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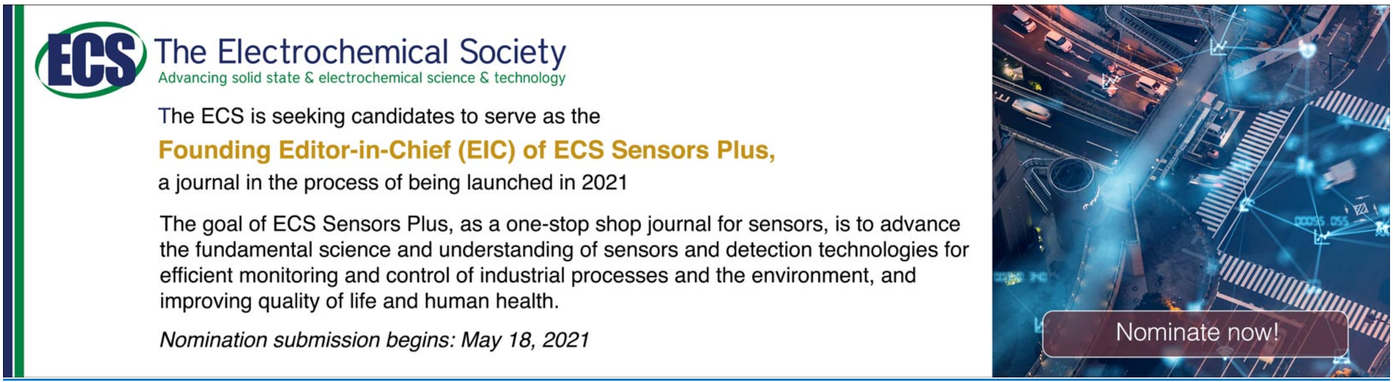

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Numerical prediction on resistance reduction of multi-purpose amphibious vehicle (MAV) due to air-cushion effect in a regular wave

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Abstract: In this paper, the resistance acting on Multi-Purpose Amphibious Vehicle (MAV) hull navigated in regular waves condition was investigated numerically. A simplified MAV model was established for computing the resistance of air cushion effect on regular head waves. Simulations were carried out in finite element analysis ANSYS CFX 15.0 in 0.5m wave height conditions. The resistances of the MAV model with and without the air cushion effect were compared in a graph of total resistance versus MAV speed. According to the results, the maximum resistance reductions occur at forwarding speed 6kn with 0.2 l/s airflow rate injection for wave height 0.5m at 10.89%.

1. Introduction

In a recent year, the shipping industry had been extensively developed as a countermeasure from the economic growth of a country, the rise of raw materials price as well as the regulations for CO_2 emission from international shipping operation. Most of the ships using diesel as a fuel for combustion process in order for a vessel to navigate in the seaway. The combustion process will emit the greenhouse gases which are carbon dioxide (CO_2), Sulphur dioxide (Sox), Nitrogen dioxide (Nox), as well as particulate matter which contribute to greenhouse effect. A concern from the public on this situation had led the academician and transportation industry to extensive developed and explored on fuel-efficient and energy concept ship.

Scholars had come up with the introduction of air cushion concept vehicles. In this concept, the air is injected at the bottom of the hull and stimulated the cushioning effect, and generally, it is widely used for a high-speed craft. Several years back, a Russian scientist [1] had developed this concept in order to minimize a viscous resistance on the ship. He concluded that artificial air cavity concept gave a promising impact on viscous drag reduction. This is because of decrease in the wetted surface of a vessel caused by lift effect and lubrication.

Multi Amphibious Vehicle (MAV) is a transport that able to transport in on land and water, including underwater [2]. These days, amphibious vehicles not only used in regular operation but also widely utilized in military service for years [3]. MAV has a blunt-shapebow where it produces a massive bow wave forming and hydrodynamic resistance. A higher in resistance resulted in a bow submerging and swamping on the MAV. So, the air cushion concept is introduced to reduce these problems.

Air cushion is one of the reliable concepts to reduce skin friction. This air cushion effect will have reduced the friction between the hull and respected surfaces and at the same time, can reduce the power consumption of a vehicle [4]. This statement also supported and agreed by Zhang [5] that the interaction will reduce the friction and at the same time, it can increase the vehicles speed up to 50-80 knots.

Numerous study had been carried out by the researcher to reduce ship resistance. Experimental study on the reduction of skin friction by microbubbles effect had been extensively carried out by researchers [6]. It is also explored by Nagamatsu et al. [7] using SEIUN MARU training ship in SR239 project. It proved that the effect of bubbles on frictional resistance at injection rate of 40 m3/min gave 2% of net energy saving.

It is elaborated by Kodama et al. [8] with a full-scale experiment using cement carrier Pacific Seagull which equipped with a blower to supply air for producing air bubbles. Two years later, in 2007 Kodama et al. [8] stated that only 1% maximum frictional reduction at an air injection rate of 50 m3/min and concluded that the ship bottoms inadequately cover with air bubbles. Somehow, it was carried out again the full-scale experiment using the same ship. It found out that in full load condition; the net fuel consumption reduced about 4% whereas in ballast condition is reduced to 7% consumption [9].

Hoang et al. [10] improve the full-scale experiment by using the same ship and produced a result in a total maximum reduction in ballast as well as full load condition about 11% and 6% respectively. From the experimental result, he proved that air bubbles produced a promising impact on frictional resistance reduction. This statement came with the assumption that the value of thrust deduction is constant with and without bubbles.

In contrast with the experimental, a study had been conducted using Computational Fluid Dynamic (CFD) software ANSYS-CFX 14.0 reported by Nakisa et al. [11]. V-shape Multi-purpose amphibious vehicle used for craft model simulation. It focused on hydrodynamic resistance involved in both frictional and pressure resistance reduction. Based on the computer result analysis, it is confirmed that air bubbles had satisfactory resistance reduction. It is because of air bubbles flowed along the ship bottom and produced a lubrication surface on the hull.

According to Matveev [12], the technology of artificial air cavity, which is providing a wetted hull with an air layer had proved. Besides, this situation had reduced the hydrodynamic resistance between the ship hull and water. It is also shown by a previous development of air cavity ship (ACS) [1] [12] roughly about 10-30% ACS drag can be reduced which also depended on the ship type as well as below 2% additional air supply of the ship propulsive power. Drag reduction of planing hulls due to the artificial air cavity utilization is 20–35%, while it is 15–30% for semi-planing hull forms. The air supply pressure in the cavity is retained by low-pressure air fans, and power consumption due to airflow fans is reported to be within 3% of the main engine power [1].

Recently, Author Ngo and Yoshiho [14] also support the study on resistance reduction by using the air circulating tank method using CFD using ballast ship hull (OPU-NBS) development in calm and head wave condition. The CFD analysis is then validated through towing experimental tank procedure. In this study, it is shown that the resistance in calm and wave condition can be reduced with the effect of air circulating tank method.

The same method on air circulating tank (ACT) had been conducted by Suguwa et al. [15] but on a vast and shallow draft ship. It is found out that there is a resistance reduction of about 37% achieved by the application of the Air circulating tank. Somehow, the effect only can remain until the Froude number 0.19 in calm water. In regular head waves, the resistance reduction effect disappears at the head waves of 1.1 m wave height in real seas.

International Maritime Organization (IMO) aimed at improving ship eco-efficiency through EEDI regulatory framework contributes to the new concept to reduce greenhouse gas emission by reducing ship resistance. In 2016, it was reported Air Cavity System (ACS) Post Panamax container ship gives the most promising reduction at 15-20 % in EEDI. It is shown that investment in ACS concept is financially affordable [16].

This research work focuses on air cushion effect on hydrodynamic resistance of MAV in calm and waves water condition. It also presents the comparison of the hydrodynamic resistance of MAV with and without the air cushion effect by injected the air from the bottom compartment of the hull of the vehicle.

2. MAV Modelling and Simulation

The ship is a twin-screw vessel, characterized by its full breadth medium draft. The calculation results are reported based on a full-scale ship navigating in a straight line using double model approximation with consideration of wave on a free surface. Only the port side was considered for the calculations, based on the line of symmetry along the hull centerline. CFD Simulation is carried out by using a simplified MAV model in ANSYS CFX 15.0. The simplified MAV model and its specification as in Figure 1 and Table 1

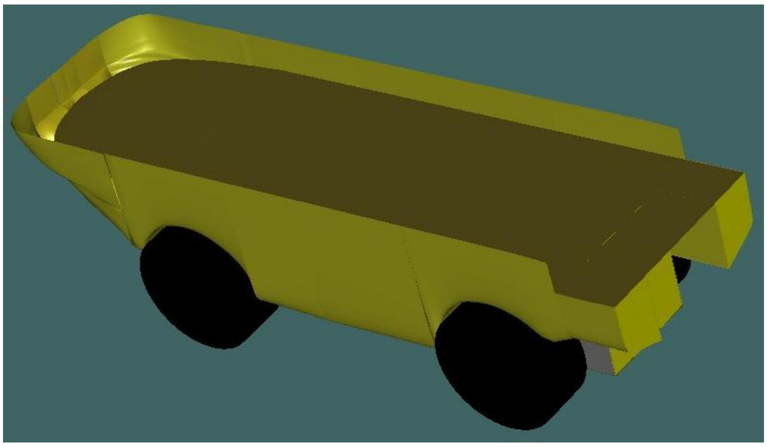


Figure 1. Simplified MAV geometry modelling

Table 1. Specification of MAV

Loading condition	Actual size	Model size	Unit
LWL	5.945	1.201	m
Beam	2.024	0.368	m
Draft	0.60	0.1	m^3
Displaced volume	5.314	0.0319	m^2
Scale	-	1:6	-
Air density	1.225	1.225	kg/m^3
Water Density	1025	1000	kg/m^3

The size of the air compartment in full-scale MAV (Figure 2) is 2m x 0.5m x 0.15m, and the air injection was assumed uniform and remains unchanged. Air injection outlet was created symmetrically on both sides of the centerline at the bottom compartment location of the hull. A velocity boundary was built at the air injection outlet; air cushion along the bottom air was formed injected at a constant flow rate.

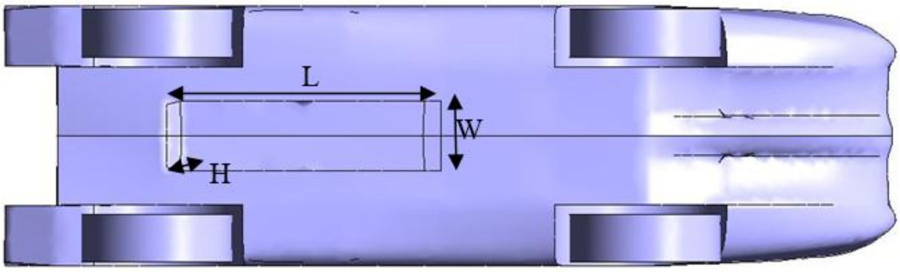


Figure 2. Overview of air injection compartment

Figure 3 and Table 2 show the mesh configuration and mesh information, which is modelled and simulated in analysis ANSYS 15.0 whose simulation set up is shown in figure 4. The mesh defined such that it is dense in areas where the flow is most dynamic and coarse in areas where there is less activity. In the case of ship flow, this usually means high grid density near the hull and about the water plane whereas the areas far from the hull can be fitted with coarser meshes.

Table 2. Mesh Information of the numerical domain

Total number of element	1456043
Total number of nodes	345818

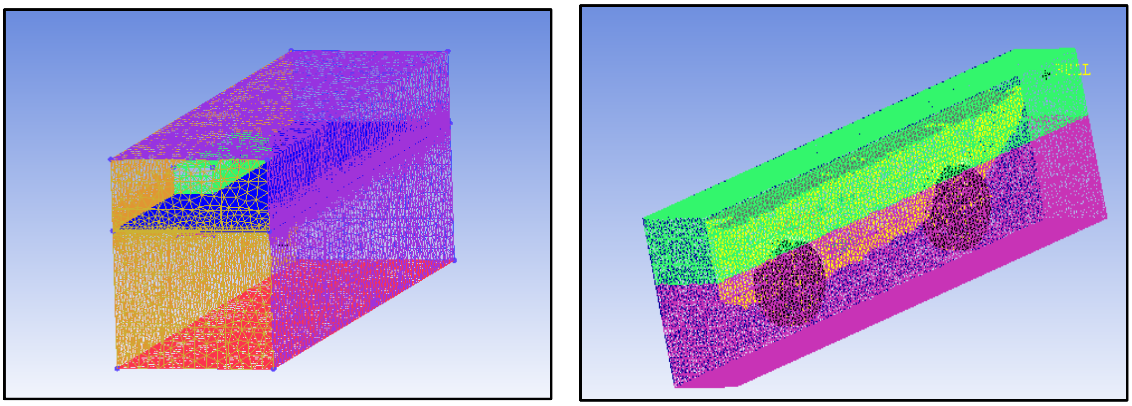


Figure 3. MAV mesh configuration

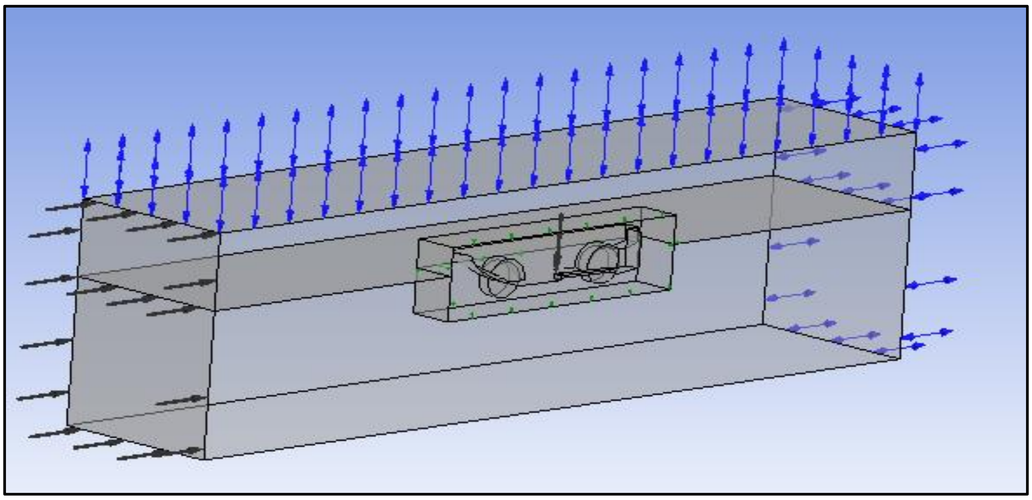


Figure 4. Overview of simulation set up

3. Results and discussion

Simulated result in wave water

The contour in Figure 5 and 6 represents the wave profile on the free surface from the sea bed at MAV speed 8kn in calm and wave condition. The highest values of wave displacement from in red and yellow colour represent the wave crest. Meanwhile, the green colours on the contour represent the wave trough. The CFD simulation is run based on Malaysia water wave height of 0.5m with period 6s in head wave condition. The wavelength is assumed as a shorter wave at 0.4Lpp.

In this study, MAV is considered two points (bow and stern) stationary in a straight line over the free surface, the speed of a ship is defined at the inlet boundary where it was sending out waves which combined to form a characteristic pattern.

On the other hand, Figure 7 illustrated the overview of air cushion effect on the MAV hull. The blue contour colour in Figure 7 denoted the air cushion effect, which helps to reduce the MAV resistance.

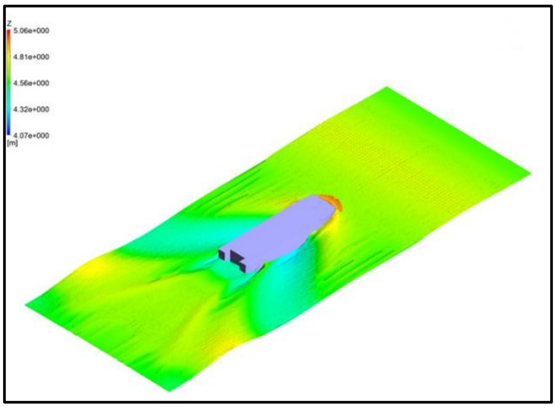


Figure 5. Wave profile at MAV speed 8kn in calm water

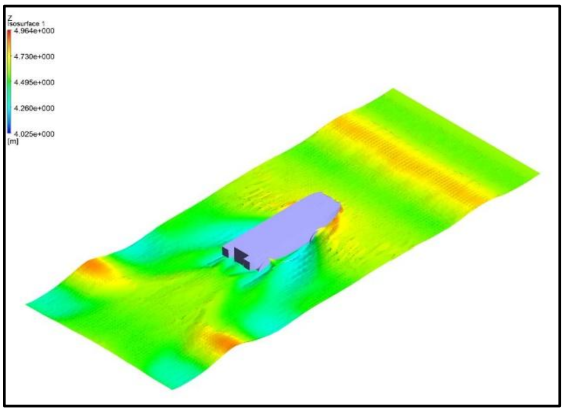
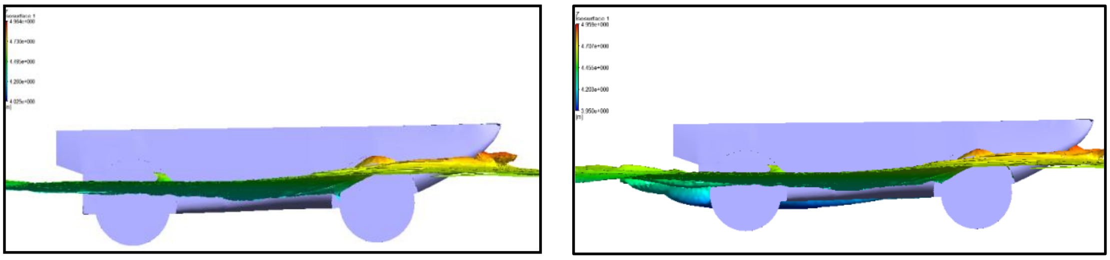


Figure 6. Wave profile at MAV speed 8kn in 0.5m wave height



(a) without air cushion effect (b) with aircushion effect

Figure 7. Overview of air cushion effect

The total resistance of the MAV model with and without the effect of air cushion increase because the speed is increased in Figure 8. This is because, at high speed, the induced water and waves are broken and guided to go underneath both sides of the hull resulted inan increase in MAV total resistance. Other than that, the plot of resistance in Figure 8 shows that there is also resistance reduction occur when the MAV with air cushion effect cruise in regular wave.

At wave height 0.5m, the highest resistance reduction percentage occurred at MAV speed 6kn, which is 10.89%. This is because, at a lower speed, the stream can expand the air cushion to the whole region of the boundary layer below the MAV hull and keep enough air to reduce the resistance. It is also noticeable that; the percentage of resistance reduction decreases as the wave height increase. It is due to the increment on ship motion displacement lead to escape of pressurize air below the hull to the surrounding.

However, the lowest resistance reduction, which is 0.03% occurs at MAV speed of 10kn. The reason behind this phenomenon is because, at high speed, the air cushion below the hull cannot stay in the boundary layer due to insufficient airflow rate injection. Then the air cushion is pushed out and mixed together with broken waves resulted in decrease in resistance reduction. This means that by raising the MAV speed, the airflow rate injection must be increased.

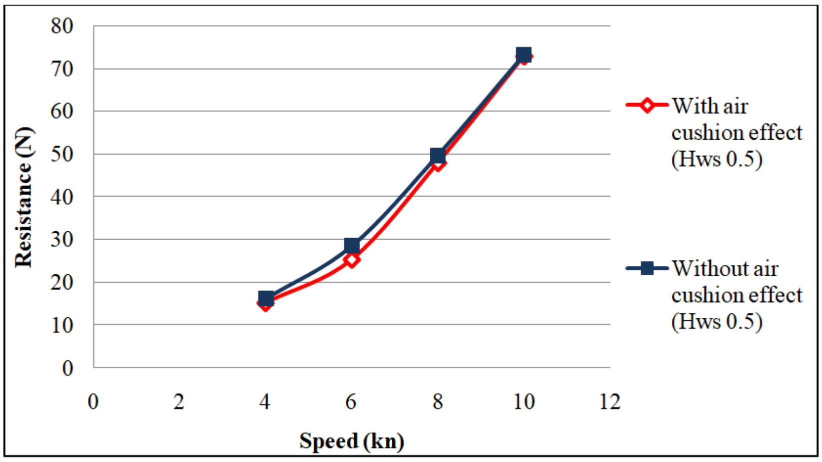


Figure 8. MAV resistance at wave height 0.5m

4. Conclusion

In this study, a numerical simulation based on the CFD method was used to analyze effect of air cushion on the resistance with the variation of forwarding speed. The same curve pattern has been recorded with and without air cushion effect for resistance test simulation. It can be clearly seen that the resistance is increased as the forward speed increased. In addition, the resistance acting on the MAV can be reduced in regular wave condition with air cushion effect.

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