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Hydrodynamic analysis of submersible robot

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Abstract

Underwater robots have garnered more attention in recent years for various uses including deep sea exploration. As these robots operate underwater, they experience various forces and moments from the surrounding fluid. Researches have to be conducted on these forces and moments so that ways to better improve the robots can be discovered. One such model of the underwater robots is the OpenROV. It is a type of remotely operated vehicle, which means that it requires a user to control its operations underwater. As it is still a new model, not much analysis had been done on the model. In this research paper, it was discovered that the robot experienced instability in its forward motion. The vehicle was shown to tilt slight downwards in forwards motion through water. To improve the motion of the robot, hydrodynamic analysis was conducted to determine the cause behind the instability. There are various ways to conduct hydrodynamic analysis and CFD was chosen as the method in this research paper. After conducting hydrodynamic analysis, it was determined that the cause of the instability was due to the Centre of Mass (COM) and Centre of Pressure (COP) not aligning. The concentrated pressure at the frontal area of the robot caused the vehicle to tilt downwards. To increase the stability of the vehicle, a modification was added to the model in the form of a fin attached to the rear end of the model. It was shown by the addition of the fin that the pressure distribution was even out between the frontal area and rear end. A study to determine the optimum length for the fin was conducted and the optimum length was determined to be 0.0053m or 5.3 mm. This result was validated by running the simulation of the forwards motion. The motion of the model without and with fin was captured by frames and compared. It was concluded that with the addition of the fin modification, the model will tilt slightly upwards when starting from rest and tilting back down as the motion continues. However, the tilt downwards was shown to be less than the situation prior to modification. Therefore, the modification improved the stability of the model slightly.

Keywords: OpenROV, Simulation, Hydrodynamic

1. Introduction

Technology advancements in present times have enabled the development underwater vehicles for aid Technology advancements in present times have enabled the development of underwater vehicles for aid in various activities such as deep-sea observations, offshore oil exploration, marine life studies among others. These activities were previously too dangerous for humans as they require them to dive into deep waters with an immense amount of pressure and limited oxygen supplies prevent long exploration periods underwater. As these underwater vehicles operate underwater, the stability of these vehicles when operating underwater are of upmost importance. Hydrodynamic analysis studies to find the hydrodynamic coefficients of underwater vehicles have been done to aid in the design of the vehicles to improve their performance and stability underwater. There are a variety of underwater vehicles being used including autonomous underwater vehicles (AUV) and remotely operated vehicles (ROV). This research project focuses the hydrodynamic analysis of a specific ROV model which is the OpenROV.

Background of OpenROV

OpenROV is an open source underwater vehicle which was developed by an NASA engineer by the name of Eric Stackpole [1, 2]. It is now an open development project that is accessible by anyone who is interested and the community is constantly working together to improve the model. As there are multiple versions of OpenROV available, the version that is being researched on is the OpenROV 2.7 Mini Observation Class ROV. As this research is dealing with the virtual model of the ROV, for the sake of brevity, the features and specifications of this model is available for reference on the official OpenROV website (see Figure 1).

According to Lam's article "A Mini Sub Made from Cheap Parts Could Change Underwater Exploration", the director of the National Deep Submergence Facility at Woods Hole Oceanographic Institution in Falmouth, Mass, Andy Bowen states that, there exist a gap between the depth at which humans can safely dive into and the depth at which present market underwater vehicles can explore. The OpenROV fits into this gap as the robot cannot explore ocean beds that are too deep which are beyond the target depth of 100m. This is because of its design that uses relatively cheap parts compared to commercial underwater vehicles. Therefore, the model is unable to withstand the high amount of pressure at lower depths. However, it can go deeper than the depth limit of 50 meters [3, 4]. As the OpenROV is relatively new in the underwater business compared to other commercial underwater vehicles, the community is working together to better improve the ROV. This has become the motivation for the aim of this research project, which is to conduct a hydrodynamic analysis of the OpenROV [5-7].

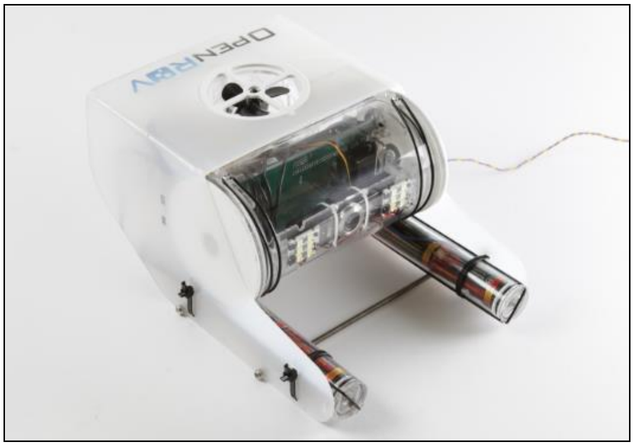

Fig 1: The OpenROV Test Platform

2. Methodology
2.1 Pre-Simulation Work
Before porting the model to the CFD software, the CAD model of the robot have to be simplified to avoid technical difficulties during meshing. The center of gravity is also determined together with the center of pressure which give rise to the objective of this research.

2.1.1 Geometry Simplification
In order to simulate flow around the OpenROV in a virtual environment, the virtual model of the ROV had to be constructed. The CAD model of the ROV was obtained from the OpenROV website as it is an open-source project, therefore, dismissing the need to draw a CAD model of the ROV from scratch. However, the model had to be simplified as there were irregularities on the model surface, (e.g. edges and holes) that would have caused technical difficulties during the meshing process. Figure 2 shows the initial CAD model of the OpenROV that was imported to the SOLIDWORKS software. Simplification of the CAD model was done in the same software which included patching multiple holes at the side of the model as well as smoothing out some edges that could have affected the meshing and simulation processes. Figure 3 shows the CAD model of the ROV post-simplification which was ready for import into STAR CCM+ for simulation set up.

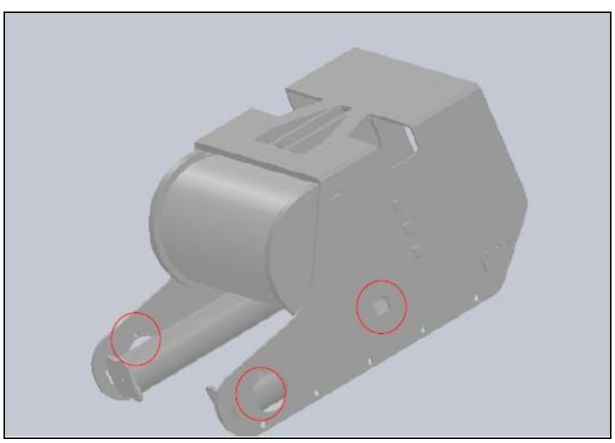

Fig 2: Initial CAD model of OpenROV

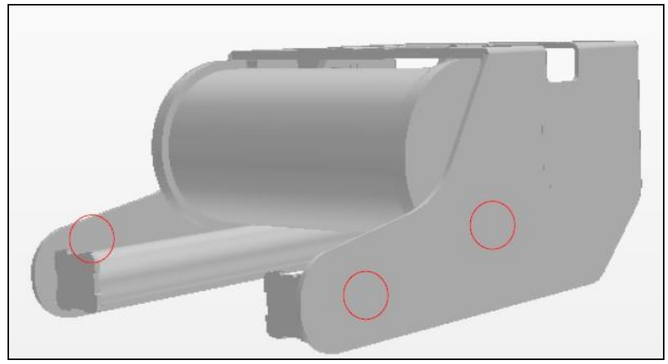

Fig 3: Simplified CAD model of Open ROV

2.1.2 Finding Centre of Gravity
SolidWorks CAD package was used to determine center of gravity through the ‘Mass Properties’ tool. Acrylic was the material that was chosen for the material. Figure 4 shows the result of the location of the C.O.G of the model.

Fig 4: Centre of Gravity of model

2.2 Simulation Set Up
In this section, the software that was used for CFD simulation was discussed as well as the preparation that was done in order for the simulation to be run. This includes the meshing process, mesh refinement and choosing relevant physics models.

2.2.1 Software Background
The hydrodynamic analysis for the OpenROV in this research project is conducted using the simulation software developed by STAR CCM+® by CD-adapco™. As stated on the product description for the software in the CD-adapco™ webpage, STAR CCM+ is not just a CFD solver, it also computes and solve other engineering problems involving flows, heat transfer and stress tests. The software is able to compute and solve these problems because of the various algorithm that were programmed into the software to ensure that it is efficient and user-friendly. The simulations were conducted on a university computer with Intel(R) Core(TM) i7-4770 processor and 32 GB installed RAM.

3. Results and Discussion

3.1 Simulation Results

Figure 5 shows the pressure distribution around the simulated model. It was discovered that the pressure is concentrated at the frontal area of the model. The concentrated pressure was highlighted in both the figures. The position of these concentrated areas of pressure could be the reason that was causing the vehicle to tilt downwards in forwards motion. Therefore, a study to determine the center of pressure was conducted. The study was conducted by resolving the forces and moments obtain through simulation into a single force with a direction in relevance to the COM as the moments are determined through the COM. Figure 6 below shows position of the COP after the study was conducted. It can be seen that the COP is slightly below the center of mass. Thus, it was determined that this was the reason why the vehicle's frontal end tilted downwards in forward motion. The Z-moment was also determined to be in negative value which also explains the tilt downwards. Therefore, an attempt to correct this problem, it was suggested that a modification be added to the rear end of the model in order to even out the pressure distribution.

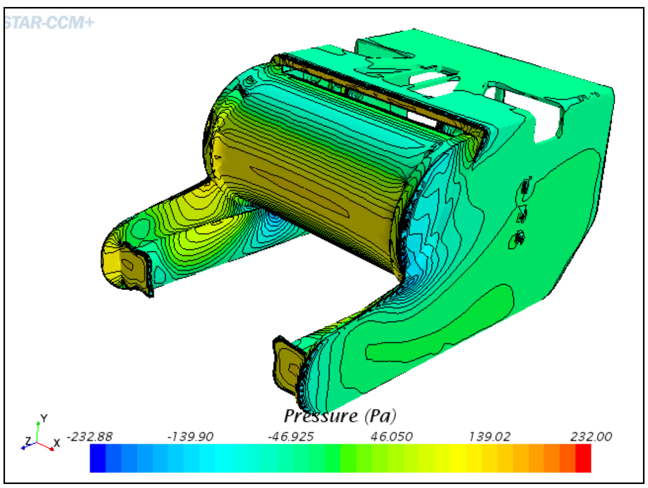

Fig 5: Surface pressure distribution

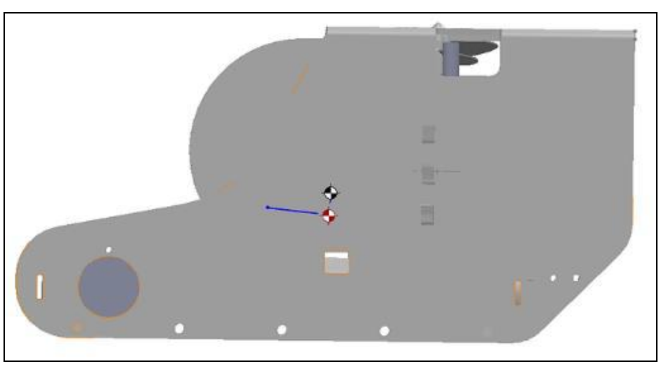

Fig 6: COP in red

The modification of the OpenROV model was done by installing a spoiler at the rear end of the model. Figure 7 shows the modification which is extruding out from the rear end. To obtain the optimum length in which the Z-moment, which is the moment that causes the model to tilt downwards, equals to zero, the length is adjusted in the CFD program and run to obtain its relevant Z-moment. The results were tabulated in Table 1. These values are based on 100 iterations run in the simulation.

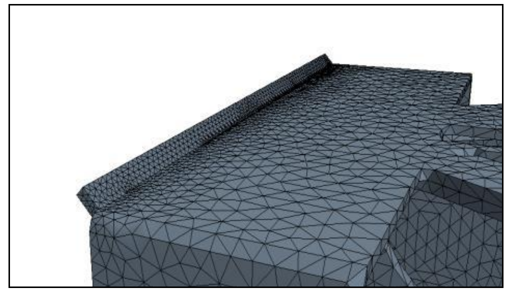

Fig 7: Addition of fin to the rear end

Table 1: Extrude distance of spoiler and their corresponding Z-moment

Extrude distance (m)	Z-moment (N-m)
0.000	-7.6328×10^{-4}
0.002	-7.6513×10^{-4}
0.004	-4.0522×10^{-4}
0.006	1.3918×10^{-4}
0.008	9.9326×10^{-4}
0.010	0.0015×10^{-4}

A graph of Z-moment against Extrude distance was plotted to obtain the best-fit line.
The equation of the line is:

$$y = 20.671x2 + 0.0397x - 0.0008$$

To determine the extrude length required in order for the Z-moment to be zero, the y-value which represents the moment is equal to 0.

$$0 = 20.671x2 + 0.0397x - 0.0008$$

By solving for x,

$$x = 0.0053 \text{ m}, -0.0073 \text{ m}$$

As the length cannot be negative, therefore the optimum fin length required is 0.0053 m or 5.3 mm.

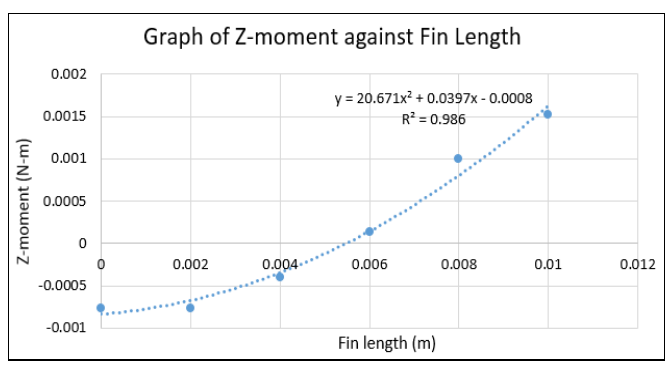

Fig 8: Graph of Z-moment against Fin Length

3.2 Validation

To validate the effect of the attachment of the fin to the rear end. Simulation of the forward motion of the model was simulated using Star CMM+. To simulate motion virtually, the Dynamic Fluid Body Interaction (DFBI) function was utilized.

DFBI allows the modelling of motion of a body resulting from the forces and moments on it (both from the fluid and other external forces). It includes at its core a Six Degree of Freedom (6DOF) solver which is used in conjunction with other motion methods such as the mesh morphing and overset methods to allow bodies to move in response to the forces on them (Model unlimited scenarios involving relative motion of components 2016).

3.3 Validation results

These options were selected for two simulation models. The model prior to the addition and the model with the modification of fin attached. The simulations for both models were run and the results were captured and shown below.

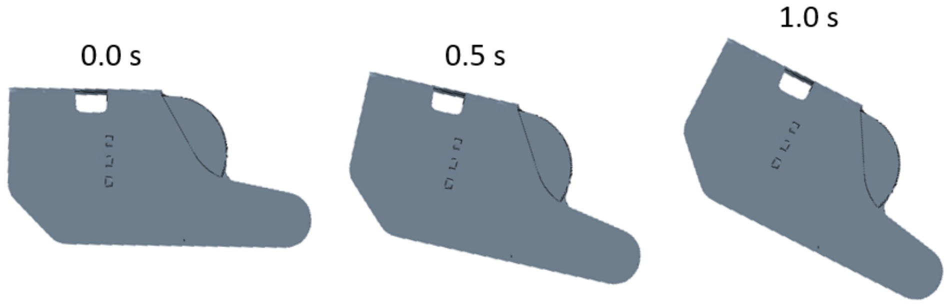

Fig 9: Motion of simulation model without fin for intervals of 0.0 to 1.0s

The motions of the simulation models were captured in time intervals of 0.0 s to 1.0 s. It could be seen that the model without modification tilted downwards as it moves forward. Figure 10 shows the motion of the modified model and while it tilted slight upwards when it started from rest, it gradually tilted downwards with less intensity than the model without modification. Thus, the modification done to the model proved to provide slight stability to the model.

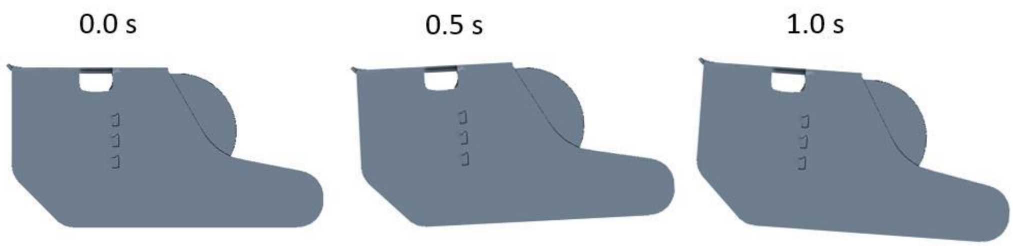

Fig. 10 Motion of simulation model with fin for intervals of 0.0 to 1.0 s

8. Conclusions

Hydrodynamic analysis had been done through CFD simulation to determine the cause of the instability that was present when the OpenROV was in forward motion. The instability caused the robot to tilt slightly downwards in forward motion. Through CFD simulation, it was discovered that the pressure distribution was concentrated on the frontal area of the model. This in turn caused the COP to be situated lower than the COM. This was the cause of the instability. In order to stabilize the model, a modification in the form of a fin attached to the rear end of the model was constructed. The simulation was run again with the addition of the fin and the pressure distribution was compared to the previous ones. It was determined that with the addition of the fin, the pressure distribution was evened out between the frontal and rear area of the model. However, the initial length for the fin that was constructed was 0.01m and the resulting Z-moment from that length was of positive value. A negative Z-moment will cause the model to tilt downwards and a positive value will have the opposite effect that is to tilt upwards. Therefore, a study was conducted to obtain the optimum length of the fin which will result in a zero Z-moment. The result of the study showed that the optimum length of the fin was 0.0053 m or 5.3 mm. This result was validated by running the simulation of the forwards motion. The motion of the model without and with fin was captured by frames and compared. It was concluded that with the addition of the fin modification, the model will tilt slightly upwards when starting from rest and tilting back down as the motion continues. However, the tilt downwards was shown to be less than the situation prior to modification. Therefore, the modification improved the stability of the model slightly. This research also established a simulation model in which further analysis of the model can be achieved in the future.

9. Acknowledgments

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10. References

1. Ann S, Faltinsen OM. An experimental and numerical study of heave added mass and damping of horizontally submerged and perforated rectangular plates. Journal of Fluids and Structures. 2013; 39:87-101. Available at: http://dx.doi.org/10.1016/j.jfluidstructs.2013.03.004.

2. Gribben Sean. Depth Limits. British Sub-Aqua Club, 2015. Accessed August 20, http://www.bsac.com /page.asp?section=2674&sectionTitle=Depth+Limits
3. Hannoura A, McCorquodale J. Rubble Mounds: Hydraulic Conductivity Equation. Journal of Waterway, Port, Coastal, and Ocean Engineering. 1985; 111(5):783-799.
4. Model unlimited scenarios involving relative motion of components. Accessed 24 April. http://www.cd-adapco.com/products/star-ccm%C2%AE/motion
5. OpenROV 2.7 Mini Observation Class ROV. OpenROV, 2015. Accessed August 10, http://www.openrov.com/products/2-7.html
6. Lin Z, Liao S. Calculation of added mass coefficients of 3D complicated underwater bodies by FMBEM. Communications in Nonlinear Science and Numerical Simulation. 2011; 16(1):187-194. Available at: http://dx.doi.org/10.1016/j.cnsns.2010.02.015.