DESIGN OF PROPULSION SYSTEM FOR UNDERWATER REMOTELY OPERATED VEHICLE (ROV)

By

Fauzan bin Fakurruddin

Dissertation submitted in partial fulfillment of

Requirements for the

Bachelor of Engineering (Hons)

(Mechanical Engineering)

June 2009

Universiti Teknologi PETRONAS

Bandar Seri Iskandar

31750 Tronoh

Perak Darul Ridzuan

CERTIFIVATION OF APPROVAL

Design of a Propulsion System for Underwater Remotely Operated Vehicle (ROV)

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Fauzan Bin Fakurruddin

A report submitted to the
Mechanical Engineering Programme
Universiti Teknologi PETRONAS
In partial fulfillment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(MECHANICAL ENGINEERING)

Approved by,

____

(Mr. Azman Zainuddin)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK

June 2009

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

____
(Fauzan Bin Fakurruddin)

Mechanical Engineering Department

Universiti Teknologi PETRONAS

Bandar Seri Iskandar

31750 Tronoh

Perak Darul Ridzuan

ACKNOWLEDGEMENTS

I would like to take this opportunity to express my sincere and gratitude to everyone who has contributed either directly or indirectly throughout this project especially to my supervisor, Mr. Azman Zainuddin for patience, consistent consultation and invaluable advice throughtout the preparation and completion of the project.

Special thanks go to my highly skilled and professional panel, Assoc. Prof. Dr Fakhruldin Mohd Hashim and Dr. Syed Ihtsham Ul Haq Gilani who are willing to spend their golden time to evaluate my project.

I also would like to express my appreciation to my beloved parents, Hj. Fakurruddin Bin Hj. Eshak and Hjh. Norliza Binti Hj. Hussain for the financial support, prayers, motivation and encouragement throughout my years in UTP. Last but not least, credits to all my friends for their ideas, suggestion and assistance in completing this project.

ABSTRACT

Underwater Remotely Operated Vehicle (ROV) has been widely used in oil and gas industry to assist in the development of offshore oil fields. The use of appropriate propulsion device for ROV is important from the point of view of higher propulsive efficiency and directional stability as thruster; the main component of the propulsion system, is one of the most common sources of failure of ROVs.

This report is on a project to design a propulsion system for a ROV .The primary focus of this design is on mechanical design of the ROV with special emphasis on the propulsion system; propeller, motor, and configuration of the thruster. The propulsion system includes the forward thruster to propel the vehicle and side thruster for turning. Water current acting on the ROV will not be considered in this research. Research need to be done to calculate the needed thrust in order for the ROV to maneuver under the water at the desired speed. Collection of technical details and data regarding the existing ROV in the market will be done. A study on types of propulsion system needs to be carried out in order to determine the best propulsion system. A simple hydrodynamic analysis of a typical ROV has been carried out to compare the motion values with the actual performance data.

Drag is very important in designing the thruster, it give significant effect to the power input of the motor. In this report the description of the specification and the design concept for a new ROV propulsion system has been describe, and discussed the mechanical design, namely in what concerns modularity, configurations, and mechanical.

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CHAPTER 1

INTRODUCTION

1.1 Background Study

Underwater Remotely Operated Vehicles (ROVs) are unoccupied, highly maneuverable underwater robots operated by a person aboard a surface vessel. They are linked to the ship by a group of cables that carry electrical signals back and forth between the operator and the vehicle. Most are equipped with at least a video camera and lights. Additional equipment is commonly added to expand the vehicle’s capabilities. These may include a still camera, a manipulator or cutting arm, water samplers, and instruments that measure water clarity, light penetration, and temperature. First developed for industrial purposes, such as internal and external inspections of pipelines and the structural testing of offshore platforms, ROVs are now used for many applications, many of them scientific. They have proven extremely valuable in ocean exploration, and are also used for educational programs at aquaria and to link to scientific expeditions.

ROVs range in size from that of a bread box to a small truck. Deployment and recovery operations range from simply dropping the ROV over the side of a small boat to complex deck operations involving large winches for lifting and A-frames to swing the ROV back onto the deck. Some even have “garages” that are lowered to the bottom. The cabled ROV then leaves the garage to explore, returning when the mission is completed. In most cases, however, ROV operations are simpler and safer to conduct than any type of occupied-submersible or diving operation. Two typical designs of industrial ROV are shown in Figure 1.

ROVs also support exploration and scientific objectives. When the submersible cannot be used because of weather or maintenance problems, the ROV often can take its place. It can also be used to investigate questionable dive sites before a submersible is deployed, limiting risk to the expensive subs and their pilots.

Conventional ROVs are constructed with a large flotation pack on top of steel or alloy chassis, to provide the necessary buoyancy. Syntactic foam is often used for the flotation. A tool sled may be fitted at the bottom of the system and can accommodate a variety of sensors. By placing the light components on the top and the heavy components on the bottom, the overall system has a large separation between the center of buoyancy and the center of gravity; this provides stability and the stiffness to do work underwater.

Electrical cables may be run inside oil-filled tubing to protect them from corrosion in seawater. Thrusters are usually located in all three axes to provide full control. Cameras, lights and manipulators are on the front of the ROV or occasionally in the rear for assistance in maneuvering.

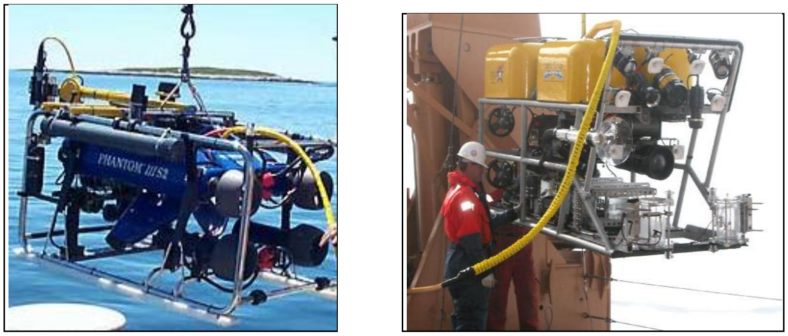


Figure 1: ROV [10]

1.2 Problem Statement

The current and future underwater exploration is moving towards deepwater. Human divers are restricted by this kind of hazardous, human unfriendly and extreme environment. In order to accomplish the underwater task, the remotely operated vehicle (ROV) is the only choice.

But underwater vehicles are liable to fault or failure during underwater missions. Thrusters are one of the most common and most important sources of failure. In all but the most trivial cases the existence of fault may lead to the cancelation of mission. The implication of small fault could be very costly and time consuming.

Usually ROV have a horizontal and vertical thruster system. Both systems should enable direct control of motion in 6 degree of freedom (DOF); pitch, surge, sway, yaw, roll and heave. This propulsion is a crucial part in the designing process. Because the thruster need to overcome the water current on it mission, and also need an adequate power in order to maneuver underwater.

The ROV design by Ahmad syukri is not complete with a proper propulsion system. In order for the ROV to maneuver at a required speed, it need to have a proper propulsion system.

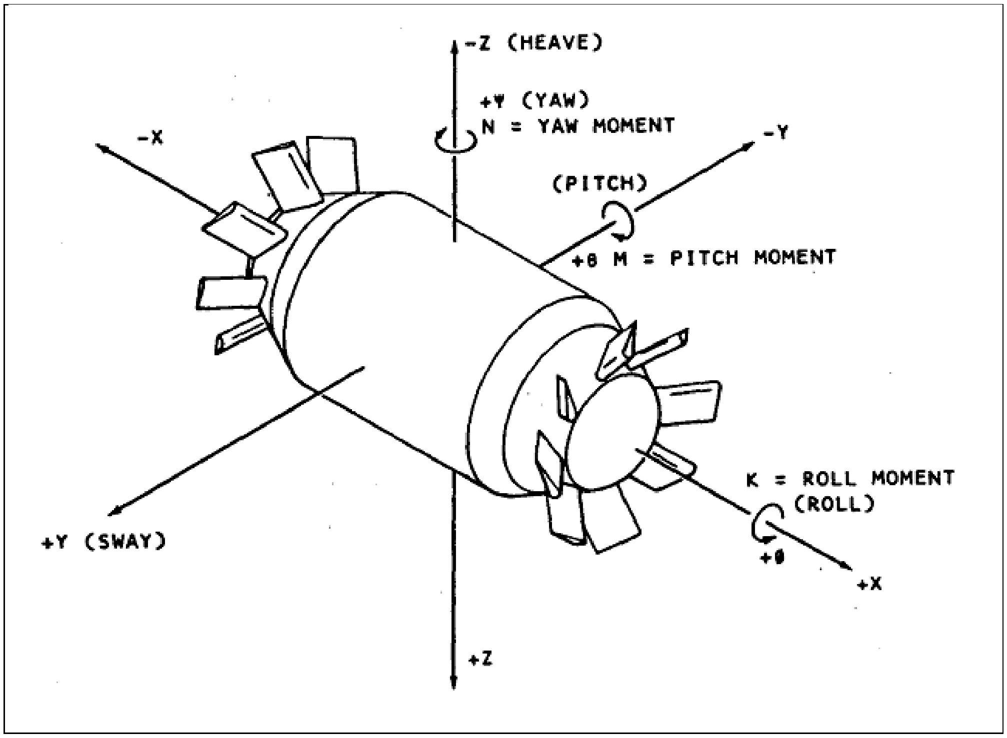


Figure 2: ROV Maneuverability [10]

1.3 Objective and Scope of study

The objective of this project is to design a propulsion system for an underwater remote operated vehicle.

The design has to satisfy the following criteria;

- Calculate the adequate power in order to withstand the water current and also to smoothly maneuver in the water.
- Calculate thrust needed by the thruster in order the ROV can achieve max speed of 2 m/s
- Select the appropriate motor and propeller for the ROV
- Design the arrangement and number of motor and propeller to be used in by ROV
- Production of detail drawings

1.4 Significance of the project

The output of the project will benefit directly the designing of the propulsion system for the ROV and indirectly to the oil & gas industry as it is moving towards deepwater explorations & production.

CHAPTER 2

LITERATURE REVIEW AND THEORY

2.1 Buoyancy Force

It is common experience that an object feels lighter and weight less in the liquid that it does in air. This can be demonstrated easily by weighing a heavy object in water by a waterproof spring scale. Also object made of wood or other light material float on water. Such phenomenon is called Buoyancy Force.

Buoyancy is the upward force on an object produced by the surrounding liquid or gas in which it is fully or partially immersed, due to the pressure difference of the fluid between the top and bottom of the object. The net upward buoyancy force is equal to the magnitude of the weight of fluid displaced by the body. This force enables the object to float or at least to seem lighter. Buoyancy is important for many vehicles such as boats, ships. [1]

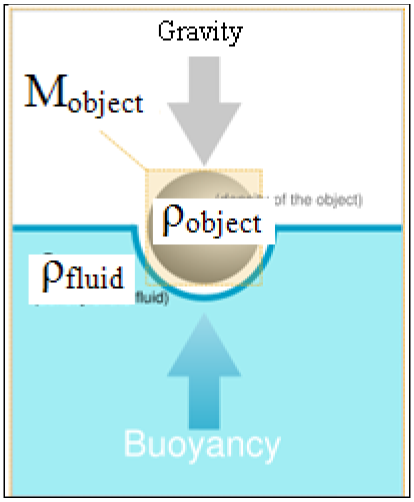


Figure 3: Buoyancy Force [1]

2.2 Flow Analysis

In order to establish a realistic modeling of the propeller, the flow around and behind the body should be analyzed. This would yield the wake velocities at necessary locations which are essential for propeller design and analysis. [4]

A fundamental picture of the flow around a deeply submerged vehicle is shown in Fig.4. Two main regions may be distinguished: one adjacent to the body surface, ex- tending backwards as wake, and one outside this region. The former is usually referred to as the boundary layer where the effect of viscosity is paramount, while the latter is called the potential flow which is non-viscous.

For the evaluation of the flow characteristics, it is necessary to start with the potential flow solution so that the velocity distribution on the vehicle can be obtained. These results are then used as a basis of determining the viscous flow around the body, which is in general, much different from the potential flow, although the interest is confined to the flow into the propeller plane and slipstream of the vehicle. The method used to define the potential flow around the body is based on the Hess & Smith method, [5] which uses a source density distribution on the body surface and determines the distribution necessary to make the normal velocities zero on the boundary.

The boundary layer characteristics, such as displacement and boundary layer thickness, are calculated using the Thin-Shear-Layer (TSL) approximation of Cebeci [6] for two dimensional flows which is a simplified form of the Navier-Stokes equations. The velocity inside the boundary layer is calculated by the power-law assumption.

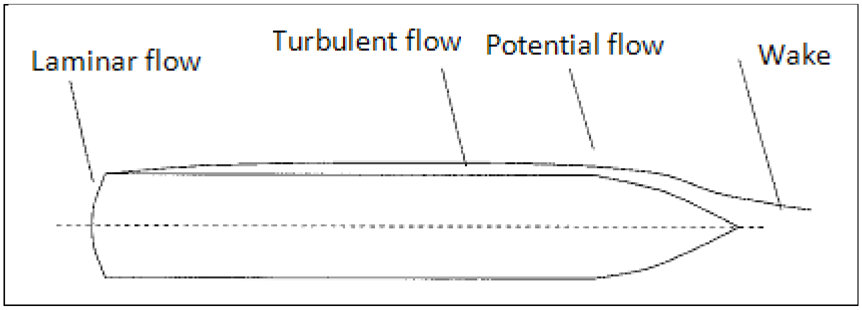


Figure 4: flow regime [4]

2.3 Propulsion Design Study

2.3.1 Propulsion

The propulsion system significantly impacts the vehicle design. Types of thruster, its configuration and the power source to drive them usually take the priority over many of the other components. [4]

2.3.2 Propulsion system

ROV propulsion system comes in three different types: hydraulic, electrical, and ducted jet propulsion. These different types have been developed to suit the size of the vehicle and also type of work that the ROV is working on.

The main goal for the design of ROV propulsion system is to have high thrust-to-physical size and power input ratios. The driving force in the area of propulsion system is the desire of the ROV operators to extend the equipment operating enveloped. The more powerful the propulsion of the ROV, the stronger sea current the vehicle can operate. Consequently, extend the system's performance envelope.

The reliability of the propulsion system and its associated sub-component need to take into consideration. In the early development of the ROV, a general practice was to replace and refit electric motor unit in every 50-100 hours of operation. Thus, increased the inventory parts required and the possibility of error made by the technician in reassembling the motor. Thus, investing in a reliable design from the beginning can save money and time.

The propulsion system has to be a trade-off between what the ROV requires for the performance of a work task and the practical dimensions of the ROV. Typically, the more thruster power required, the heavier the ROV would be. All parts of the ROV system will grow exponentially larger with the power requirement continuing to increase.

2.4 Thruster basics

The ROV’s propulsion system is made up of two or more thruster that propels the vehicle in order that allow navigation to the work side. Thrusters must be position on the vehicle so that the moment arm of their thrust force, relatively to the central mass of the vehicle. Allow a proper maneuverability and controllability. [5]

There are many types of arrangement (figure 5) for the thruster to allow varying degree of maneuverability. Maneuverability is achieved through asymmetrical thrusting based upon thruster placement as well as varying thruster output.

The more thrusters the ROV have, means it can maneuver perfectly according to its degree of freedom, but this also will increase the weight of the ROV and also the cost.

By placing the thruster off the longitudinal axis of the vehicle will allow a better turning moment, while still providing the vehicle with excellent and strong longitudinal stability. The problem with multiple horizontal thrusters along the same axis, without counter-rotating propellers, is the torque shear issue, with two or more thruster operating on the same plane of motion, a counter-rotating thruster to this turning will result. The ROV must have counter-rotating thruster propeller in order to avoid the torque of the thrusters rolling the vehicle counter to the direction of propeller rotation. If this roll does occur, the resulting asymmetrical thrust and drag loading could give rise to course deviation.

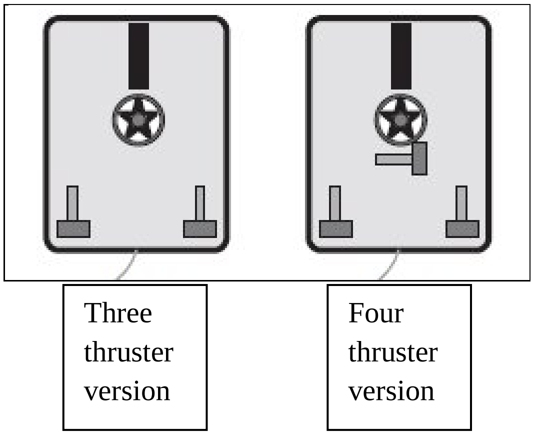


Figure 5: Thruster arrangement [5]

2.5 DC Motor

A brushed DC motor can be modeled by the equations: [9]

$$J\frac{d\omega}{dt} + \beta\,\omega + Q = k\,i \qquad (1)$$

$$L\,\frac{di}{dt} + Ri + k\omega = V \qquad (2)$$

Where;

J = Moment of inertia of motor shaft and propeller (including it added mass terms)

B= Dynamic friction coefficient due to the motor sealing and the mechanical construction

Q = Hydrodynamic load (torque)

$k\,i$ = produced motor torque

Equation (2) is the armature electrical equation

Where;

L = Armature circuit inductance

R= Resistance,

i = current,

k ω= the electromotive force (EMF)

V= Applied armature voltage (control input).

Notice that when using coherent measuring units the balance of electrical power associated with the EMF tension with the balance with the mechanical output power implies that the constant k in equation (1) and (2) is the same. Notice that the friction torque β ω is not related to the hydrodynamic load, i.e. it represent the intrinsic mechanical friction that the motor shaft would experience even if the motor would be turned on in the air rather than underwater. Possible source of this friction term are the motor sealing and the overall mechanical construction.

Method to experimentally estimate the dynamic friction coefficient β would be to fit steady state k i values versus the corresponding steady state ω values acquired running the motor out of the water (k is normally given by the manufacturer or it maybe separately measured). Of course it is not excluded that the hydrodynamic load torque could also have a component linear In ω: such term would be eventually be accounted for in the term Q. Notice that by Performing identification experiments in water there would be no means of discriminating between the mechanical friction and the hydrodynamic alone if they were both in linear with ω. Moreover even if the hydrodynamic load should have a different scaling law with ω, e.g. quadratic rather than linear, the experimental identification of the two terms, would be problematic both because of the different orders of magnitude (hydrodynamic load will certainly dominate Effective Mechanical friction) and because of possible difficulties in generating persistently exciting profiles.

Hydrodynamic load Q_n, and the produced thrust T_n, under bollard pull-conditions ,in steady state nominal conditions for a fixed pitch propeller are usually written [8]as:

$$\mathrm{T_n} = k_t\rho\, D^4\, n\, n \qquad (3)$$

$$Q_n = k_q \rho D^5\, n\, n \qquad (4)$$

Where;

ρ = water density

D= propeller diameter

n= propeller shaft angular speed

k_t = torque coefficient

k_q= thrust coefficient

These equations strictly refer to the so called first quadrant that is positive values of both the propeller shaft angular speed n and the advance according to the vehicle [9]. Torque, k_t and thrust coefficients, k_q are experimentally shown to be, with a good degree of approximation, affine functions of the advance ratio Ja=υa/nD [10] being υa the ambient water velocity [1][8].

The most common objective of low level control architectures for underwater vehicles is to control the shaft speed n in closed loop having a reference value n computed by inverting equation(3) for a desired thrust Tn.

Given the steady state nature of equation (3), this approach is theoretically expected and experimentally known [4] to have poor performance in terms of produced thrust control when operating in non nominal conditions. To improve the control performance of the produced thrust, recent results by Smogeli et al· [5] [4] suggest designing low level controllers having as objective the produced motor torque or the motor power. In terms of the DC motor model in equations (1-2), controlling the motor torque Q_m would correspond to a current I control as Q_m= ki. The alternative, yet closely related, control objective proposed is to control the quantity y;

$$y := k\, i - \beta\omega \qquad (5)$$

That corresponds to the hydrodynamic propeller load at constant motor shaft speed, name $Q|_{\omega=0.}$ The rationale behind this control objective is related to the observation that over a wide range of operating conditions, even far from steady state ones, the produced thrust T is approximately proportional to the hydrodynamic propeller load Q. In steady state this is well documented and experimentally confirmed, by example, in [3] or in [1][8][4] where experimental measurements of Kq and Kt at different advance numbers J_a show that they are approximately proportional. The approximate proportionality of T and Q far from steady state condition can be heuristically conjectured based upon energy conservation consideration. Indeed result to the model presentation in [12] support Q and T may be computed as

$$\Theta = \rho - \boldsymbol{\alpha_e} \qquad (6)$$

$$T = Lift(cos\Theta) - Drag(sin\Theta) \qquad (7)$$

$$Q = 0.7R\big(Lift(sin\Theta) + Drag(cos\Theta)\big) \qquad (8)$$

Being ρ the propeller (fixed) pitch, R its radius and α_e the so called effective angle of attack depending on the velocity of the incoming fluid relative to the propeller blades. The Drag and Lift forces in equations (7) and (8) are also functions of α_e.The plots of T and Q for a 7cm radius,45́ pitch propeller computed on the basis of equations(6-8)and with proper Drag and Lift terms computed according to[12] are reported

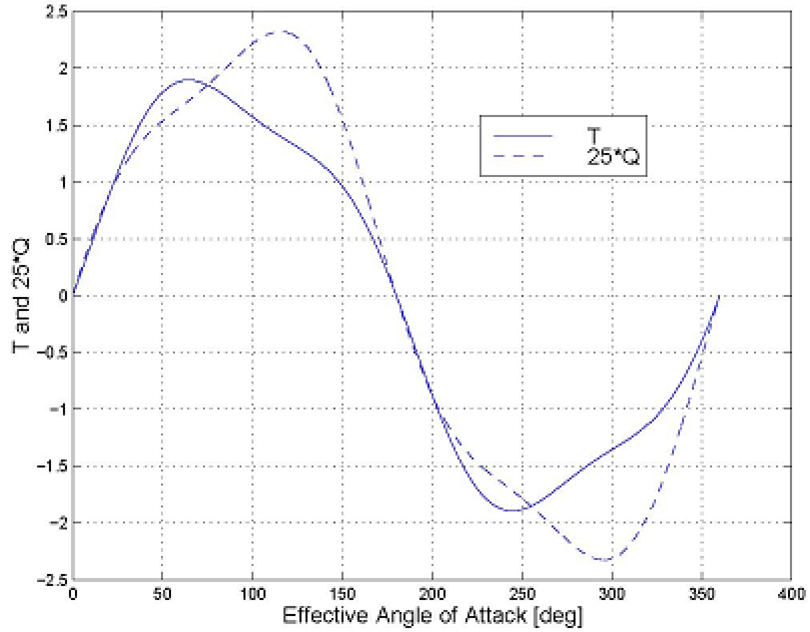


Figure 6: T and 25 Q according to [12]. The factor 25 issued for scaling purposes only.

2.6 Propeller

When a propeller is added to a hull, performance of the vehicle is altered; there are mechanical losses in the transmission of power; a general increase in total resistance; and the hull also impedes and renders non-uniform flow through the propeller. The ratio between a propeller's efficiency attached to a ship (P_D) and in open water (P'_D) is termed relative rotative efficiency. [10]

The overall propulsive efficiency (an extension of effective power (P_E)) is developed from the propulsive coefficient (PC), which is derived from the installed shaft power (P_S) modified by the effective power for the hull with appendages (P'_E), the propeller's thrust power (P_T), and the relative rotative efficiency.

P'_E/P_T = hull efficiency = η_H

P_T/P'_D = propeller efficiency = η_O

P'_D/P_D = relative rotative efficiency = η_R

P_D/P_S = shaft transmission efficiency

Producing the following:

$$PC = \left(\frac{\eta H \ X \ \eta o \ X \ \eta R}{appendage\ coefficient}\right) X\ transmission\ efficiency$$

The terms contained within the brackets are commonly grouped as the quasi-propulsive coefficient (QPC, η_D). The QPC is produced from small-scale experiments and is modified with a load factor for full size ships.

Propulsion systems are currently classified as either Electro-hydraulic or Electric.

Typical direct drive electric propulsion systems use a separate electric motor for each propeller, although a multiple output gearbox can be driven by a single motor. Electrical propulsion has weight advantages in small ROVs.

Propulsion unit styles include:

- Continuous pitch propellers with constant speed motors
- Variable frequency DC driven
- Brushless DC motors

The ROV can be characterized as a small tugboat, with the consequence that the thrusters must be pitched to obtain good bollard pull—essentially the thruster's maximum static thrust. But one must be careful using bollard pull to determine thruster requirements. System efficiency must be taken into consideration along with the fact that most thruster output will decrease as velocity increases. The optimum pitch is also a function of vehicle speed. Therefore, the wise engineer will use the design curves available on the candidate thrusters to determine the proper size and location of thrusters based on expected vehicle speed.

Since the velocity of the water surrounding the thruster, essentially the inlet velocity, affects the output of the thruster, the location of the thruster is very important. Accordingly, the location of the thruster in the vehicle frame or body is not just a matter of strapping on a thruster. Thruster size and location should be considered within the overall system, including the balance of power used by the thruster and other subsystems, ensuring that one doesn't rob the other of needed output in a critical situation.

Thrusters come in several sizes and configurations and may be powered electrically or hydraulically, through direct or gear drives, with or without shrouds or ducts. Generally, most thrusters will have a ducted shroud or a Kort nozzle to increase the output efficiency such as the Innerspace high performance thrusters

2.7 Drag Force

To estimate the thrust required to move through water, an adequate thrust is needed to overcome the drag force, F_D which can be expressed as:

$$F_D = -\frac{1}{2}\rho C_D A_D V^2$$

Where,

V = design speed of vehicle.

A_D = the frontal area of the component

ρ = the water density, and

C_D = the drag coefficient

Thrust force provide by propeller, F_T

The amount of thrust depends on the mass flow rate through the propeller and the velocity change through the propulsion system.

$$F_T=\rho A_P V_P (V_E - V_0)$$

Where,

ρ = density of water

A_P = area swept by propeller blade length, $(D/2)^2/2$

V_P = average velocity, $V_P = (V_E - V_0)/2$

V_E, V_0 = exit and inlet water velocity, respectively

The propeller pitch has the same meaning as the thread pitch on a wood screw – it is a distance that the propeller would travel in one revolution if advanced into a solid material. Almost every commercial propeller has quoted pitch value (e.g. a 6x3 propeller corresponds to diameter = 6 in, P =3 in).

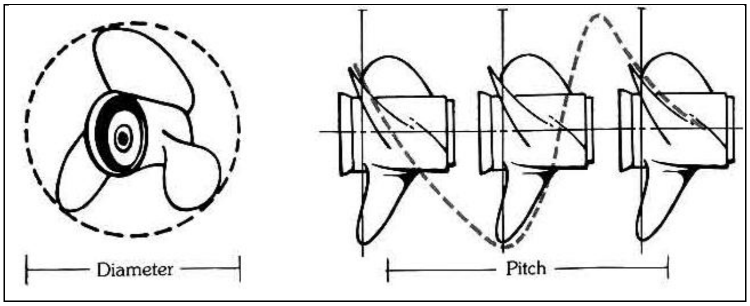


Figure 7: Propeller pitch and diameter

Velocity of the water through the propeller and relation between the rotational speeds of propeller can be estimated as

$$V_P = np\eta$$

Where,

n = rotational speed of the propeller in radian per second

η = the propeller efficiency

p = propeller pitch

2.8 Project Design and Criteria

The specification of the ROV was taken from a project that was done by Mr. Ahmad Syukri bin Shafie, Final Year Project Thesis, Design of Underwater Remotely Operated Vehicle for Offshore Oil and Gas Industry [7]. In the report, the specification and the limitation of the ROV have been listed as below.

Table 1: ROV specification

Mission	Survey and inspection
Water depth capability	Maximum depth of 30m
Power source	Electric (battery)
Weight	Maximum weight of 10 kg
Control method	Umbilical
Top speed (surge)	2 m/s
Size	0.5m L x 0.45m H x 0.3m W
Frame/chassis	Open frame

From the specification that has been done by Ahmad Syukri, the ROV weight must not exceed 10 kg, this means, the material for the propulsion must be made of a light material since the propulsion system is the heaviest component in the ROV, this is including the thruster (including the motor, the propeller and also the casing of the unit).

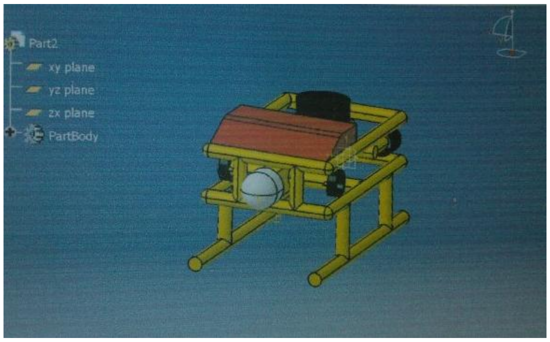


Figure 8: ROV design by Ahmad Syukri [7]

CHAPTER 3

METHODOLOGY / PROJECT WORK

3.1 Design Methodology

In ensuring this project can be executed smoothly, it has been divided into two major phases, as shown in figure.

- Pre-Design phase

  The project was started with defining the problem, identifying the needs, understanding and revamp knowledge about the application of propeller in ROV. This phase was conducted in the 1st semester.

- Design phase

  This project will continue the design phase (second phase) during the 2nd semester. Based on the research during the 1st phase, there might be some modifying in the propulsion system and at this phase, final design will be select in this phase.

The primary focus of this design is on mechanical design of the ROV with emphasis on the propulsion system; propeller, motor, and configuration of the thruster. The propulsion system includes the forward thruster to propel the vehicle and side thruster for turning. Water current acting on the ROV is will not be consider in this research. The needed thrust is to be calculate to find an appropriate thrust in order for the ROV to maneuver under the water at the desired speed. Collection of technical details and data regarding the existing ROV in the market will be done. A study on types of propulsion system needs to be carried out in order to determine the best propulsion system. A simple hydrodynamic analysis of a typical ROV will be carried out to compare the motion values with the actual performance data.

3.2 Tools/Equipment Used

In the designing phase, Autocad and CATIA software are being used for the design because the software is capable to do a design in 3D image. Any change and redesign task can be done easily by using this software. CATIA software also provides the finite element analysis which is used for simulation and stress distribution analysis.

For the propeller design, JavaProp Software is being used. This software is easy to use, users have to key in the data and the software will calculate the required propeller according to the data input.

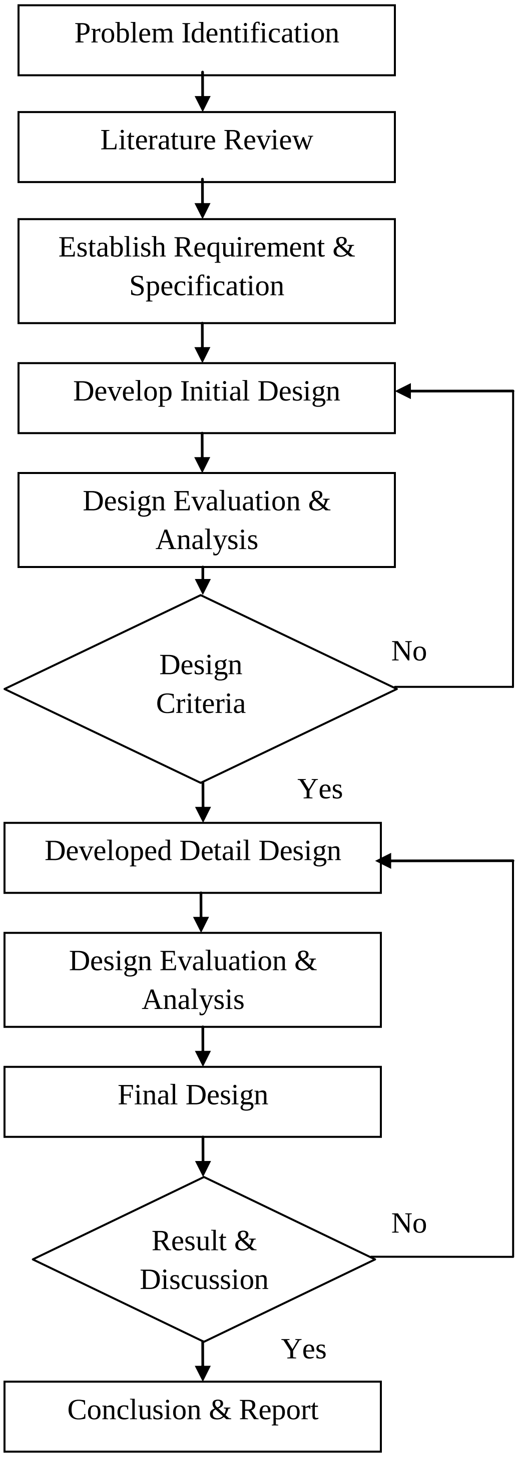
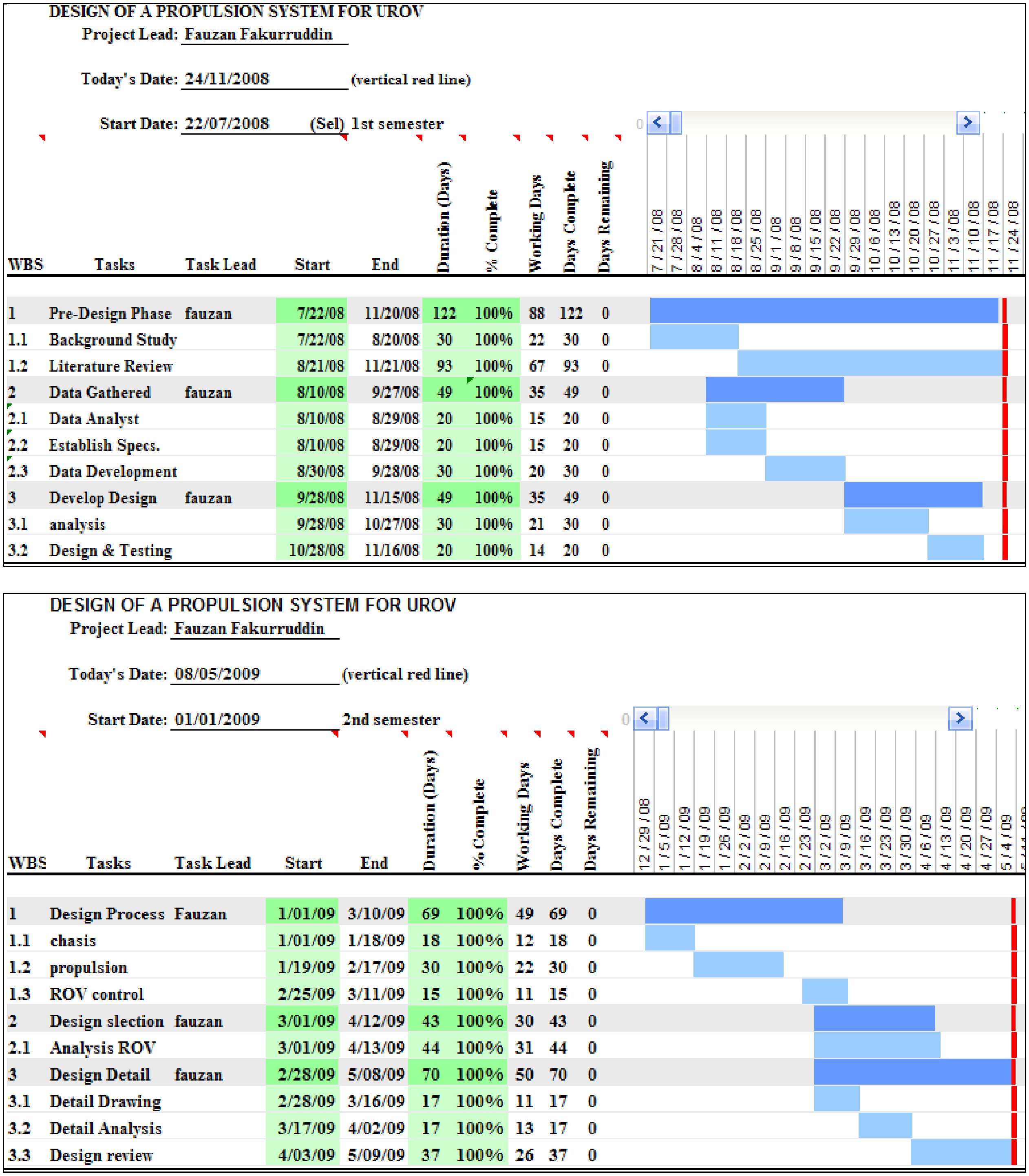


Figure 9: Design Project Works Process Flow



DESIGN OF A PROPULSION SYSTEM FOR UROV

Project Lead: Fauzan Fakurruddin

Today's Date: 24/11/2008 (vertical red line)

Start Date: 22/07/2008 (Sel) 1st semester

WBS	Tasks	Task Lead	Start	End	Duration (Days)	% Complete	Working Days	Days Complete	Days Remaining
1	Pre-Design Phase	fauzan	7/22/08	11/20/08	122	100%	88	122	0
1.1	Background Study		7/22/08	8/20/08	30	100%	22	30	0
1.2	Literature Review		8/21/08	11/21/08	93	100%	67	93	0
2	Data Gathered	fauzan	8/10/08	9/27/08	49	100%	35	49	0
2.1	Data Analyst		8/10/08	8/29/08	20	100%	15	20	0
2.2	Establish Specs.		8/10/08	8/29/08	20	100%	15	20	0
2.3	Data Development		8/30/08	9/28/08	30	100%	20	30	0
3	Develop Design	fauzan	9/28/08	11/15/08	49	100%	35	49	0
3.1	analysis		9/28/08	10/27/08	30	100%	21	30	0
3.2	Design & Testing		10/28/08	11/16/08	20	100%	14	20	0

DESIGN OF A PROPULSION SYSTEM FOR UROV

Project Lead: Fauzan Fakurruddin

Today's Date: 08/05/2009 (vertical red line)

Start Date: 01/01/2009 2nd semester

WBS	Tasks	Task Lead	Start	End	Duration (Days)	% Complete	Working Days	Days Complete	Days Remaining
1	Design Process	Fauzan	1/01/09	3/10/09	69	100%	49	69	0
1.1	chasis		1/01/09	1/18/09	18	100%	12	18	0
1.2	propulsion		1/19/09	2/17/09	30	100%	22	30	0
1.3	ROV control		2/25/09	3/11/09	15	100%	11	15	0
2	Design slection	fauzan	3/01/09	4/12/09	43	100%	30	43	0
2.1	Analysis ROV		3/01/09	4/13/09	44	100%	31	44	0
3	Design Detail	fauzan	2/28/09	5/08/09	70	100%	50	70	0
3.1	Detail Drawing		2/28/09	3/16/09	17	100%	11	17	0
3.2	Detail Analysis		3/17/09	4/02/09	17	100%	13	17	0
3.3	Design review		4/03/09	5/09/09	37	100%	26	37	0

Figure 10: Gantt chart for semester 1 and 2

CHAPTER 4

RESULT AND DISCUSSION

To match the ROV design speed of 2 m/s, a suitable motor is needed to ensure the ROV can operate at its desirable speed and also to withstand resistance such as drag force.

4.1 Drag force analysis

The main resistance to motion comes from quadratic linear friction also known as drag. The main equation for drag is given as

$$F_D = -\frac{1}{2}\rho C_D\, A_D V^2$$

The drag coefficient is empirically determined using the above relation, where the Reynolds number is a relation between density ρ, characteristic length L, velocity, U and fluid viscosity μ.

ROV thruster must produce enough thrust in order it to overcome the drag produce by the tether (umbilical) and the vehicle. The drag on the ROV system is measureable quantity derived by hydrodynamic factor that include both vehicle and ether drag.

Vehicle drag = $\frac{1}{2} \times \rho\, A\, V^2 C_d$

Where
ρ = (density of sea water)/ (gravitational acceleration), where density of sea water = 1025 kg/m^3 and gravitational acceleration = 9.8 m/s^2.
A = characteristic area
C_d= drag coefficient
V = velocity per second =0.51 m/s

Drag computations for the vehicle assume a perfectly closed frame box. Drag computations for the umbilical are in the range of a cross-section of ROV system sampled during recent filed trial.

The Reynolds number for the ROV in the water with $\rho = 1025\ kg/m^3$ and $\mu = 1.31\ cP = 1.31 \times 10^3\ kg/ms$ and moving at 2 m/s is,

$$Re = \frac{\rho U L}{\mu}$$

$$Re = \frac{1025 \times 2 \times 0.45}{0.00131}$$

$Re = 704{,}198$

This clearly shown that the flow is in turbulent region because $Re > 2300$. From the chart, the value of C_D would be 0.42.

From that, the drag force for the vehicle can be calculated,

Velocity, $V = 2m/s$

Density, $\rho = 1025\ kg/m^3$,

Frontal area, $A_D = 2\ \pi\ r^3$; $r = 0.2$ m (area of half sphere)

$= 2(3.142)\ (0.2)^2$

$= 0.211m^2$

$C_D \approx 0.41$

$F_D = 0.5(1025)\ (0.41)\ (0.211)\ (2\ m/s)^2$

$F_D = 177.35\ N$

Table shows the drag force of the vehicle at different ROV velocity.

Table 2: Drag force of ROV at different velocity

Velocity,V	Drag Force,Fd
0	0
0.25	2.77
0.5	11.08
0.75	24.94
1	44.34
1.25	69.28
1.5	99.76
1.75	135.78
2	177.34

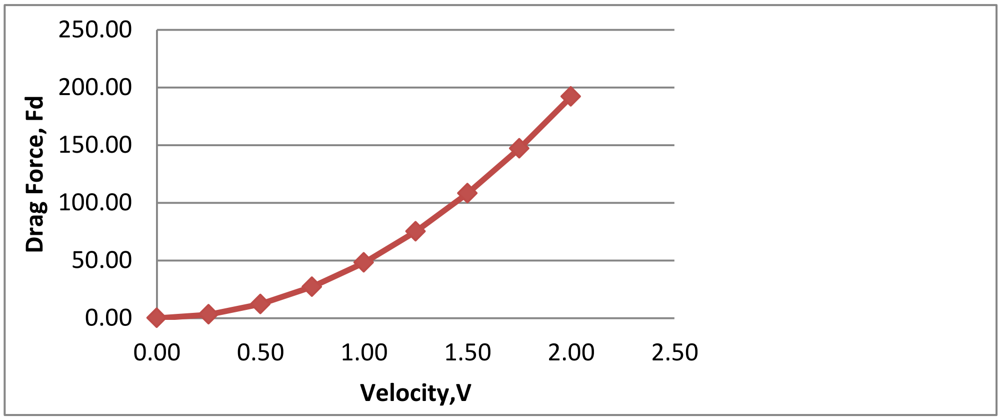


Figure 11: Drag force versus velocity

4.2 Power of motor analysis

The maximum speed of the ROV is a function of the maximum mechanical power output for the thruster motor. The power required to overcome the hydrodynamic drag is

$$P_{req} = F_D.v_{max}$$

$$P_{req} = 177.34 \text{ x } v_{max}$$

$$P_{req} = 354 \text{ W}$$

Thus, to achieve the initially specified max speed of 2 m/s, the thruster must be capable of supplying 354 W.

The required power output for the motor is rate of energy change required to move the system. Initial requirement specified a change in velocity from 0 m/s to 2 m/s in 4 second, or accelerate at 0.5 m/s^2.

$$P_{\text{max motor}} = {}^{dW}/_{dt} = {}^{dE}/_{dt}$$

$$E = E_{potential} + E_{kinetic}$$

$$E = ½\ mv^2$$

With constant system mass, the power is

$$P_{\text{max motor}} = \frac{½ \text{ x } 10 \text{ kg x } (2\text{m/s})^2}{0.5s}$$

$$= 40 \text{ W}$$

Total drag of the system is vehicle drag plus the tether drag. In case of cables, the characteristic area, A, is the cable diameter in inches divided by 12, times the length perpendicular to the flow. The C_d for the cable ranges from 1.1 for unfaired cable; 0.5-0.6 for hair-faired cable; and 0.1-0.2 for faired cable. Since the cylindrical form has the highest coefficient of drag, the use of cable fairings to aid in drag reduction can have significant impact.

The total drag of the system is defined as:

Total drag= $\frac{1}{2} \times \rho A_v V^2 C_{dv} + \frac{1}{2} \times \rho A_u V^2 C_{du}$ (v = vehicle, u= umbilical) [5]

a simple calculation can be perform if it is assumed that the umbilical cable is hanging straight down and the tether from the end of the umbilical to the vehicle is horizontal and a little drag. Let assume vehicle is working at a depth of 30m. unfaired umbilical diameter = 1.0 cm and A = 0.93 m.

Vehicle drag = ½ x 1025/9.81 x 0.211 x 2^2 x 0.8 = 35.27 Kg

Umbilical drag = ½ x 1025 x (0.01/12 x 30) x 2^2 x 1.1 = 5.75 Kg

Total mass added = 35.27 + 5.75 = 41.03 kg

Drag computations for the vehicle assume a perfectly closed frame box. Drag computations for the umbilical are in the range of a cross-section of ROV system sampled during recent filed trial.

Total mass for the ROV in the water, m_{total} = 10 + 41.03 = 51.03 kg

Hence, the maximum power will now be significant greater.

$$P_{max\ motor} = \frac{\frac{1}{2} \text{ x } (10+41.03)\text{kg x } (2\text{m/s})^2}{0.5s}$$

$$= 204.12\text{W}$$

By including the design factor of 1.5,

$$P_{max\ motor} = 204.12 \text{ x } 1.5$$

$$= 306.18 \text{ W}$$

In order to achieve top speed of 2 m/s, the ROV required a total power of 306.18 W. the total thrust force required to achieving top speed of 2 m/s is

Power = Force x Velocity

Force = Power / Velocity

Force, F = 306.18 W / 2 m/s

F = 153.09N

From the calculation, ROV must have a total of 45.2 N of force for it to have a maximum speed of 2 m/s. since this ROV will have 4 thruster in a surge direction, the size of propeller can be estimated by following equation

$F_T = \rho\, A_P\, V_P\, (V_E - V_0)$

By assumption that, each of the thruster will have a same amount of force generated,

153.1/4= 38.3 N,

$F_T = 38.3 = \rho\, A_P\, V_P\, (V_E - V_0)$

With $\rho = 1025$, $A_P = \pi r^2$, where r is propeller radius, $V_0 = 2$ m/s. V_P can be related to V_E as $V_E = 2 V_p + V_0$.

Substituting all the value will simplify the equation to

$38.3 = (1025)\, (\pi r^2)\, V_P\, (2V_p + 2)$

$38.3 = (1025)\, (0.03^2 \pi)\, V_P\, (2V_P + 2)$

$6.61 = V_P^2 + V_P$

$V_P^2 + V_P - 6.61 = 0$

$V_P = 2.1$ m/s

V_P is related to angular speed and efficiency as

$$V_P = np\eta$$

Pitch, P = 0.057 m

Efficiency, η= 65%

Hence, the angular speed of propeller would be

$$n = V_P / (p\eta)$$

$$n = 1.582/ (0.057 \times 0.65)$$

n = 42.64 rad/s or **407 rpm**

4.3 Thruster design

Underwater electrical thrusters are composed of the following major components:

- Power source
- Electric motor
- Thruster housing attachment to vehicle frame
- Gearing mechanism
- Drive shaft, seal, and coupling
- Propeller
- nozzle and stators

4.3.1 Power source

The type of power delivered to the submersible is a trade-off of cost, safety, and needed performance. Direct current (DC) allows for lower cost and weight, it also have a minimal inductance noise, which allows for less shielding of conductor in close proximity to the power line.

The separated power source is needed in the offshore application. Because when the ROV needs more power when it tries to escape a hazardous bottom condition, it tends to lose power when the vessel is making power-draining reposition thrusts on its engine. With the separate power source, ROVs maneuvering power is separated from the power needs of the vessel.

With the advent of lightweight micro-generator for use with small ROVs, the portability of ROV system is significantly enhanced. A combination usage of battery and AC power is also possible. For this ROV, the most suitable power source system is to use a DC power source since it is a small ROV and also cost effective. Either method (DC or AC) should have the power source capable of supplying uninterrupted power to the system at its maximum sustained current draw for the length of the anticipated operation. The ROV will have the power source from a 24V DC battery.

4.3.2 Electric motor

Electric motor comes in many shapes, size and technologies, each of it designed for different function. The most common thruster motor for the observation-class ROV system is the DC motor, due to its power availability, variety, and reliability and easy of interface. The DC motor however has some difficult design and operational characteristic. The factors that make it less than perfect for the application is:

- The optimum motor speed is much higher than the normal in-water propeller rotation speed, thus requiring gearing to gain the most efficient speed of operation.
- DC motor consume a high amount of current
- They required a rather complex pulse width modulation (PWM) motor control scheme to obtain precise operations.

4.3.3 Gearing

DC motor can run from 8000 to 20000 RPM and higher. Clearly, this is to far too fast for ROV applications if the vehicle is driven directly. Thus, to match the efficient operational speed of the motor with the efficient speed of the thruster propeller, the motor will required gearing. Gearing allows two distinctive benefits – the power delivered to the propeller is both slower and powerful. With the proper selection of a gearbox with a proper reduction ratio, the maximum efficiency speed of the motor can match the maximum efficiency of the thruster/propeller/kort nozzle combination.

4.3.4 Drive shafts, seals, and couplings

The shafts, seals, and couplings for a ROV thruster are much like those for a motorboat. The shaft is designed to provide torque to the propeller while the seal maintains watertight barriers that prevent water ingress into the motor mechanism.

Drive shaft and coupling vary with the type of propeller driving mechanism. Direct drive shafts, magnetic couplings, and mechanical coupling are all used to drive the propeller. There is various methods for sealing underwater thruster. Some manufactures use fluid-filled thruster housing to lower the different between water and the internal thruster housing pressure by simply matching the two pressures. Still other uses a lubricant bath between the air-filled spaces and the outside water. A common and highly reliable technique is the use of a magnetically coupled shaft, which allow the air-filled housing to remain sealed

4.3.5 Propeller design

The propeller is a turning lifting body designed to move and vector water opposite to the direction of motion. Many thruster propellers are designed so their efficiency is much higher in one direction (most often in forward and the down directions) than in the other. Propeller has a nominal speed of maximum efficiency, which is hopefully near the vehicle's operating speed. Some propeller is designed for speed and other is designed for power. When selecting a propeller, choose

4.3.6 Kort nozzle

A kort nozzle is a common on most underwater thruster models. The efficiency of a kort nozzle is the mechanism's help in reducing the amount of propeller vortices generated as the propeller turn at high speed.

A Kort Nozzle is specifically designed around this principle. Taking into consideration Bernoulli's continuity equation for incompressible flow between cross sectional area one (A1) and cross sectional area two (A2):

$$pA1V1=pA2V2$$

Where p is the fluid density andV1 andV2 are the fluid velocities.

This equation states that the volumetric flow into the system must equal the volumetric flow out of the system. IfA1 is greater thanA2, thenV2 must be greater thanV1. In other words, if the input cross sectional area is greater than the output cross sectional area, then the exit fluid velocity will be greater than the input fluid velocity. Hence, more water is moved and thrust is increased for the same input power and torque.

Put in simpler terms this is what happens: One cross sectional area is greater than the other and since the fluid density is constant then the water must accelerate from one to the other. Hence the water is already moving faster as it reaches the propeller than it would on a conventional open propeller. Therefore more water is moved and more thrust created for the same input power and torque.

The nozzle consists of a ring of aerofoil section which forms a nozzle surrounding the propeller. The suction of the propeller causes an acceleration of flow in the mouth of the nozzle and hence a drop of pressure in this region. Since the pressure on the outer part of the nozzle remains relatively unchanged, there is a resulting differential in pressure, which acting on the projected annulus of the nozzle, gives the additional forward thrust. It also helps reducing the incident of foreign object ingestion into the thruster propeller. Also, stators help reduce the tendency of rotating propellers swirling discharge, which tend to lower propeller efficiency and cause unwanted thruster torque acting upon the entire vehicle.

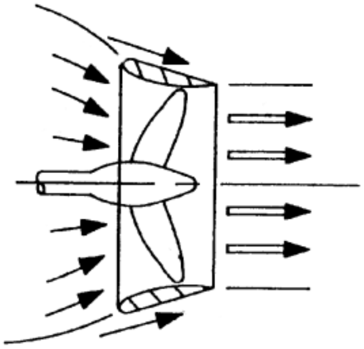


Figure 12: Kort nozzle [10]

4.3.7 Brushless DC motor

These thrusters are the most reliable electric thrusters available. However, the performance and reliability of these thrusters can suffer if filled with seawater. These designs offer extremely lightweight performance producing around 1kN thrust.

- Best Reliability
- Lightweight
- Forward / Reverse Thrust Within 5% Band

The motor/gearbox is at the heart of the thruster, providing rotational energy to the propeller which then develops the thrust that moves the underwater vehicle. The motor/gearbox assembly is comprised of the Pittman GM9236S014 gearmotor, which can be purchased as a single unit that does not require any assembly or modification. The picture below shows the motor/gearbox unit (figure 11).

Choosing the motor for the low cost thruster involved considering the motor as taking into account alternatives which could give better performance and/or a lower overall cost. The first requirement for a motor was that it be large enough to provide sufficient thrust for small ROVs. As calculated that a small ROV would require 45.2 N of total thrust in order to move forward at an approximate speed of 2 m/s

It was assumed that this thrust would be provided by four thrusters aligned to the length of the ROV, and from the thrust estimation, calculated that each motor would need to operate at around 90 W.

The second requirement called for finding a motor which would be compatible with the motor controller selected for the thruster. The decisions for choosing the motor and the speed controller were codependent, because certain motors have specific controller requirements.

During the search for motors, geared motors were mostly sought, since most ungeared motors operate well above this RPM.

Also, since the torque demand was unknown for the thruster, motor selection was primarily based on RPM and current draw.

In addition to the above requirements, cost was another factor in choosing a motor, as in all of the components used for the thruster. For the final design, the Pittman GM9236S014 gearmotor was selected. This motor fulfilled the above requirements and its use involved making only minor tradeoffs with other related components in the thruster, specifically the shaft sealing mechanism.

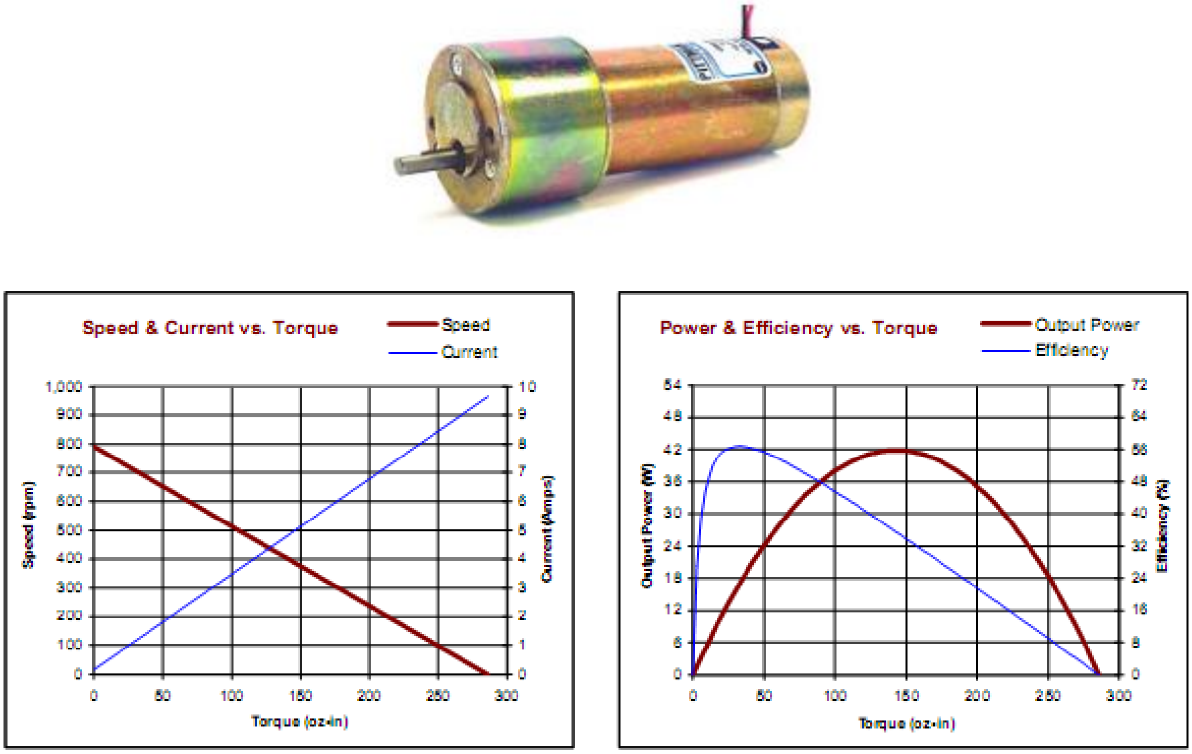


Figure 13: Pitman brushless DC gearmotor and its performance

Table 4: Motor specification

Model	Pittman GM9236S014
Size	Ø 0.03 m, L = 0.07 m
Net weight	19.7 g
Motor speed	3700 rpm
Voltage	24 V
Torque	2.3 kg-cm
Efficiency	90%

Thruster Assemblies

5- Pittman GM9236S014 gearmotor

Power Requirements 12 V DC, 6.0 Amps each (approximate)

Thruster Configuration Four (4) horizontal mounted at 25°.

Two (2) fore/aft thrusters mounted forward on port and starboard side, two (2) fore/aft thrusters aft on port and starboard side. One (1) vertical thruster mounted mid-vehicle.

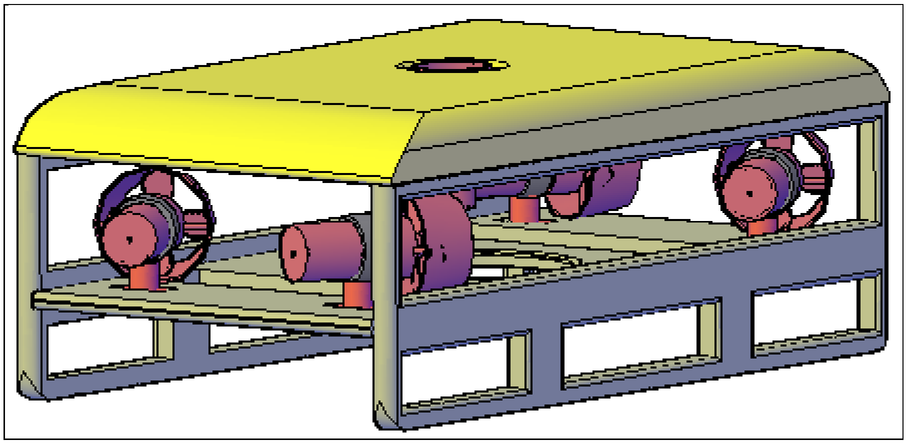
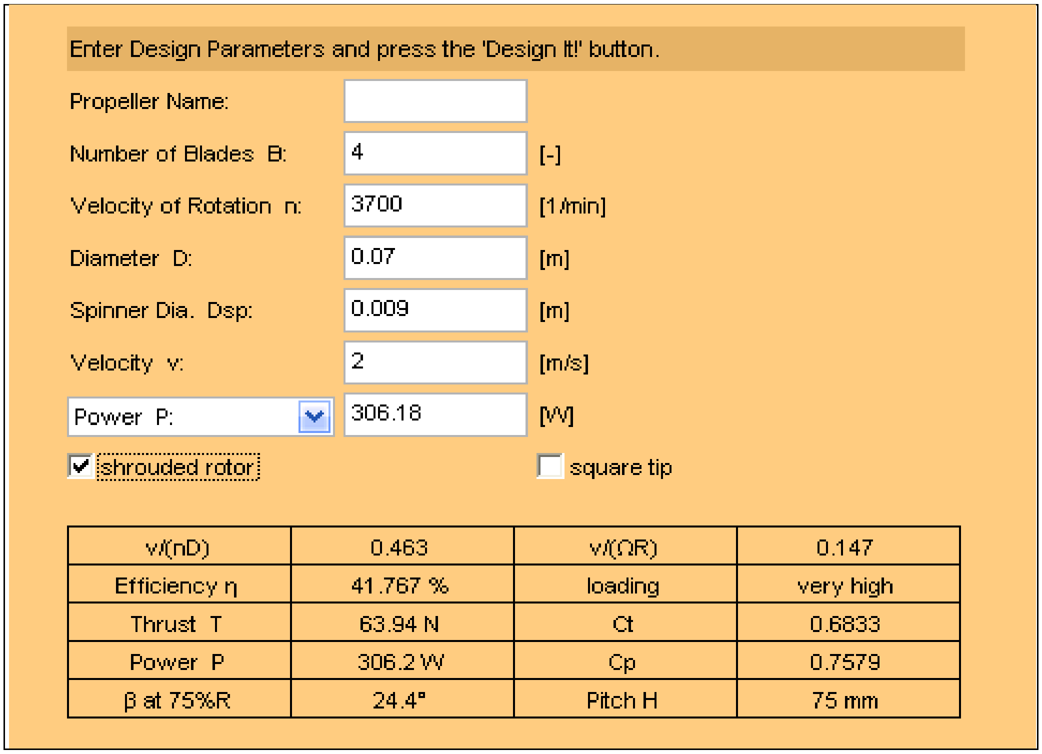


Figure 14: Thruster assembly on the ROV

4.4 Analysis using JavaProp



Enter Design Parameters and press the 'Design It!' button.

Propeller Name:

Number of Blades B: 4 [-]

Velocity of Rotation n: 3700 [1/min]

Diameter D: 0.07 [m]

Spinner Dia. Dsp: 0.009 [m]

Velocity v: 2 [m/s]

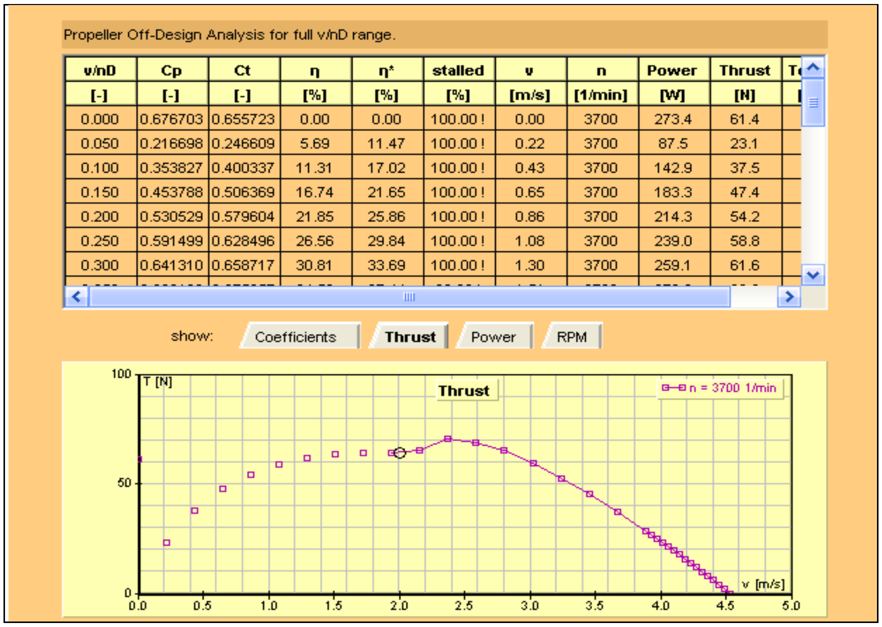
Power P: 306.18 [W]

☑ shrouded rotor ☐ square tip

v/(nD)	0.463	v/(ΩR)	0.147
Efficiency η	41.767 %	loading	very high
Thrust T	63.94 N	Ct	0.6833
Power P	306.2 W	Cp	0.7579
β at 75%R	24.4°	Pitch H	75 mm

Figure 15: JavaProp analysis

By using JavaProp [12], (software to design a propeller) it help to designing a propeller according to the input data such as no of blade of the propeller, its diameter, velocity and also power. Javaprop is a helpful software that is can be use to design a propeller for an airplane but it can also design the propeller for application in the water, this is just by simply fill the required parameters such as the water density and water kinematic viscosity. Thus it can be use to design a propeller for water application.



Propeller Off-Design Analysis for full v/nD range.

v/nD [-]	Cp [-]	Ct [-]	η [%]	η* [%]	stalled [%]	v [m/s]	n [1/min]	Power [W]	Thrust [N]
0.000	0.676703	0.655723	0.00	0.00	100.00 !	0.00	3700	273.4	61.4
0.050	0.216698	0.246609	5.69	11.47	100.00 !	0.22	3700	87.5	23.1
0.100	0.353827	0.400337	11.31	17.02	100.00 !	0.43	3700	142.9	37.5
0.150	0.453788	0.506369	16.74	21.65	100.00 !	0.65	3700	183.3	47.4
0.200	0.530529	0.579604	21.85	25.86	100.00 !	0.86	3700	214.3	54.2
0.250	0.591499	0.628496	26.56	29.84	100.00 !	1.08	3700	239.0	58.8
0.300	0.641310	0.658717	30.81	33.69	100.00 !	1.30	3700	259.1	61.6

Figure 16: JavaProp analysis for thrust

In this analysis, the JavaProp give a great designing data, it will give the data such as the efficiency of propeller, its thrust, and all the specification needs to develop the propeller design. In the multi analysis column, it will give a data such as, the coefficient, thrust and also the power. By this analysis, we can determined the suitable blade for the required propeller, and also the effect of the nozzle in the propeller, this can be done by clicking the shrouded rotor box in designing phase, it give a very significant effect to the performance of the propeller, the efficiency is increase by almost 20%. This analysis has proved that the kort nozzle will have a significant effect on the efficiency of the propeller

Table 3: Propeller Specification

Parameter	Design
no of blade	4
velocity of rotation, n	3700 rpm
Diameter, D	0.07 m
spinner diameter, d	0.009 m
velocity of ROV, v	2 m/s
Power, P	306.18W
Thrust, T	64 N

4.5 Thruster Layout Configuration

The actuation system is composed by a vectored thruster system for surge, sway, and yaw. The system consists of four thrusters mounted at angle of 25° with respect to the surge axis. In these degrees of freedom the vehicle is over-actuated. This feature is used to control the force system in several modes. In the differential mode the system is capable to deliver thruster instantaneously at zero velocity. One thruster to the control motions in z.

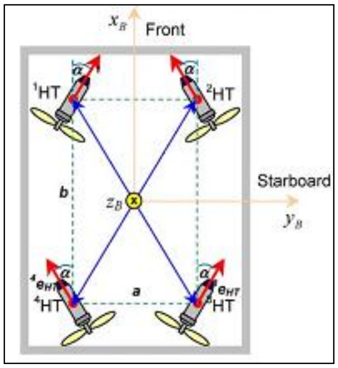


Figure 17: Initial design of the ROV

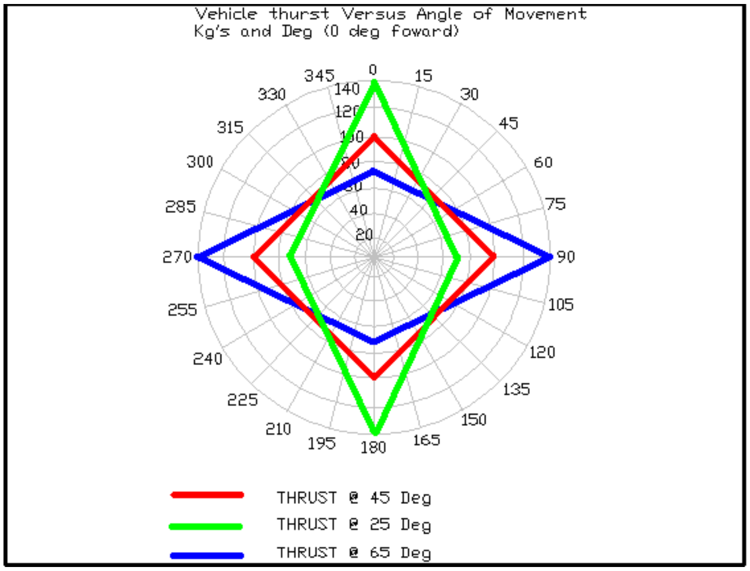


Figure 18: Determining the angle of positioning thruster

In this figure above (figure 16), it show how are the position of thruster will affect the ROV thrust. This also shows that 25° is the most suitable angle to position the thruster in order the ROV to achieve a maximum 2 m/s of speed in the horizontal (x-axis).

Vector addition of each thruster to get the total thrust of the ROV,

$$F = 2\sin(25°)F_{Thruster} + 2\sin(155°)F_{Thruster}$$

$$= 1.69\ F_{thruster}$$

Maximum thrust developed is nearly one and a half times larger than having both thrusters inline with the principle axes. The cost to the system is in the lost energy from the thrust that cancels out.

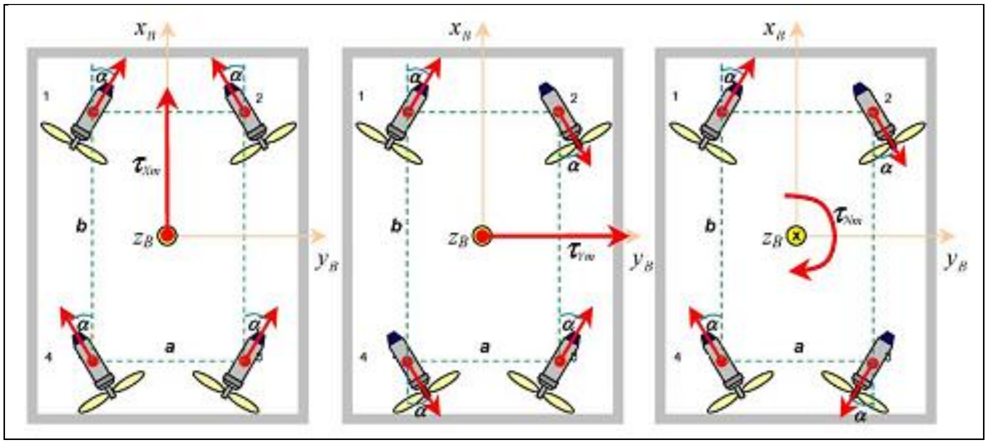


Figure 19: Movement of the ROV with the thruster arrangement

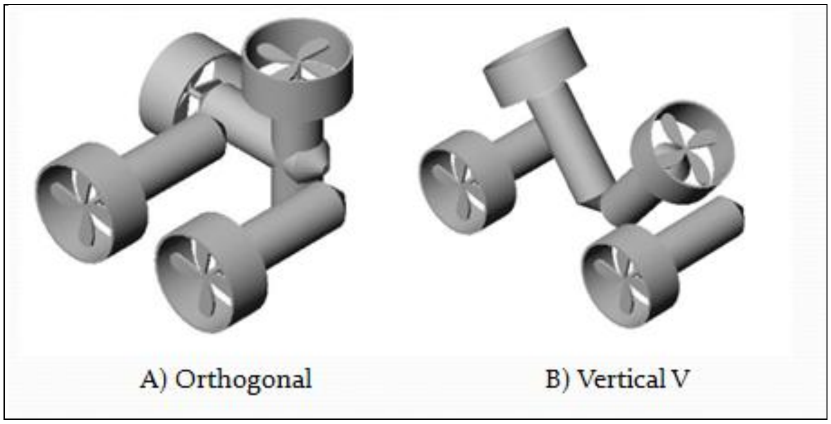


Figure 20: Ways to mount the thruster

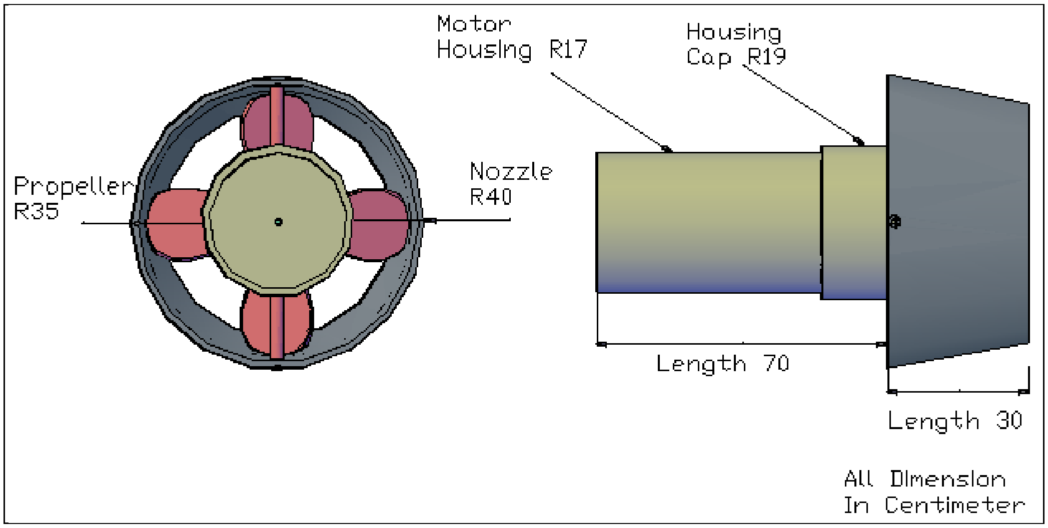
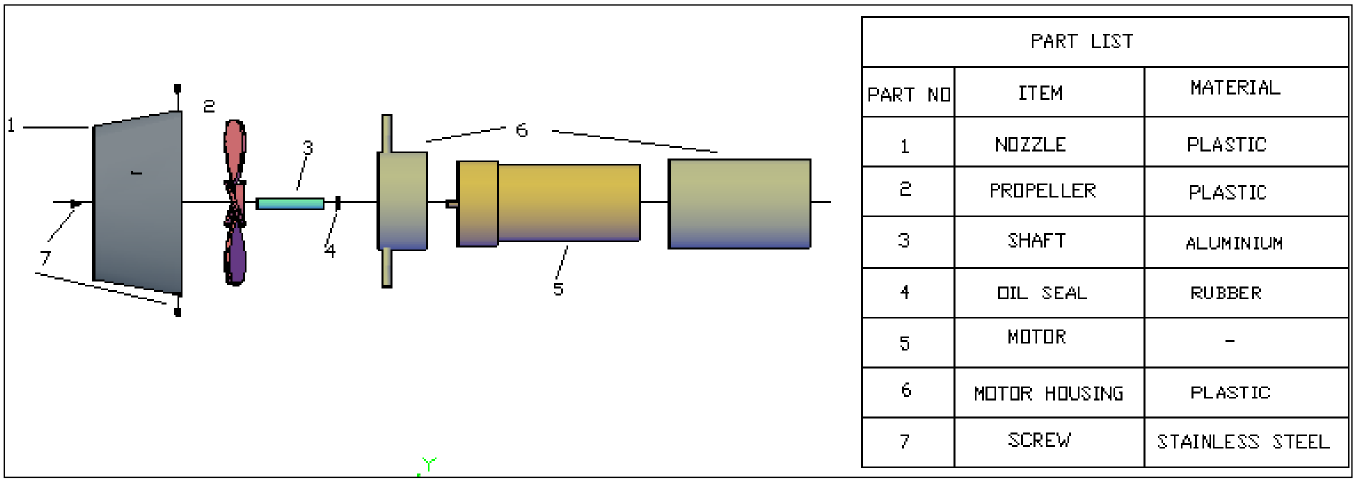


Figure 21: Technical drawing of the thruster



PART LIST		
PART NO	ITEM	MATERIAL
1	NOZZLE	PLASTIC
2	PROPELLER	PLASTIC
3	SHAFT	ALUMINIUM
4	OIL SEAL	RUBBER
5	MOTOR	-
6	MOTOR HOUSING	PLASTIC
7	SCREW	STAINLESS STEEL

Figure 22: Assembly drawing of the thruster

4.6 Flow Dynamic Analysis

The analysis was done to visualize the drag effect with the ANSYS CFD program. In addition to validating the calculations, this program enabled to visualize the fluid flows and the distributions of pressure which provided for a better understanding underlying hydrodynamic behavior as being shown in figure below (figure 22). As can be seen in the figure, there are hydrodynamic effect on the ROV. The frontal area of the vehicle should be minimized and the components of the ROV need to be design so that it will minimize the sharp edge, this is to ensure there is less drag on the vehicle. By comparing both models, it clearly shows that by minimize the frontal area of the ROV, it can minimize the pressure/drag to the ROV.

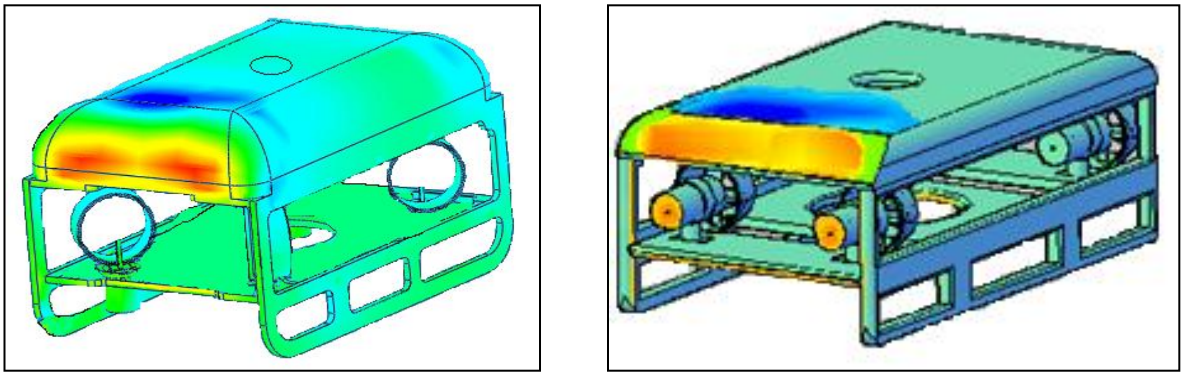


Figure 23: Computational Fluid Dynamics simulation

CHAPTER 5

CONCLUSION

In this report the description of the specification and the design concept for a new ROV propulsion system has been describe, and discussed the mechanical design, namely in what concerns modularity, configurations, and mechanical.

A total of 310 W of power is required in order for ROV to maneuver at 2 m/s Sets of 4 thruster will be use for surge, yaw, and sway with 40 N of force for each thruster.

Drag is very important in designing the thruster, it give significant effect to the power input of the motor. A simple hydrodynamics analysis has been conducted on a design ROV. The resulting motion response has been compared with actual performance data for objective evaluation of the ROV's concept.

The arrangement of the thruster has been specify that is 25° from the x-axis. Detail drawing of the thruster has been developed to illustrate the ROV propulsion system

There are several directions for future work: i) to further develop the design tools to account for parametric uncertainty; ii) to use these tools in conjunction with system identification procedures to further refine the performance of the vehicles; and iii) to develop a small scale prototype for testing the model.

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http://www.mh-aerotools.de/airfoils/javaprop.htm

APPENDIXES

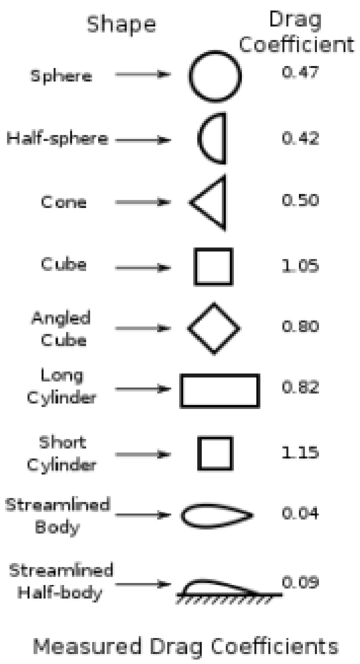

Figure 24: Drag Coefficient, Cd [2]

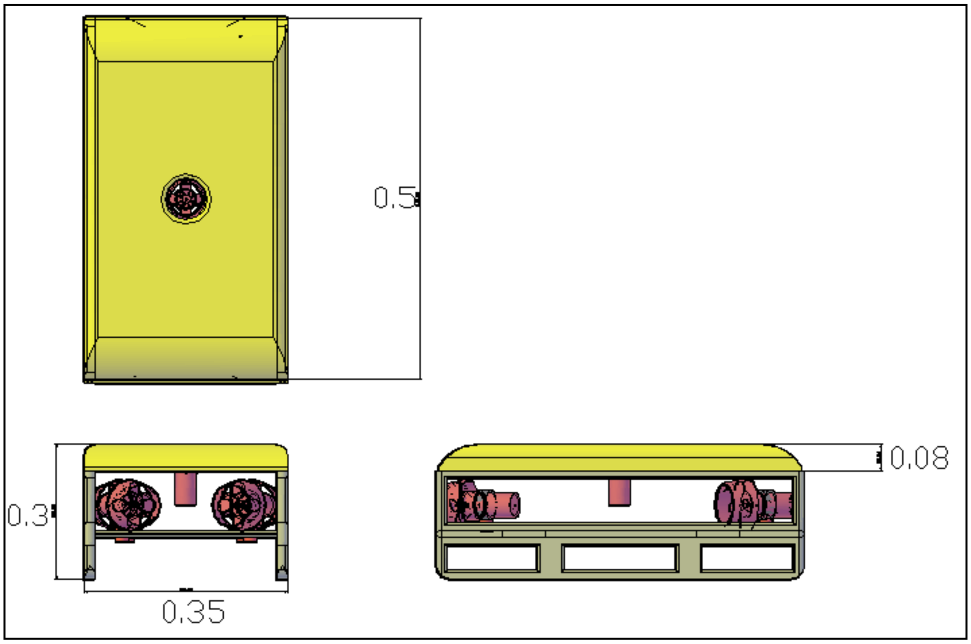

Figure 25: Top, side & front views of ROV

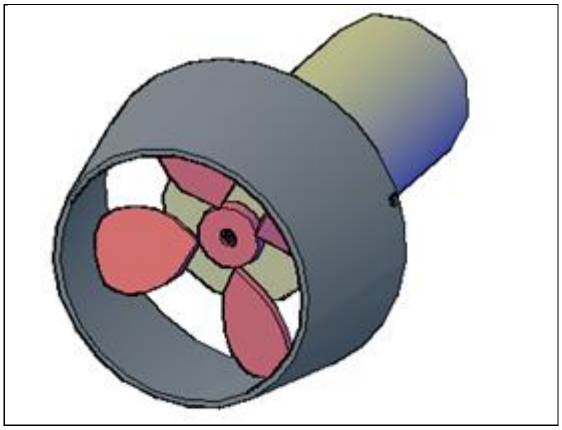

Figure 26: Thruster

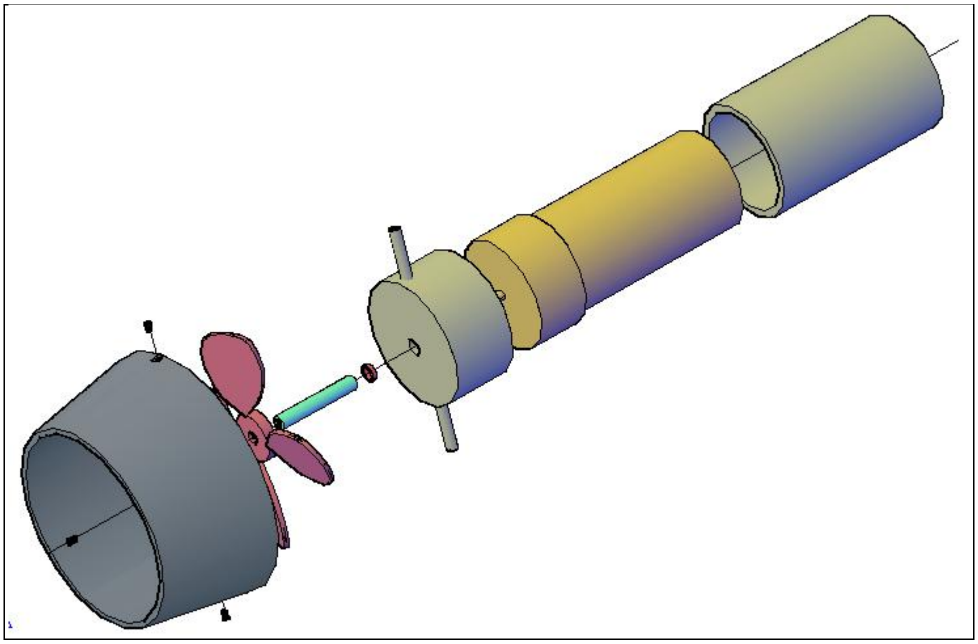

Figure 27: Isometric view of thruster assembly

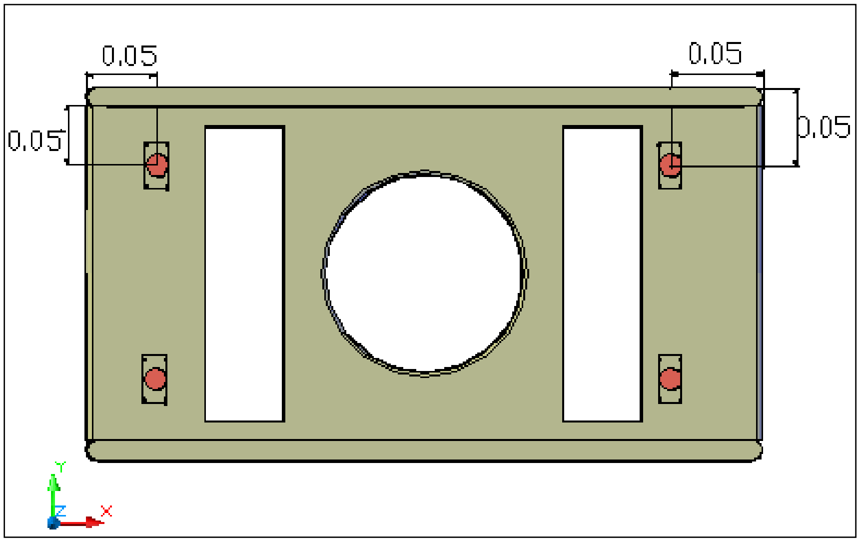

Figure 28: Location of thrusters