Design Process and Hydrodynamic Analysis of Underwater Remotely Operated Crawler

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***Abstract*—Underwater Remotely Operated Crawler (ROC) is a type of underwater Remotely Operated Vehicle (ROV) that able to operate underwater and even on land. The distinctive design of the ROC compared to other underwater vehicle is, ROC allows for underwater intervention by staying direct contact with the seabed. The common issues faced by all underwater vehicles are the drag that occurs when the vehicles move underwater. It is important to reduce the drag in order to increase the speed of the ROC with less power consumption. As such, the study of hydrodynamics to the ROC is essential so that the stability and maneuverability of the ROC can be guaranteed. SolidWorks software is used to design and analyses the ROC. The dimension of the ROC is 100-mm high, 449.60-mm long and 297.60 width. The body or chassis of the ROC is made of stainless steel. Based on the design and the capability of the ROC, it is estimated that the ROC can operate with less drag, withstand the underwater forces and stable to operate on the seabed.**

***Index Terms*—Remotely Operated Crawler; SolidWorks Software; Hydrodynamics.**

I. INTRODUCTION

The Earth's surface is covered by land and water. In fact, 71% of the Earth's surface is covered with water. Thus, there is a vast area that still uncovered by a man. The underwater terrain of the sea are still unknown and till today still not completely mapped. Same goes to the most of the sea creatures live in the deep of the water which they are not yet fully uncovered. Various underwater vessels and technology are developed as a tool to survey and observe the deep sea such as Autonomous Underwater Vehicle (AUV), Underwater Remotely Operated Vehicle (ROV), sonar and submarine.

Remotely Operated Vehicle (ROV) mostly being used in underwater operations such as in research and development, observation, military and many more. In order to conduct work or survey operations, ROVs need to move and withstand the reaction force operations. Furthermore, ROVs sometimes needs to remain stationary and keep their posture stable during operations [1]. Thus, in order to cater these requirements, Remotely Operated Crawler (ROC) is developed. Since the ROC will operate underwater, it should be designed to tackle all the conditions of the underwater environments. There are a few necessary elements to consider while developing ROC which are; water pressure and the environment, sinking mechanism, power supply and controlling method [2]. It is important that the ROC have a chassis that can withstand the underwater pressure and have a hydrodynamic design in order to reduce drag.

The objective of this study is to determine the capability of the ROC in term of having a hydrodynamic properties. In [4 -7] stated that the difference in the mobility of a crawler on land and underwater is due to the hydrodynamic effect, which includes the added mass, buoyant force and center of buoyancy. Also stated in [4 -7] investigated the equilibrium during operation including the hydrodynamic influences. It showed that the equilibrium operating characteristics of the crawler system in water are lower than those on land because of the buoyant force, including the effect of the center of buoyancy. This means that the ROC with a crawler system tends to wheelie more in underwater than on land. These investigations examined operation not only on a flat and even safer, but also on a steep seafloor, while climbing over a bump.

Upon completion in development, the crawler’s main goal is to operate alongside with other remotely operated vehicles for underwater pipeline inspections in oil and gas industry. They will help to monitor and at the same time doing some repair or construction of the pipeline at certain depth where divers cannot dive. This technology will reduce the risk taken by all offshore divers as helping to reduce costs in manpower for deep sea diving.

II. METHODOLOGY

The flow of the project is started with getting information from the literature review. Later, all the information is gathered to identify problems to be solved. Concept review refers to the reviewed design of the available crawler in the market. Then, a new design is proposed and tested with simulated in SolidWorks software. Any changes or dissatisfied design is then redraw and simulated again until gaining a desired specification.

A. Selecting materials

Material selection must consider a material that's strong enough to stand the underwater pressure and at the same time anti-corrosion. Common steel is strong enough, but it will corrode when exposed to humidity and water. Aluminium is one of the metals that cannot corrode. Even that so, aluminium do not have the strength to sustain the constant underwater pressure and force without being treated into alloy or composite material [8]. Thus, the chassis of the ROC is made of stainless steel where both the properties of steel and corrosion resistance are required. Stainless steel is a steel alloy which does not readily corrode, rust or stain with water as ordinary steel does. However, it is not fully stained-proof in low-oxygen, high-salinity, or poor air-circulation environments [8].

B. *Simulation Planning*

This crawler is set to move at any terrain of the seabed. Even that so, the wave current, underwater pressure and turbulent also influenced the hydrodynamic ability of the crawler. These factors oppose the driving force to the crawler and hence, reducing the crawler speed. This test is basically to analyze the hydrodynamic properties of the crawler chassis when operates underwater before fabrication process. The inputs of the simulation are shown in the next chapter.

III. DESIGN OF THE ROC

In [9] discussed the design of most underwater vehicles. They stated that the surface of the UUV is a revolution surface which has many advantages. Besides the shape is cheaper and easier to construct, the shape will reduce the motion resistance, overall structure can have higher strength and stability including better pressure resistance [9]. The revolution surface of UUV is formed through the revolution of a certain line about the longitudinal axis as represented by the geometry of the certain generating line [9]. Figure 1 shows one of the shapes of the revolution surface. As shown in Figure 1, the line-type and outline section of the UUV is composed of four sections: head-curve, parallel mid-curve or cylindrical section, tail-curve section and tail cone section.

The ROC is designed by taking more likely the concept of a tank without neglecting this revolution shape. The chassis consists of three parts: small front area, bigger middle area and small tail area as shown in Figure 3. It has two degrees of freedom and two motors as the actuators. Track type of wheel is used because it covers a larger surface area than the conventional wheels. Besides that, this type of wheels are more suitable in any surface conditions. On the seabed, there could be muddy, sandy, rocky and unstable surfaces. Thus, with the track wheel, it is more suitable since it provides a huge amount of tractions due to larger surface area covered.

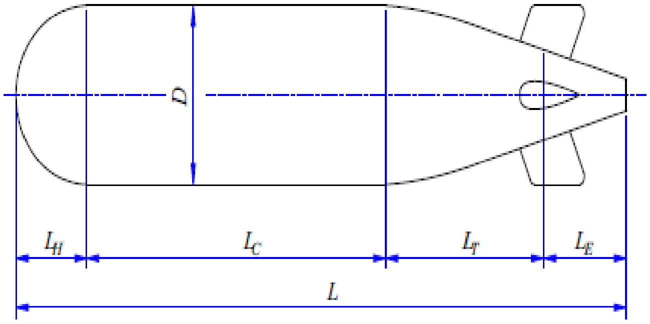

Figure 1: The design of revolution surface

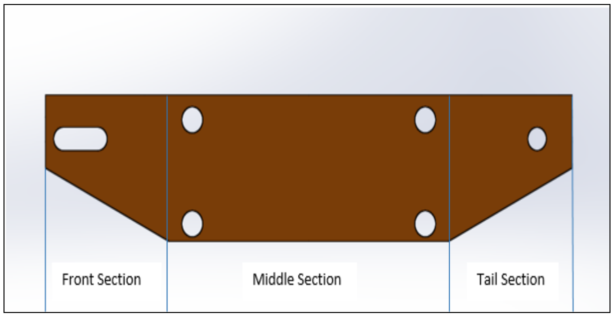

Figure 2: Side view of the ROC

In Figure 3 shows the complete assembly parts of the crawler including the internal parts. The motors and the wheel are connected with chains. The crawler chassis is a closed body and let to be hollow for improvements such as adding a ballast tank, sensors or even a buoyant. Table 1 shows the specification of the ROC.

A. *Parameter Settings*

In this part discusses on the parameters settings for simulation purpose. Table 2, Table 3, Table 4, Table 5, Table 6, Table 7, and Table 8 shows the information about domains, features, ambient, material settings and global goals applied to the simulation.

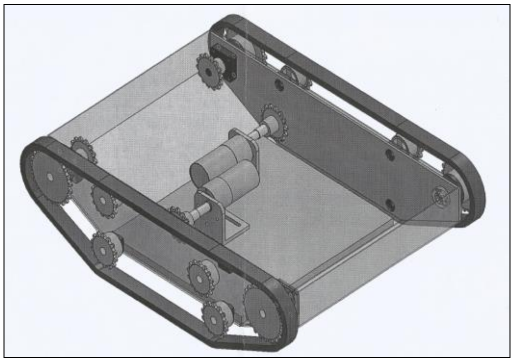

Figure 3: Drawing of the ROC using SolidWorks software

Table 1
Specification of the ROC

Items	Dimensions
Length	449.60 mm
Height Of The Chassis	100.00 mm
Width	297.60 Mm
Height Chassis to the Ground	±30mm
Type of Wheels	Track or chain type wheels
Gear Ratio	1:1 (Use sprocket and chain)
Motor Type	DC Geared Motor
Material	Stainless steel, aluminium, steel
Weight	9.8 kg

Table 2
Project's title and analysis specifications

Project name	Flow Test for Remotely Operated Crawler
Units system	SI (m-kg-s)
Analysis type	External (not exclude internal spaces)
Coordinate system	Global coordinate system
Reference axis	X

Table 3
Size of the Domain

X min	-0.575 m
X max	0.879 m
Y min	-0.369 m
Y max	0.330 m
Z min	-0.495 m
Z max	0.952 m

Table 4
Boundary Conditions

2D plane flow	None
At X min	Default
At X max	Default
At Y min	Default
At Y max	Default
At Z min	Default
At Z max	Default

Table 5
Ambient Conditions

Thermodynamic parameters	Static Pressure: 101325.00 Pa Temperature: 293.20 K
Velocity parameters	Velocity vector Velocity in X direction: 0.100 m/s Velocity in Y direction: 0 m/s Velocity in Z direction: 0 m/s
Turbulence parameters	Turbulence intensity and length Intensity: 0.10 % Length: 9.983e-004 m

Table 6
GG Av Velocity (X) 1

Type	Global Goal
Goal type	Velocity (X)
Calculate	Average value
Coordinate system	Global coordinate system
Use in convergence	On

Table 7
GG Av Velocity

Type	Global Goal
Goal type	Velocity
Calculate	Average value
Coordinate system	Global coordinate system
Use in convergence	On

Table 8
GG Av Velocity (X) 2

Type	Global Goal
Goal type	Velocity (X)
Calculate	Average value
Coordinate system	Global coordinate system
Use in convergence	On

IV. SIMULATION TEST RESULTS

SolidWorks Flow Simulation takes the complexity out of Computational Fluid Dynamics (CFD) to simulate design critical fluid flow, heat transfer and fluid forces. With this simulation, it helps in simulating liquid and gas flow under real world conditions by testing scenarios and analyzing the effect of fluid flow, heat transfer and more force on surrounding or immersed component parts. Thus, by comparing design variations, the simulation also helps to aid better decision making and ensure superior performing products.

In this part, the simulation of design is done by taking 50 iterations of calculations. The more iterations give more accurate data. Liquid flows by 0.1 m/s on the x-axis in order to imitate the forward movement of the crawler. Table 9 shows the value of data obtained from simulation.

In [10], they explained how a reasonable hydrodynamic design can result in low drag and noise with minimum compromise in volume, which in turn results for reduced development and production costs.

Table 9
Min/Max Table

Name	Minimum	Maximum
Pressure [Pa]	101319.92	101330.2
Temperature [K]	293.2	293.2
Density (Fluid) [kg/m^3]	997.56	997.56
Velocity [m/s]	0	0.127
Velocity (X) [m/s]	-0.047	0.124
Velocity (Y) [m/s]	-0.069	0.079
Velocity (Z) [m/s]	-0.072	0.071
Temperature (Fluid) [K]	293.2	293.2
Vorticity [1/s]	4.56E-05	8.977
Shear Stress [Pa]	0	0.25
Relative Pressure [Pa]	-5.08	5.2
Heat Transfer Coefficient [W/m^2/K]	0	0
Surface Heat Flux [W/m^2]	0	0

Figure 4 shows the chart of the density properties of water against the temperature. The density of the water decreasing as the temperature increase. It is the cause by the effect of heat is added to the water, there is a greater kinetic energy of the molecules and there are also more vibrations of the water molecules. Together these mean that each H_2O unit in liquid water takes up more space and the volume increases as the temperature increases.

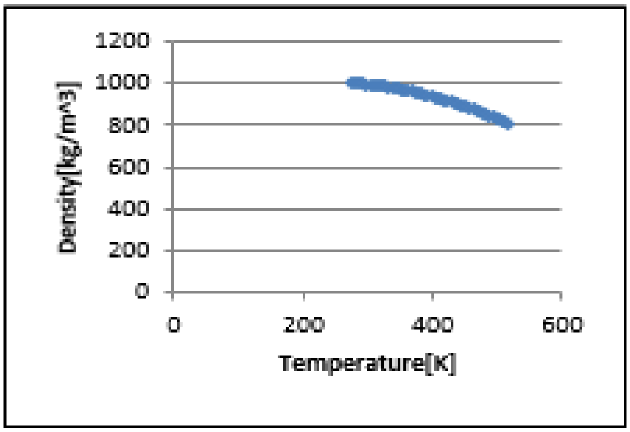

Figure 4: Graph of Density vs Temperature of Water

A. Dynamic viscosity

Figure 5 is a chart of the dynamic viscosity of the liquid against temperature. As the temperature increases, the time of interaction between neighboring molecules of a liquid decreases due to the increased velocities of individual molecules. The macroscopic effect is that the intermolecular force appears to decrease and so does the bulk (or shear) viscosity.

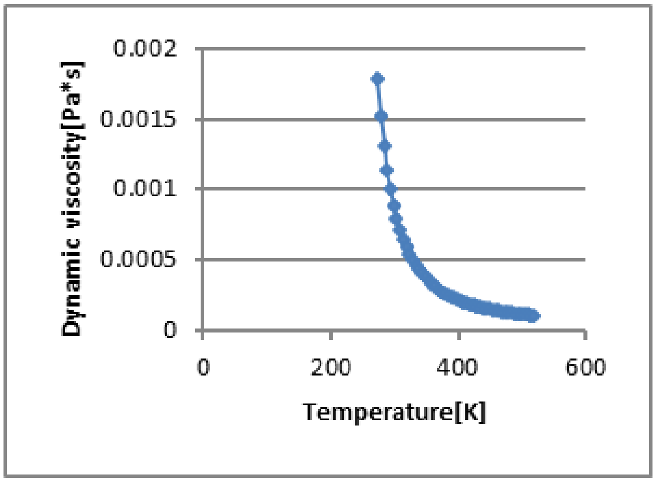

Figure 5: Graph of Dynamic Viscosity Vs Temperature of Water

B. Specific heat (Cp)

Specific heat is a measure of the ability of the substance to absorb heat. The heat goes first into increasing the kinetic energies of the molecules since the energies of molecules are quantized. Molecules can also store energy in vibrations and rotations. As the fluid heats up, the average temperature of the molecules increases, so when they collide, they are more likely to impart enough energy to allow rotation and vibration to occur as the energy jumps to a higher state. The chart of the result is shown in Figure 6.

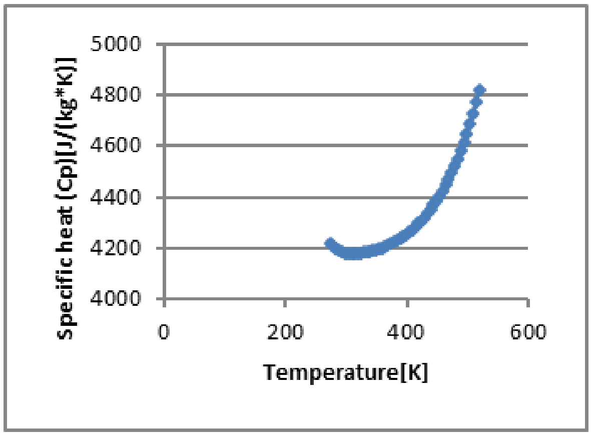

Figure 6: Graph of Specific Heat Capacity Vs Temperature of Water

C. Thermal conductivity

Figure 7 shows the properties, reaction of thermal conductivity as the temperature of water increases. Thermal conductivity is a property that help liquid to change its physical properties of liquid to gas. Water will can turn into solid, liquid and gas. At certain the range of the temperature, the water molecules gain energy to break down the bonds between molecules. As temperature increasing, the energy increasing and thus the bond between molecules weaken. When this happens, each molecule tend to be separated with each other.

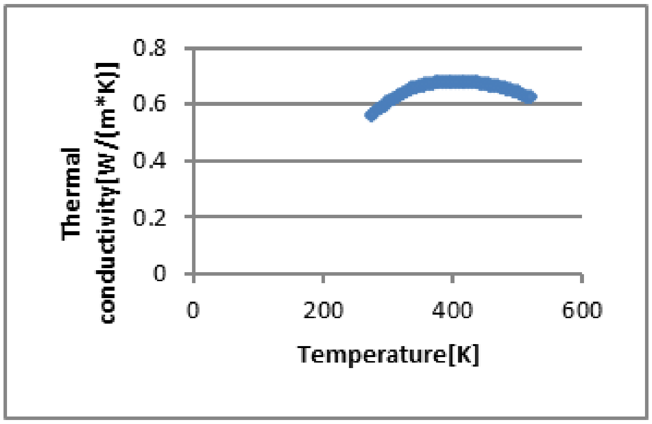

Figure 7: Graph of Thermal Conductivity Vs Temperature of Water

Figure 8(a) to 8(d) shows the fluid flow through the chassis. Initially, the fluid is in laminar state where most the water molecules travel at the same velocity. Then, when the molecules hit the chassis, drag is occur between the metal surfaces and water molecules. When this condition happens, the water molecules tend to move with different velocity and uneven fluid trajectories occurs through the chassis. At the rear of the crawler, there are turbulence occur at the rear of the crawler chassis. Turbulence happens when water molecules tend to move in different directions at different speed. As a result, unsteady vortices appear on many scales and interact with each other and increase the drag. The effect of the drag become significant as crawler moves faster.

In order to reduce the turbulence, some adjustment need to be done at the rear of the crawler. For example by adding skirt or vertical tail. With these kind of attachment, the flow of the turbulence will be disturbed and cause the fluid to flow more smooth without colliding with each other. Treating the surface of the chassis also help in reducing drag to the body.

From the analysis, the turbulence velocity is ranging from 0.03 to 0.05 m/s. It can be concluded that there are variations of the velocity at the rear part due to the different angle of attack among the flow. The flow of fluid at of the chassis is smooth and almost maintain the initial velocity which is around 0.08 to 0.1 m/s. A slight uneven flow occurs on top of the chassis since the water molecules travel with different speed and colliding with each other.

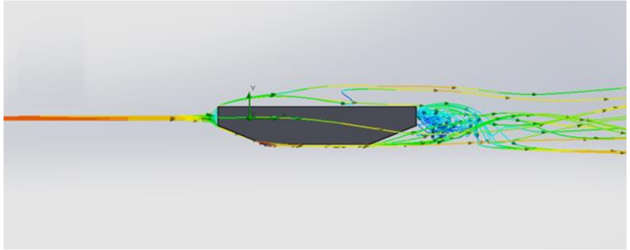

Figure 8 (a): Left view of the flow test

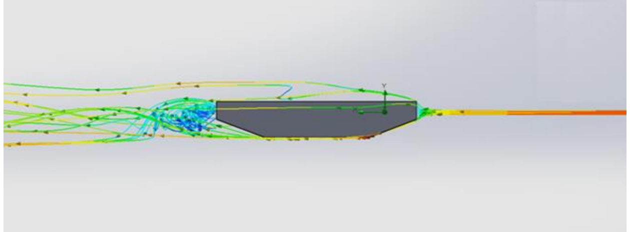

Figure 8 (b): Right view of the flow test

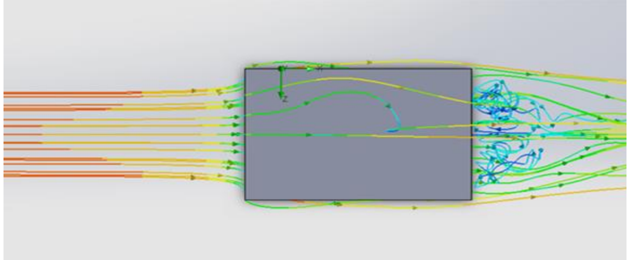

Figure 8 (c): Top view of the flow test

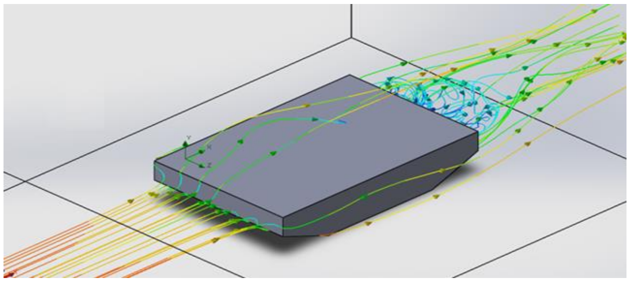

Figure 8 (d): 3D view of the flow test

V. CONCLUSION

As a conclusion, drag and turbulence become one of the main factor in reducing the motion of an underwater vehicle. The uneven fluid flow could make the vehicle to become unstable, reducing the velocity and could make the crawler to wheelie. In order to overcome this problem, researchers tend to design the underwater vehicle in revolution shape by based on their hydrodynamic properties. Turbulence occurs at the rear part of the crawler due to the molecules of the fluid move with different velocity. By adding a skirt or vertical tail, the turbulence and drag of the rear part could be reduced. More development of an enhanced crawler will proceed to improve current technology available.

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