Jurnal
Teknologi

Full paper

Air Lubrication Influence on Frictional Resistance Reduction of Multi-Purpose Amphibious Vehicle

M. Nakisa[a,c], A. Maimun[b*],Yasser M. Ahmed[a,d], F. Behrouzi[a], Jaswar[a], A. Tarmizi[a]

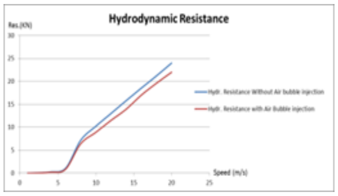
[a]*Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia*
[b]*Marine Technology Center, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia*
[c]*Faculty of Engineering, Islamic Azad University, Boushehr Branch, Boushehr, Iran*
[d]*Faculty of Engineering, Alexandria University, Alexandria, Egypt*

*Corresponding author: adi@fkm.utm.my

Article history

Received :25 December 2014
Received in revised form :
25 March 2015
Accepted :15 May 2015

Graphical abstract



Resistance graph of Multipurpose Amphibious Vehicle

Abstract

The presentarticle focuses on the hydrodynamic resistance reduction of Multipurpose Amphibious Vehicles (MAV) usingthe air lubrication layer effect. The use of air cushions to support marine vehicles, heavy floating structures and in other operation is well known. The main problem in Multi-purpose Amphibious Vehicles (MAV) is the amount of power needed in order to overcome the hydrodynamic resistance acting on the hull which is included the frictional and pressure resistances. Therefore, more power is needed to move the MAV forward. In this respect, more fuel will be required to operate the amphibious vehicles. This problem could be effectively reduced by the introduction of the air cushion concept. With the air being drawn from top of craft to the cavity below the hull will produce some cushioning effect and also help to reduce skin friction drag. In this paper, air cushion effect will be studied in rigid surface cavity instead of using flexible skirts. This would avoid the problem of high maintenance due to replacement of damaged skirts. Finally, the MAV will be supported using air cavity and bubbles generated by an air pump (compressor and air pressure vessel) to pushes the hull of multi-purpose amphibious vehicle up and reduce the frictional resistance due to draft and wetted surface reduction and layer of air between hull surface and water. This research would be done via CFD (ANSYS-CFX 14.0) and analyzed the hydrodynamic resistance.

Keywords: Air lubrication; hydrodynamic resistance; CFD; multi-purpose amphibious vehicle

■1.0 INTRODUCTION

The development of energy-saving ships has been greatly anticipated by the shipping industry as a countermeasure against the surging prices of raw materials, including oil, arising from the economic growth of developing countries, and environmental issues such CO2 emission regulations for international shipping operations. The air lubrication method, which reduces the resistance of the hull by using air bubbles, has been studied by a number of institutes because the method is expected to result in prominent energy-saving effects[1]. Performed tests using a flat-plate model ship with a total length of 50 m and confirmed that the total resistance working on the model ship and the local frictional force working on the ship bottom were reduced by bubbles. Verifications on actual ships have also been conducted and demonstrated an energy-saving effect of 5% in an actual ship test using a cement carrier[2].

Any amphibious vehicle design inherently involves optimization in hull form to increase the maneuverability and hull performance with fairing the flow structure around it, as competing requirements and design parameters force the design to evolve, and as designers strive to deliver the most effective and efficient platform possible within the constraints of time, budget, and performance requirements. A significant number of applications of computational fluid dynamics (CFD) tools to hydrodynamic optimization, mostly for reducing calm-water drag and wave patterns, demonstrate a growing interest in optimization. One difficulty with designing such new concepts is the lack of experience from which to draw from when performing design studies. Thus, optimization techniques may be particularly useful.

An air cushion multipurpose amphibious vehicle is a vehicle supported on a cushion of air which is generated by pumping the air bubble from hull surface, able to traverse of water with lowest hull surface friction. These are machines that slide along while balancing on top of an "air cushion" bubble. This bubble is generated by an air pump while the ship is going forward retain the bubble beneath the vessel by limiting the air loss. Since the friction against the bottom of the amphibious ship has been significantly reduced because of this cushion of air, less energy is required to move it across a surface[3].

The frictional resistance is the dominant resistance component for low-Froude-number ships. Pressure drag (i.e., form resistance) and wave resistance are frequently optimized using Computational Fluid Dynamics (CFD) but the total wetted surface remains a given. Reducing this frictional resistance by air lubrication is attractive. The power needed to compress air and inject it under the vessel should be less than the alleged power reduction due to the air lubrication[4].

For displacement ships, any reduction of the local skin friction leads to decreases of the resistance and commensurately fuel savings. As the Froude number increases and the wave resistance become progressively larger, the effect of air lubrication on the total resistance expectedly decreases. The injection of air requires constant pumping power and if the ship sails too slowly it represents a significant part of the propulsive power. Therefore air injection is expected to be suited for moderately fast ships with a target speed range of Froude numbers between 0.05 and 0.15[3].

Laboratory results of micro-bubble injection by Madavan *et al.* (1983) showed reductions of the frictional drag up to 80%. These micro-bubbles are very difficult to create on a ship scale. As the bubble increases in size, so does its tendency to deform in the shear and turbulent fluctuations of the flow and it is no longer a spherical micro-bubble. Bubbles are on a millimeter scale for current ship applications; the term micro-bubble is no longer applicable. As the term micro-bubble is used ambiguously, a distinction between (mini-)bubble drag reduction and micro-bubble drag reduction is required. At very low speeds, around 1 m/s, bubbles with a diameter of only a few Kolmogorov length scales of the flow can generate a 10% decrease in resistance at only 1 volume percent of air in the boundary layer[6,7].

At more realistic flow speeds of 5 to 15 m/s, this viscous length scale drops rapidly, enforcing a small bubble that is difficult to produce in large quantities. Sanders *et al.* (2006) used bubbles between 0.5 and 2.5 mm and reported up to a 40% decrease in resistance for air contents over 10% [9], using smaller bubbles between 0.03 and 0.5 mm, found a 20% drag reduction at an air content of 20%. No appreciable influence of bubble size was found here, but using bubbles from 0.3 to 1.3 mm scale, found that larger bubbles persisted downstream longer and were more effective at reducing the resistance[9]. As larger bubbles showed less dispersion this may have been an effect of concentration only [11].

Although air lubrication by mini-bubbles can show a decrease of frictional resistance for ships, the results are not always convincing.Pauzi, (2003) studied on catamaran operating at high speed in shallow water[12]. In order to gain more experience with air lubrication, a consortium of industrial companies and research institutes initiated the EU-funded project SMOOTH.

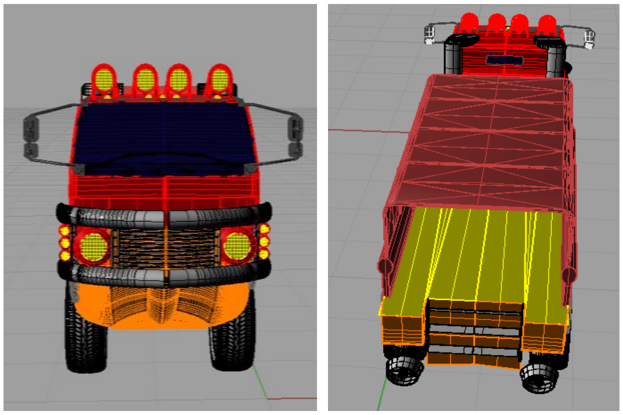
This research work focuses on air bubble lubrication and its effects on hydrodynamic resistance of Multi-purpose amphibious vehicle. This paper presents the results of the hydrodynamic resistance comparison of MAV with and without air bubble which is supported by air bubble injected from hull surface of the vehicle.

■2.0 SHIP SPECIFICATIONS AND FLOW CONDITIONS

The multi-purpose amphibious vehicle shape and its specifications are shown in Figures 1-2 and Table 1 respectively. The ship was a twin-screw vessel characterized by its wide breadth medium draft. The calculation results reported here are based on a full scale ship navigating in a straight line using double model approximation without considering waves on a free surface. The calculations were performed on the port side only based on the line of symmetry along the hull centerline.

All of the air bubbles were assumed to be of a uniform diameter and remain unchanged by the flow. No consideration was given to bonding of bubbles or division of a bubble into multiple bubbles. The bubble diameter for actual ships was assumed to be 2 to 3 mm.

Bubble outlets were created at three locations along the bottom of the hull, symmetrically on both sides of the centerline. The bubble outlets were created at two locations, one near the front and the other near the rear, because the calculations were performed on the port side only in this study. A velocity boundary was created at the bubble outlet; the air was blown at a constant flow rate to form the bubbles.



(a) Front view (b) Back view

Figure 1 Multi-purpose amphibious vehicle

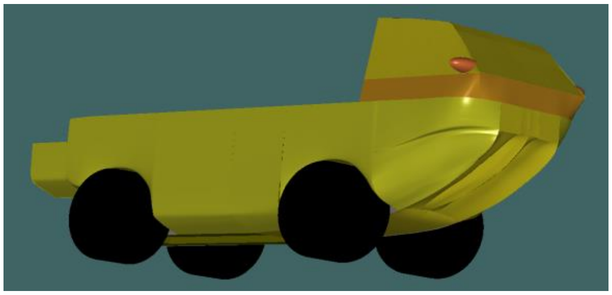


Figure 2 Simplified MAV model for using in simulation

Table 1 Specifications of MAV

Loading Condition	Actual size	Model Size	Unit
LWL	6.607	1.65175	m
Beam	2.024	0.506	m
Draft	0.99	0.2475	m
Displaced volume	5.314	0.08303	m^3
Wetted area	31.719	0.33212	m^2
Prismatic coeff.	0.559	0.559	---
Scale	----	1:4	---
Air density	0.001	0.001	t/m^3
Water Density	1.025	1.00	t/m^3

■3.0 MATHEMATICAL MODEL

Figure 3 shows the computational domain which is modeled and simulated in Ansys14.0 using Finite Volume Method (FVM).

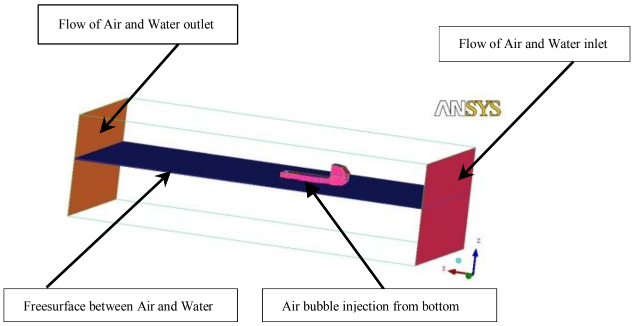


Figure 3 Multipurpose amphibious vehicle computational domain

■4.0 RESULTS AND DISCUSSION

Total calm water resistance against Froude number are shown in Figure 4. Considering to following resistance graph V-shape of hull bow with air bubble injection in the bottom has the lowest resistance in service speed which is 15 kt because in these high speeds the induced waters and waves are broken and guided to go underneath of the hull bow and both sides of hull. Frictional resistance in V-shape with air bubble of hull bow has more significant effect for decreasing the total resistance.

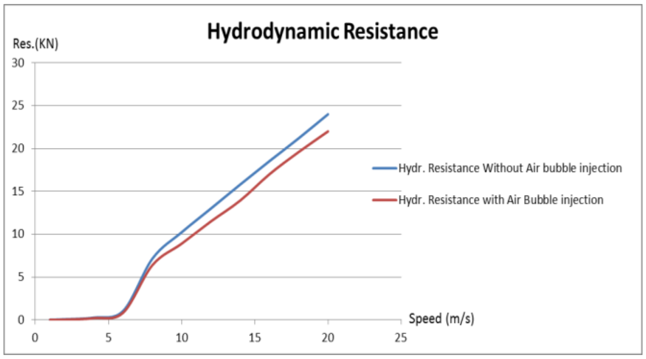


Figure 4 Total calm water resistance for V-hull bow shape

■5.0 CONCLUSION

The air bubble distribution on the hull surface of a multi-purpose amphibious vehicle was roughly predicted using a full-scale analysis. The results confirmed that the air bubble distribution on the ship bottom surface varied little in response to changes in the air bubble diameter. Comparison of the computational analysis results confirmed that the reduction resistance due to air bubbles has very significant because the air bubbles flowed along the ship bottom to make an air lubricant surface on the hull.

However, the resistance reduction mechanism of the air lubrication method have not yet been thoroughly examined, including the causes and effects of changes in fluid density and the turbulence modulation effects of air bubbles inside the boundary layer. CFD will play an important role in determining these causes by providing a detailed understanding of the physical phenomena.

Acknowledgment

The authors would like to express their sincere gratitude to MOHE–UTM- Vote No.7809.4F321 (UniversitiTeknologi Malaysia-UTM) and Marine Technology Center (MTC) for its supporting of this research project.

References

[1] Y. Kodama, A. Kakugawa, T. Takahashi, S. Nagaya, S., and K. Sugiyama. 2000. Experimental Study on Microbubbles and their Applicability to Ships for Skin Friction Reduction. *International Journal of Heat and Fluid Flow*. 21(5): 582.

[2] Y. Kodama, S. Nagaya, S., and K. Sugiyama. 2008 A Full-Scale Air Lubrication Experiment Using a Large Cement Carrier for Energy Saving (Result and Analysis). Conference Proceedings, the Japan Society of Naval Architects and Ocean Engineers. 6: 163.

[3] K. Fukada, J. Tokunaga, T. Nobunaga, T. Nakatani, and T. Isawaki. 2000. Frictional Drag Reduction with Air Lubricant Over a Super-Repellent Surface. *J. of Marine Sc. and Techn*. 5: 123–130.

[4] M. Harleman, R. Delfos, J. Westerweel, T. Terwisga. 2009. Characterizing 2-phase Boundary Layer Flow, Wall Turbulence Conference, Lille, France.

[5] N. K. Madavan, S. Deutsch, and C. L. Merkle. 1983. Reduction of Turbulent Skin Friction By Microbubbles. *Phys. Fluids*. 27: 356–363.

[6] Y. S. Park and J. H. Sung. 2005. Influence of Local Ultrasonic Forcing on a Turbulent Boundary Layer. *Exp. Fluids*. 39: 966–976.

[7] K. Jaswar, Siow, C. L., Maimun, A., Guedes Soares. 2014. Estimation of electrical-wave power in Merang shore, Terengganu, Malaysia. *Jurnal Teknologi (Sciences and Engineering)*. 66(2): 9–14.

[8] W. C. Sanders, E. S. Winkel, D. R. Dowling, M. Perlin and S. L. Ceccio. 2006. Bubble Friction Drag Reduction in a High-Reynolds-Number Flat-Plate Turbulent Boundary Layer. *J. Fluid Mech*. 552: 353–380.

[9] T. Kawamura, A. Fujiwara, T. Takahashi, H. Kato and Y. Kodama. 2004. The Effects of Bubble Size on the Bubble Dispersion and the Skin Friction Reduction. 5th Symp. Smart Control of Turbulence.

[10] J. C. MENG and J. S. ULHMAN. 1998. Microbubble Formation and Splitting in a Turbulent Boundary Layer for Turbulence Reduction. Intl. Symp. on Seawater Drag Reduction, Newport, RI, USA, ONR, Arlington, VA. 341–355.

[11] O.Watanabe and Y. Shirose. 1998. Measurements of Drag Reduction by Microbubbles Using Very Long Ship Models. *J. Soc. Naval Architects Japan*. 183: 53–60.

[12] Pauzi, M. Abdul G. 2003. Design Aspects of Catamarans Operating at High Speed in Shallow Water'. Ph.D. Thesis, University of Southampton.