV which was 1400 kg and could operate at 2 m/s for 40 hours with an aluminum oxygen fuel cell. It has accomplished over 17702 km of geophysical mapping since the vehicle was first offered in 2000. [7]

Nowadays, by the developing technology most AUVs work in connection between surface and vehicle for navigational purposes, although ultra-low power consumption and long range variants provide operating for weeks or months in open ocean areas, periodically relaying data by satellite to shore, before returning to be picked up.

The objective of our project is designing a vehicle that works underwater and detecting mines which are hanging on water and be dangerous for military or trade ships. When we are contemplating the shape of the vehicle, we must focus on the all advantages and disadvantages of both type underwater vehicles. After thinking up deeply, we prefer to use Autonomous Underwater Vehicle type in our project. When you want to protect yourself from mines, being so closed to them is not very logical and safe. If you use ROV when you are trying to find mines, you are in the danger zone, because of the restriction of controlling distance. However, AUVs can be controlled far enough from where the mines are located in the water, because of the absence of the cable connection with the surface. Then you are in safety when your vehicle finding out the mine’s location. Another reason that we choose for making our vehicle in AUV type is the operating speed difference between two types of vehicles. ROVs are used in scientific researching such as ocean habitat, in spite of this AUV vehicle are used that there is possibility of traveling long distance and desired velocity. Another difference between these vehicles is duration of being underwater in terms of objectives of usage. Most of ROV vehicles are utilized to repair petroleum pipes using some extra device called as manipulator which are used for controlled to welding, cutting, fixing operation and connection with pipes. Another usage area of ROV vehicle is observation of water life and sea bed. As we regard to all usage of the ROV, it is noticed that if it is desired to detect mines, vehicles have to opportunity remoting in long distance and can be supplied enough operating durations. Autonomous Underwater Vehicle is ensured partially traveling duration and long range of operation. AUV vehicle just only have advantages that is controlled easily with hardware device, can be in underwater long durations to deep water.

4. CALCULATIONS

4.1. Properties of Seawater

The most important in terms of hydrodynamics are density, viscosity and surface tension.

Sea water has temperature interval from -2ºC and 40ºC which depends on geography and depth. The temperature in deepness of ocean is +2ºC.

Salinity in oceans is 3.5 % in average. In Black Sea, it is 1.6% and can reach 7% in other seas.

Pressure increases 1 atm per 10 meters increasing of depth.

Density can be calculated from the formula below in terms of temperature, salinity and pressure.

$$\boxed{\rho = \rho_0 + \left[a\left(T - T_0\right) + b\left(S - S_0\right) + kP\right]} \qquad \text{(Equation 1.)}$$

ρ_0 : Average density: 1027 kg/m^3
T_0 : Average temperature: 10 ºC
S_0 : Average salinity: 35
a: for 1 ºC -0.15 kg/m^3
b: for 1000 salinity 0.78 kg/m^3
k: for 1 decibar 0.0045 kg/m^3

Maximum Depth = 500 meters → T = 13 ºC
→ Salinity = 34.3
→ Pressure = ρgh = 4905 ρ x 10^{-4} decibar

When we put the Pressure value into the Equation 1, we can get;

$$\boxed{\rho = 1028.06 \text{ kg/m}^3}$$

These calculations are done for ocean. If we consider the maximum working depth of the vehicle we design as 500 m, temperature and salinity can be found from the Figure 3[8] and Figure 4[9]. Then we have to take density of water as calculated above for ocean.

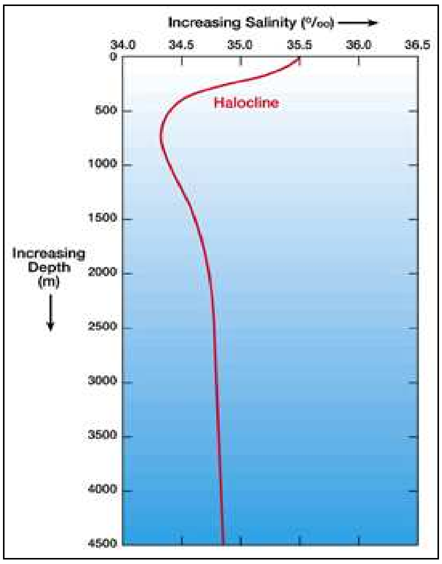

Figure 3. Salinity vs Depth

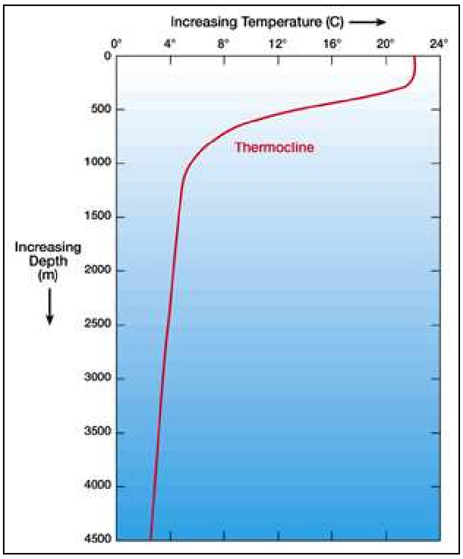

Figure 4. Temperature vs Depth

On the other hand the vehicle is supported to work in worse condition than ocean such as sea. Sea has greater density due to more salinity. Sea has density range of 1020 kg/m^3 to 1070 kg/m^3. Since the vehicle will be able to work in various conditions, we have to think of the density as maximum. Consequently, that will compel us to take the density as 1070 kg/m^3.

4.2.Design Calculations

Design calculations are started with mass assumption of empty vehicle because;

1. The vehicle is supposed to be transportable so the most logical mass assumption range is taken into consideration.
2. Since buoyancy force and mass of the empty vehicle are both related with radius (*r*), we need to assume mass first.

After doing several calculations for assumed masses, we obtain the most suitable radius value to selected equipment such as height of sonar when we consider the mass of empty vehicle as 100 kg.

In or design, the vehicle submerges on its own. So the buoyancy force has to lower than the mass of the vehicle. The difference between buoyancy force and the mass of the vehicle can be obtained by the mass of sonar, propeller and additional equipments. Hence we can start the calculations with being equaled the buoyancy force and the mass of the empty vehicle which is 100 kg at first.

$$m_a = F_B = 100\,\text{kg}$$

$F_B = \rho \times V$ (Equation 2.) , $V = \left(\frac{4}{3}\pi.r^3 + \pi.r^2.L \right)$ (Equation 3.)

We take the length of cylinder (L) as 2D and put the values into Equation 3.

$$V = \left(\frac{4}{3}\pi.r^3 + 4\pi.r^3 \right)$$

Take density of water as it has its mean value which is;

$\rho_{mean} = \frac{\rho_{max} + \rho_{min}}{2}$ where $\rho_{max} = 1070 kg / m^3$ and $\rho_{min} = 1000 kg / m^3$

Then we find $\rho = 1035 kg / m^3$

$$F_B = \rho. \left(\frac{4}{3}\pi.r^3 + 4\pi.r^3 \right) = 100kg \quad \text{(Equation 4.)}$$

After we put values into Equation 4, then we can get; $r = 0.179m = 17.9cm$

Then we need to find thickness (t) by using assumed mass and radius that found above;

$m = \rho.V$, $V = \left[\pi.r^2 - \pi.r_i^2\right].L + \left(\frac{4}{3}\pi.r^3 - \frac{4}{3}\pi.r_i^3 \right)$ (Equation 5.)

ρ : Density of stainless steel: 7860 kg/m^3 r : outer diameter $r_i = r - t$

m : Assumed mass for empty vehicle: 100kg r_i : inner diameter

Then; we rewrite the Equation 5 and set a new equation for calculating volume;

$$V = \left[\pi.r^2 - \pi(r-t)^2\right].L + \left[\frac{4}{3}\pi.r^3 - \frac{4}{3}\pi(r-t)^3 \right] \quad \text{(Equation 6.)}$$

$$m = \rho.V \quad \rightarrow \quad 4.189t^3 - 4.5t^2 + 1.2083t - 0.01272 = 0 \quad \text{(Equation 7.)}$$

After solving the third order differential equation (Equation 7) we could get a logical result; Thickness (t) = 1.09 cm

The thickness is found 1.09 cm. to make the vehicle easy to manufacture, in other words, in order to make parts suitable with the standards which provide us finding the parts easier in the markets; we can consider thickness as 1.00 cm. That will only result in decreasing of the mass of the empty vehicle. At first sight, that will cause us a problem which is about submergence. But it is predicted that the mass of additional units and instruments will be added to the mass of empty vehicle and the vehicle submerges. By selecting thickness as 1.0 cm, the calculations will be done and the prediction will be controlled at the end. That means at the end of calculations (after total mass is found) we will check whether the vehicle is able to submerge or not.

Since t = 0.01 m , we need to find new mass of the empty vehicle first.

$$m = \rho.V \quad , \quad V = \left[\pi.r^2 - \pi.r_i^2\right].L + \left[\frac{4}{3}\pi.r^3 - \frac{4}{3}\pi.r_i^3\right] = 0.0116 m^3 , \quad \rightarrow m = 91.4 kg$$

In our design, there are two roll bars which are made of stainless steel and used for supporting propellers to the vehicle. They are considered as having 0.5 cm thickness, 3 cm diameter and 70 cm length.

$r = 0.015m$, $t = 0.005m$, $L = 0.7m$

$m_b = \rho_b.V$ (Equation 8.) , $V = \pi\left(R^2 - r^2\right).L$ (Equation 9.)

m_b : Mass of bar , $\rho_b : 7860 kg/m^3$

After the putting the values into equations and solving Equations 8 and 9 together we get the mass of bar as $\rightarrow$ m_b : 2.16 kg

However, there will be the buoyancy force acting on this bar.

$F_b = \rho.V_b = \rho.\left(\pi.r^2.L\right)$ (Equation 10.) , where $\rho : 1035 kg/m^3$;

The buoyancy force would be; $\rightarrow$ $F_B = 0.512 kg$

It can be seen that rolls will provide us with additional mass in order to submerge.

Tray is designed in order to put the equipment on a flat plate. Tray will be able to move only through the cylinder. That will result in assembly and disassembly easily of the equipment to the vehicle.

Tray will be manufactured from aluminum which has density of 2710 kg/m^3. Aluminum has also the higher strength to weight ratio, this is the reason that we choose this material in manufacturing the tray.

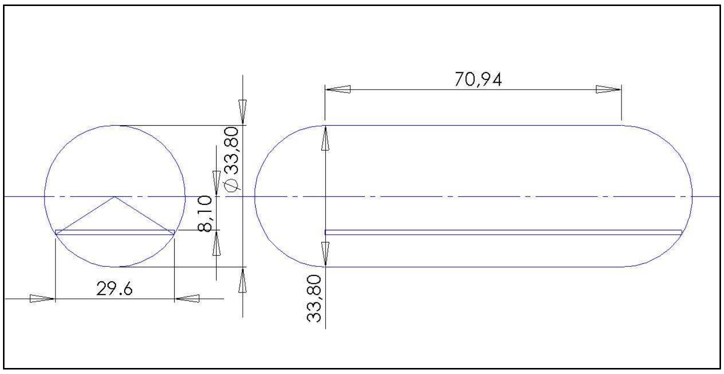

Figure 5. The location of the tray inside the vehicle

As you can see from the Figure 5. the distance between top point of vehicle and the bottom point of tray is 26 cm, and the thickness of the tray is designed as 0.01 m. After the calculations, we could get the width of tray as 29.6 cm.

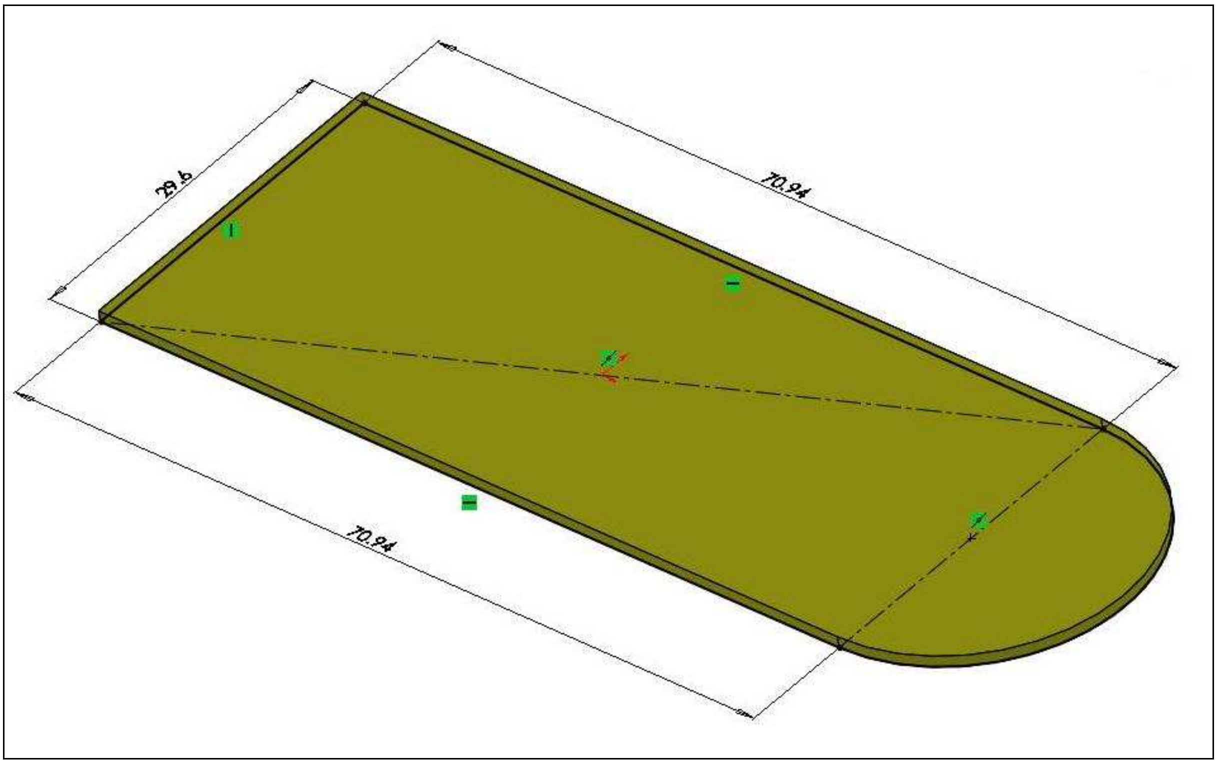

Figure 6. The tray of the vehicle

$m_t = \rho . V_t$ (Equation 11.) , $V_t = (x.l.t) + \dfrac{\left[\pi . \left(\dfrac{x}{2}\right)^2\right]}{2} . t$ (Equation 12.)

m_t : Mass of tray , V_t : volume of tray

x : Width of tray = 0.296m , L : length of tray = 0.7094m

Substituting the Equations 11 and 12 into each other, we can find the mass of tray as;

$$\boxed{m_t = 7.2kg}$$

There are six propellers that we are used so we need six assembling parts of propeller which has 20 mm diameter and 2 mm thickness.

The length of supporting parts is 40 mm. There are six supporting parts which has 30 mm diameter, 5 mm thickness and 110 mm length.

We can calculate the mass of extra bars that used for assembly and support with Equation 13 and Equation 14

- For assembly parts: $m = 6x(\rho.V) = 6x\rho.(\pi(R^2 - r^2).L)$ (Equation 13.)

$\rho = 7860kg/m^3$ $\rightarrow \boxed{m = 0.21kg}$

- For supporting parts: $m = 6x(\rho.V) = 6x\rho.(\pi(R^2 - r^2).L)$ (Equation 14.)

$\rightarrow \boxed{m = 2kg}$

4.3. Engine Specifications

When we are designing our vehicle, we must consider the required power for the vertical thrusters that provide to move it upward and downward, and power of the horizontal thrusters for the moving forward or backward in the water. The following equations state the number of thrusters and required powers for them.

4.3.1. *Vertical Thruster Selection:*

If you want your vehicle works successfully and without any problem, your vehicle must to overcome the aerodynamic drag. So, we have to calculate the aerodynamic drag firstly to determine the minimum power of thrusters.

For computing the aerodynamic drag, we use Equation 15. :

$$\boxed{P_D = F_D.V} \quad \text{(Equation 15.)}$$

After searching on the internet, we have seen that the average vertical velocities of the AUVs which were produced before is 1m/s. Then, we have to calculate the drag force.

<u>Drag force :</u> (F_D)

$$\boxed{F_D = \frac{1}{2}\rho.C_D.A_T.V^2} \qquad \text{(Equation 16.)}$$

where, ρ : density of water , C_D : drag coefficient

A_T : Cross-sectional area of the top of the vehicle , V : Velocity of the vehicle

Firstly, we take value of density of the water 1000 kg/ m^3 which is the minimum value of water. Because, when we take the minimum value of density, the drag force will be at minimum. So, we can calculate the maximum required power to avoid sinking to the bottom of the sea.

Secondly, we must calculate the area of the vehicle (with Equation 17) which is seen from top view;

$$\boxed{A_T = (2r.L) + \pi.r^2} \qquad \text{(Equation 17.)}, \qquad \rightarrow A_T = 0.818m^2$$

Finally we have to determine the drag coefficient from the following equations which are belonging to fluid mechanics. Firstly, we must compute viscosity of sea water for calculating the Reynolds number by Equation 18.

$$\boxed{\upsilon = ((0.659x10^{-3}(T-1) - 0.05076)x(T-1) + 1.7688)x10^{-6}} \qquad \text{(Equation 18.)}$$

We take the maximum temperature value of sea water as 40ºC, because in that temperature viscosity become at maximum. So, we can find the minimum required torque.

After put the temperature value into Equation 18, we found viscosity as;

$\upsilon = 0.79x10^{-6} m^2 / s$

The Reynolds number can be found with the following equation, Equation 19;

$$\mathrm{Re}_D = \frac{u.L}{\upsilon} \qquad \text{(Equation 19.)}, \qquad \rightarrow \qquad \mathrm{Re}_D = 1.359x10^6$$

We can say that the fluid motion is *turbulent*, because of the Re_D>5x10^5

$\frac{L}{D} = \frac{6r}{2r} = 3 \quad \rightarrow$ From the turbulent fluid charts [10] we can find $\boxed{C_D = 0.165}$

After computing the terms of the drag force equation, we can put the values into Equation 16.

Lift force will be; $\rightarrow$ $\boxed{F_D = 0.067kN}$

So, the aerodynamic drag will be; $\rightarrow \boxed{P_D = 67\, N.m/s = 67 watts}$

In this part of our research, we search the thrusters [11] that we can use without any problem and overcome the aerodynamic drag on the internet, we choose a thruster whose power is 150 W. The reasons of selecting those thrusters are;

- If we choose a thruster which has power about 67 watts, we can't use the thrusters with low rpm.
- If we choose a thruster which has power about 67 watts, we have to consider extra situations such as unexpected streams in the water, the thrusters can't work successfully.

Now, we have to do some specific calculations whether thrusters work or not. Before doing the number of vertical thrusters and needed power calculations we have to define the terms of effective mass of vehicle and slope resistance of the vehicle. Finally we can calculate the minimum torque of engine, the number of thrusters.

a) Effective mass of vehicle:

$$\boxed{m_{eff} = \zeta . M_{Vehicle}} \qquad \text{(Equation 20.)}$$

ζ : the experimental constant for the vehicles $1 < \zeta < 3$

In this calculation, we take ζ = 2.

We computed the mass of vehicle by adding the total mass of parts that we designed and put them into our vehicle.

$M_{Vehicle}$: mass of the shell + mass of the bars + mass of the sonar + the mass of the supporting bars and assembly bars + mass of the tray + mass of the battery + mass of the thrusters

(Equation 21.)

→ Mass of the shell: 91.4 kg , Mass of the bars: 4.3 kg

→ Mass of the sonar: 7.7 kg[12] , Mass of the sup. Assem. Bars: 2.2 kg

→ Mass of the tray: 7.2 kg , mass of the battery: 5 kg

→ Mass of the thrusters: 4.2kg (we assume that we use 6 thrusters with 0.7 kg weight and we will prove it at end of the calculations.)

We found the total mass of the vehicle by computing Equation 21 ; $\boxed{M_{vehicle} : 122 \text{ kg}}$

After putting the total mass value into Equation 20, we get ; $\boxed{m_{eff} = 244kg = 2.3kN}$

b) Slope resistance:

$$R_s = M_{vehicle}.\sin a$$ (Equation 22.)

$\sin a$: Minimum slope angle of the vehicle motion

We take the value of the slope angle of the vehicle as 10º, then put into Equation 22, we found;

$$R_s = 66.37kg = 0.65kN$$

The total resistance (R_T) of our vehicle can be calculated with Equation 23;

$$R_T = F_D + R_S + m_{eff}$$ (Equation 23.) → $$R_T = 3.017kN$$

The minimum torque of the thrusters can be computed with multiplying the total resistance and force arm which is described as propeller blade length which is described in Equation 24. The thruster that we found on the internet and assumed has a 0.038 m blade length (L_B).

$$T_{\min} = R_T.L_B$$ (Equation 24.) → $$T_{\min} = 114.664N.m$$

Each thruster that we will use has 31.85 N.m torque. The number of thrusters can be found as the ratio of Minimum torque and each thruster's torque.

By doing this calculation; the number of vertical thruster that we use in our robot should be "4".

4.3.2. *Horizontal thruster selection:*

As we stated above, we do some research on the internet and find the average horizontal velocities of thrusters which used by the AUVs is 2m/s.

The Reynolds number must be different which we calculated above, because the velocity of thruster is changed. After doing the same calculations for computing Reynolds number we get it as; Re = $2.7x10^6$, this value is again greater than $5x10^5$. So, we can say that the flow is again turbulent.

The cross-sectional area of the frontal view ($A_F = \pi.r^2 = 0.1m^2$) of our vehicle is a totally circle. That means our length to diameter ratio is 1. If we look again the turbulent flow chart of drag coefficient, we can see that $C_D = 0.2$.

Putting these values into The Drag Force Equation (Equation 16), we get;

$$F_D = \frac{1}{2}\rho.C_D.A_F.V^2$$ → $$F_D = 0.040kN$$

In our vehicle design, we contemplate the thrusters location have some angle to the direction of the horizontal motion. We design that thrusters have 10º angles with the horizontal plane. The angular location of the thruster makes the turnings of the vehicle easier.

$F_D = F_{thruster}.\cos 10^o$ (Equation 25.) → $F_{Thruster} = 40.62N$

The minimum torque can be found from Equation 26;

$T_{\min} = F_{Thruster}.L_B$ (Equation 26.) → $T_{\min} = 1.52 N.m$

After these calculations, one thruster has enough torque to move the vehicle on horizontal direction with maximum velocity (2 m/s). But, we selected two thrusters in order to design a symmetrical vehicle. In addition, horizontal thrusters are located with an angle to provide turning. This process can be obtained when the vehicle has two horizontal thrusters.

Consequently, we decide to use 2 horizontal and 4 vertical brushless DC thrusters in our autonomous underwater vehicle design.

4.4. Center of Mass

Since propeller and supports are all axis symmetrically designed, total mass of empty vehicle, supports and propellers which is represented by m_1 , will be in the middle of the vehicle.

$$\mathbf{m_1 = 91.4 + 4.3 + 2 + (6\times0.7) = 101.9\ kg}$$

In fact, forward propellers are assembled 30 mm left from the centre of mass of empty vehicle. But this can be ignored since propellers are very light (1.4 kg for 2 propellers) when compared to the mass of the empty vehicle. Consequently, centre of mass almost will not change. Hence, m_1 is the total of mass of empty vehicle, supports and propellers.

There are two effects which will change centre of mass of the vehicle. One is tray. The other is the equipment used.

Tray has mass of 7.2 kg and its centre of mass is calculated as it has 62.6 mm distance from the centre of the mass of empty vehicle.

As can be seen from our calculations, due to the centre of mass of the tray, centre of mass of the vehicle moves to through the front. Mass of sonar and battery are 7.2 kg and 5 kg respectively. Sonar is designed to stay in the front of the vehicle. That is why sonar heavier than battery, centre of gravity will exactly move to the front. It means that when the vehicle begins to submerge into water, the nose (front) of the vehicle will move faster than the back of the vehicle.

This problem that the vehicle will not be able to in balance underwater can be figured out by two ways.

1. Extra mass can be assembled to the back of the vehicle. The mass will be located inside the vehicle. By doing this, it will not affect our vehicle so much in terms of mass. It seems that 5 kg more mass added will work roughly.
2. The problem can be overcome by means of control system. If the system can be adjusted perfectly, the vehicle will be in balance underwater when the front propellers works more that means need more torque to work.

Since we are not able to think about control system and the mass of equipment which help us to operate vehicle, there will be no need to calculate the exact place of the centre of mass of the vehicle.

5. CONTROL SYSTEM

In our design, AUV system which controls its way by itself is used. To our control system, we first give the coordinates of zero points where the ship is located. Then we operate the vehicle by giving another coordinates which represent where it is desired to detect mines. There is a only one parameter that restricted to duration of vehicle working life is battery life. Thus, we need to consider how long the AUV vehicle can be operated underwater. After determining this, calculation of maximum coordinates of detecting area will be an easy concept.

The first response of the sound wave which sent by sonar system will come from the boundaries of the vehicle. It means that sonar will detect the vehicle firstly. Sonar system can be adjusted in order to detect first signal response. Behind the sonar in the vehicle, felt can be used in order to absorb sound waves. It will protect us any other signal response and possible echo in the vehicle. Consequently, by adjusting sonar system detecting and display operations, we will be able to use sonar chosen for our design.

In our design, there are two forward propellers that are located with 10^{o} angle with horizontal axis to the vehicle. It will provide us controlling the way of the vehicle. In other words, the vehicle will be able to turn it's around and turn while going forward by its control system. Propeller can be controlled by increasing and decreasing their turning speed (rpm). When left propeller is stopped, the vehicle will be able to turn left. Consequently, by assembling the forward propellers with an angle result in turning adjustment and this process is the duty of control system of the vehicle.

6. CONCLUSION

AUV vehicles are designed in order to detect mines underwater. Mechanical properties are very important in designing vehicles, besides; control system and sonar system have a huge effect on deciding limitations. Mechanism can be designed whatever the conditions are, but, for instance it will hard to find adequate thrusters in order to meet power demands of the vehicle in very deep conditions of sea or ocean. Consequently, 500 m depth rating is considered for the vehicle we designed. Thrusters and sonar system are able to work in 500 m depth conditions.

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8. SPECIFICATIONS of THE DESIGN

Length of Vehicle	1074 mm
Width of Vehicle	638 mm
Height of Vehicle	358 mm
Mass of vehicle	122 kg
Max Depth vehicle can work	500 meters
Salinity	Vehicle is able to work in minimum and maximum salinity conditions of seas and oceans in the world (Max. Salinity=40)