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Numerical simulation of the air-water interface effects of an airboat

Samson Nitonye *, Tamunodukobipi Daniel and Douglas Ibiba

Department of Marine Engineering, Rivers State University, Port Harcourt, Nigeria.

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Abstract

This paper describes the Air-Water Interface (AWI) occurrence effects of the airboat at various speed, draught, and trim angle. This evaluates the dynamics of AWI with focus on the mechanisms involved in air displacement, the formation of air cushion, boundary layer turbulence, surface tension and wave generation. The analysis involves the change in speed, draught, and trim (0, 1, 1.5 and 2 degrees). The speed of 1.01 and 3.35m/s for displacement and planning regions of the airboat operation were examined. At the AWI, the thin layer of water molecules is affected by the airboat movement at the said trim, it is observed that the layer at the boundary will experience turbulence due to passing air over the layer and the interaction between the air and water at the interface causes mixing and creates waves or ripples at that trim. The wave generated at various trim angles will also create unique wave even at the same speed and draught with a change in trim. The difference in wave formation is seen not to be the same with the change in trim and these changes are observed at the bow and the aft of the vessel. This is also connected to the volume displacement of the boat, the resistance of the vessels, the angle of trim of the airboat and the hull form of the boat. This shows that displacement, resistance, angle of trim and hull form of the boat play critical and crucial roles in wave formation especially for the airboat.

Keywords: Airboat; ANSYS; Air-Water Interface; Wave; Trim; Draught

1. Introduction

Airboats have become essential utility vessels that operate in water and very difficult terrain like the swamps and shallow waterways fill with debris, where conventional craft cannot maneuver. The unique design of airboats allows them to navigate through areas that would be impossible for traditional boats to access. An airboat is a flat-bottomed watercraft that is characterized by a large propeller mounted at the back, above the waterline. This propeller draws air in from the surrounding environment and expels it forcefully through a nozzle, creating a high-speed jet of air that propels the boat forward. This design enables airboats to glide over shallow waters and even across areas covered in vegetation or debris. The primary purpose of airboats is to provide effective transportation in areas where conventional boats would struggle due to shallow water, dense vegetation, mud, and other obstacles. By utilizing the air propulsion system, airboats can operate in water as shallow as a few inches. Their unique design also takes away the risk of propeller damage from underwater obstacles, as the propeller is positioned above the waterline [1], [2], [3].

In recent times several software and computer Aided Design (CAD) have come into play with respect to the design and analysis of the operations of planning craft hulls. Abdullah et al. (2010) used PROLINE software for simulation to analyze and evaluate the transverse and longitudinal location of the vessel's Centre of gravity and displacement of the hull in an unloaded and loaded conditioned [4]. Carlos et al. (2013) used is the DELFTSHIP software to design the hull of the boat and CAD program used to generate the drawing of the prototype hull [5]. Srinivai et al. (2012) modeled their boat hull using PRO-4.0 and meshing was done using GAMBIT software [6]. This work will also walk in the light of the use of software and CAD and improve and analysis various systems of the airboat including the seakeeping and the motion

* Corresponding author: Samson Nitonye

response of the vessel. Several others have made significant progress in the study of various aspects of the planning vessel [7], [8], [9], [10], [11]. In the construction of the airboat hull, the stability of the vessel at sea must be taken into consideration. So, the hull stability analysis must be employed to evaluate and simulate the stability of the airboat which will determine the transverse and longitudinal location of the vessels Centre of gravity and displacement in loaded and unloaded conditions and to verify its intact stability. Furthermore, the Hydrostatics and hydrodynamics parameters, Wave and frictional drag, Curve of areas and the wetted lengths were considered by several authors [12], [13], [14], [15]

Several works have been done on the hydrodynamic analysis for a planning craft, but much work have not been done on the seakeeping analysis and motion response system of the airboat. The computation of the steady wave patterns generated by a planning hull moving at a constant forward speed is a matter of high interest for naval architects and marine and ocean engineers this is because it plays a vital role in the stability and safety of the boat [16], [17], [18], [19]. The wave patterns generated by a planning hull will affect the design parameters, such as propulsion system arrangements. The accuracy of the estimation of the wave wake in the vicinity of a planned hull is essential for the calculation of the pressure distribution under the bottom of the hull and then for the prediction of the hydrodynamics of the planned hull. At moderate speeds, planning hulls produce bow waves, which increase their drag but have little effect on lift. At high speeds, the hull is lifted out of the water and starts planning, so the wave-making drag is considerably reduced. At larger Froude numbers, the transverse waves tend to disappear, so, in the far field, where the Froude number is large, the wave pattern is dominated by divergent waves [20], [21], [22], [23].

The flat-bottomed airboat with the consideration that there are no operating parts below the waterline, permits the vessel to navigate easily through swampy waters, canals, and creeks. It can also be used to fight crime by law enforcement agencies, fishing, hydrographic surveys, tourism, and conservationism. The tapping of minerals and other resources found in shallow waters, swampy vegetation, creeks, or difficult terrain becomes easier through the effective operation of the airboat. So, the study of the Air-water interface occurrence effect becomes very critical. The aim of this work is to examine and improve the AWI of the flat bottom airboat operations.

A critical subject in the design and operation of high-speed crafts like the airboat must consider the AWI occurrence effect on the vessel as it affects the vessel performance, passengers' comfort and the vessel stability in general. This is because large motions and accelerations can degrade the operational capabilities of the craft. Planning craft hull in some cases exhibit an effect such as deck wetness, slamming and loss speed caused by the couple of heave and pitch motions. The vertical motions of high-speed craft have negative consequences that limit the speed. It is not only a matter of structural damage or safety risks, but this can contribute in a cumulative way to seasickness of the crew [24], [25], [26], [27].

The AWI plays a critical and crucial role in the operation and performance of the airboat, which will enable the unique ability to navigate shallow waters and challenging operation terrains. It evaluates the dynamics of AWI with focus on the mechanisms involving in air displacement, the formation of air cushion, boundary layer turbulence, surface tension and wave generation. This is the heartbeat of the fifth objective of this work, which will help us in understanding these phenomena and to gain insight into the fundamental principles that govern the functioning of the airboat and their efficient maneuverability across diverse aquatic environments. It will also help in the analysis of the springing effect and the panting effects of the airboat at critical operation under an extreme wave condition.

2. Materials and methods

The main purpose of this research is to considers the seakeeping and motion analysis of a hydrographic survey airboat (a planning craft) for survey in the Niger Delta area of Nigeria. The materials used for research are as follows

2.1. The Airboat Parameters

Table 1 Design Parameters for the Airboat

	Hydrostatics
Main Dimensions	
Length overall	7.11 m
Length Perpendicular	7.09 m
Breath	2.40 m
Depth	0.60 m
Weight	3.201 tonnes
Volume Displacement	3.405 m^3
Mass Displacement	3.50 tonnes
C_b	0.43
Draught	0.2

The model was built to be geometrically like the vessel hull and the scale ratio is 1:15. The material for the model hull is 2mm thick Aluminum sheet metal. The ITTC recommended procedure and guidelines are used. The principal dimensions of the model are as follows.

Length overall = 484 mm

Breadth = 200 mm

Draught = 64 mm

2.2. Motion Analysis

Basically, the strip theory was derived two equations for heave and pitch respectively. According to Newton's second law, at any instant all vertical forces on the ship are in dynamic equilibrium. Thus, the heaving and pitching equation can express as:

$$m\ddot{z} = \sum F \quad \ldots\ldots\ldots\ldots\ldots(1)$$

$$I\ddot{\theta} = \sum M \quad \ldots\ldots\ldots\ldots\ldots(2)$$

Solution of the motion equation with stern foil

In its simplest form, the RAO are different for the six, rigid-body degrees freedom of ship motions. Each motion has its own characteristics and RAO. RAO are derived from the amplitudes by dividing the motion response by the wave input parameter:

RAO= (Motion Response)/(Wave Input Parameters)………….(3)

The RAO for pitching and heaving are defined as below:

Pitching RAO= (Pitch Amplitude)/ (Wave Slope)……………(4)

$$= \theta_a/(k\,\zeta_a) \quad \ldots\ldots\ldots\ldots(5)$$

Heave RAO= (Heave Amplitude)/(Wave Amplitude)…………(6)

$$= z_a/\zeta_a \quad \ldots\ldots\ldots\ldots\ldots(7)$$

3. Results and discussion

Table 2 shows the results of the Resistance and Power results for airboat model from the towing tank experiment while Figures 1 and 2 show the Resistance and Power results for the Airboat respectively. Similarly,

Table 2 Resistance and Power results for airboat model from the towing tank experiment

Speed (Kn)	Speed (m/s)	Resistance (N)	Power (W)
7.5	1.01	0.90	0.909
10	1.34	1.94	2.60
12.5	1.68	3.04	5.11
15	2.01	3.49	7.01
17.5	2.35	4.62	10.86
20	2.68	5.82	15.60
22.5	3.02	5.83	17.61
25	3.35	5.84	19.56

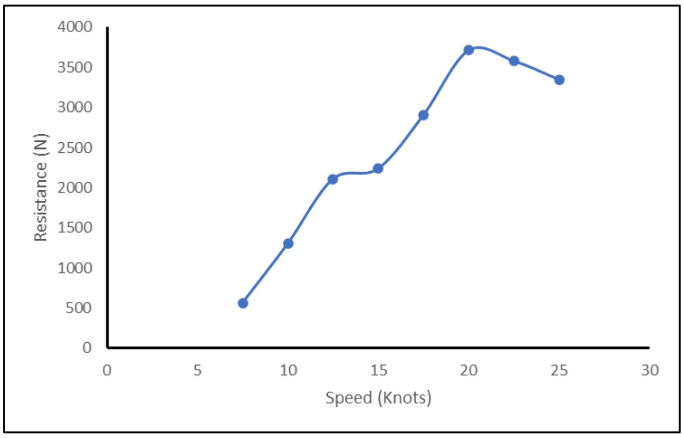

Figure 1 Resistance Result for the Airboat

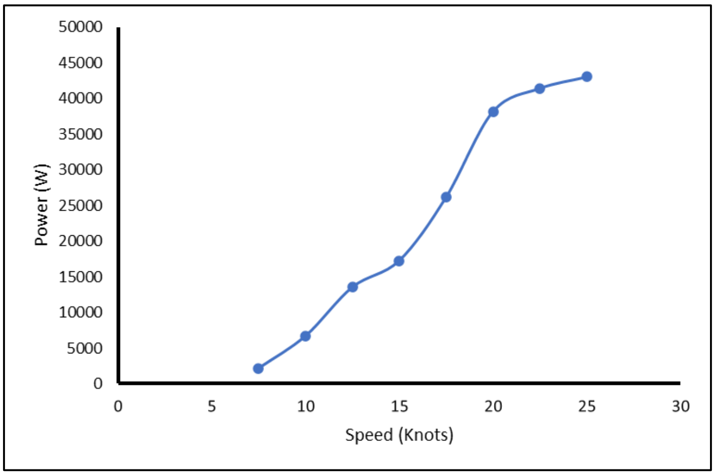

Figure 2 Power (P) versus Speed (Kn)

3.1. The Air-Water Interface simulation result for the airboat at 1.01m/s speed

Figure 3 to 5 shows the simulation result for the AWI simulation for design draught, ballast draught and mid draught respectively at the initial speed of 1.01m/s of the model airboat. The design draught is 0.020m while the ballast draught is 0.30m/s and the mid draught of the vessel is 0.25m/s.

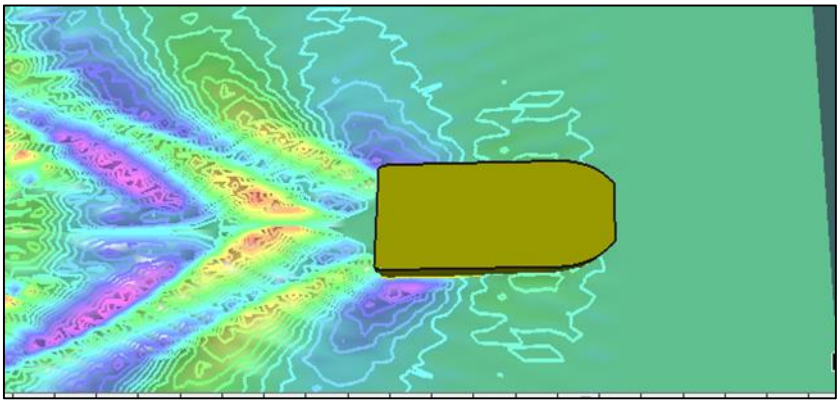

Figure 3 AWI at Design Draught

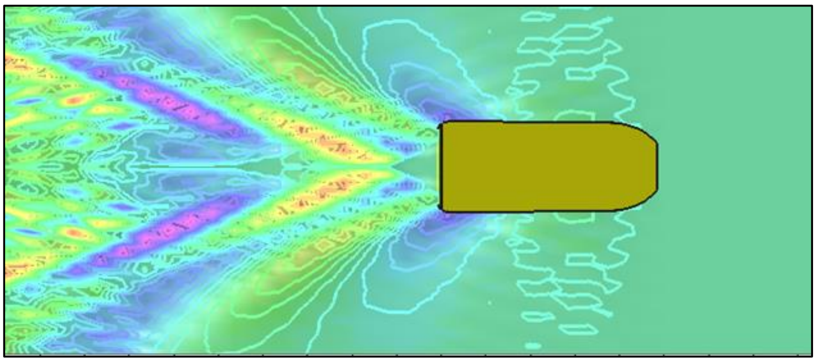

Figure 4 AWI at Ballast Draught

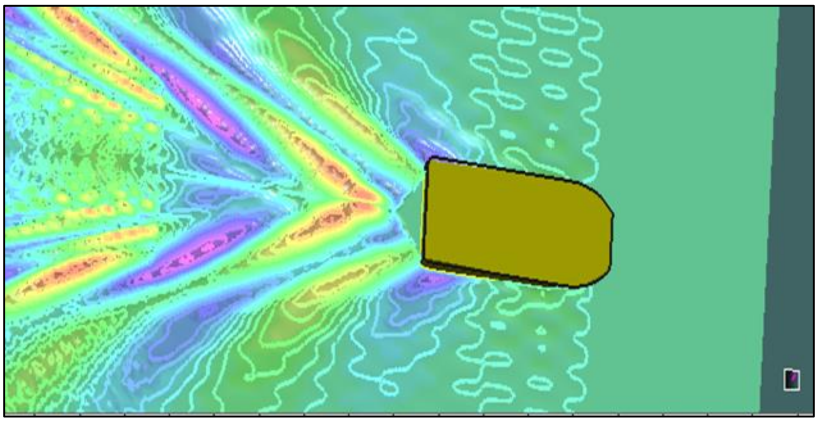

Figure 5 AWI at Mid Draught

The airboat AWI explains what happens at the boundary or contact point between the air and water surrounding the airboat and shows the unique interaction between the air and water at the interface when operating and maneuvering. At the speed under consideration, the airboat is operating like a displacement vessel and not as a planning craft. The large propeller of the airboat at the rear forcefully pushes air backward and displaces significant amount of air while in operation, this displaced air is directed downward towards the water surface which creates a high-pressure region below the airboat and forms a cushion of air between the boat's hull and the water. The cushion of air allows the vessel to move on top of the water, reducing the frictional drag that will occur between the boat and the water. At the AWI, a thin layer of water molecules is affected by the airboat movement, this layer experiences turbulence due to air passing over it and the interaction between the air and water at the interface causes mixing and creates waves or ripples as we see in the figure above. The wave generated is unique for every speed, trim and draught as we can see. For the speed of 1.01m/s at design draught the wave spread at the bow is limited when compared to the same speed at different draught

At the AWI, a thin layer of water molecules is affected by the airboat movement, this layer which is the boundary layer experiences turbulence due to air passing over it and the interaction between the air and water at the interface causes mixing and creates waves or ripples as we see in the figure above. The wave generated is unique even for the mid draught of the same speed. The difference in wave formation for the design, mid and ballast draughts can be seen at the bow and the rear part of the vessel. A careful observation at the bow it is observed that the wave spreads longer when compared to that of the design draught, this is connected to the volume displacement of the boat and the resistance of the vessels. This shows that displacement and resistance play a key role in wave formation especially for the planning craft vessels.

Further investigations were made on the dynamics of the airboat is how trim and other parameters could also affect the nature and pattern of wave generated. Figure 6 to 8 show the AWI at design draught with 1 degree, 1.5 degree and 2 degrees respectively at the speed of 1.01m/s. At the AWI, the thin layer of water molecules is affected by the airboat movement at the said trim, this layer which is the boundary layer will experience turbulence due to passing air over the layer and the interaction between the air and water at the interface causes mixing and creates waves or ripples at that trim. The wave generated at various trim angle will also create or generate unique wave even at the same speed and draught with a change in trim. The difference in wave formation is seen not to be the same with the change in trim as shown below and these changes are observed at the bow and the aft of the vessel. This is also connected to the volume displacement of the boat, the resistance of the vessels and the angle of trim of the airboat. This shows that displacement, resistance, and angle of trim play critical and crucial roles in wave formation especially for the planning craft vessels.

The airboat AWI for one-degree trim indicates that at the boundary between the air and water surrounding of the airboat shows the unique interaction between the air and water at the interface when operating and maneuvering. It is observed that the wave generated is reflective in nature when compared to the same vessel and speed without the trim. The trim gave a slight rise of the bow and reduced the turbulence at the bow which gave a circular wave pattern from the bow to the aft and regular cylindrical wave form behind the boat. So, the wave generated by the airboat is connected to the volume displacement of the boat, the resistance of the vessels and the angle of trim of the airboat. This shows that displacement, resistance, and trim angle will influence the wave generated especially for the planning craft vessels like the airboat.

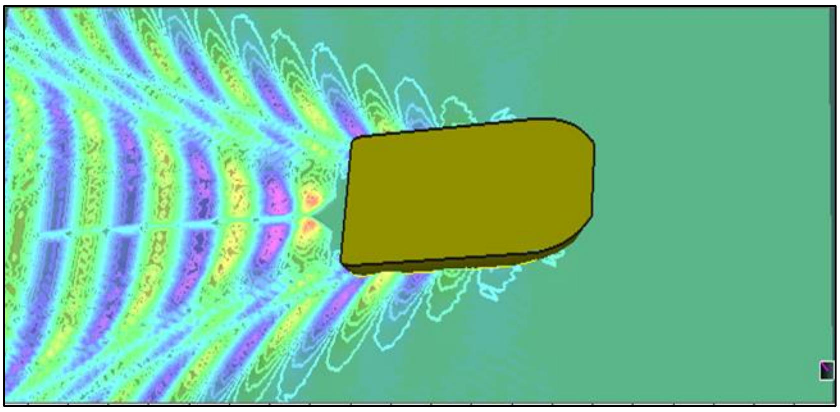

Figure 6 AWI at Design Draught @1degree Trim

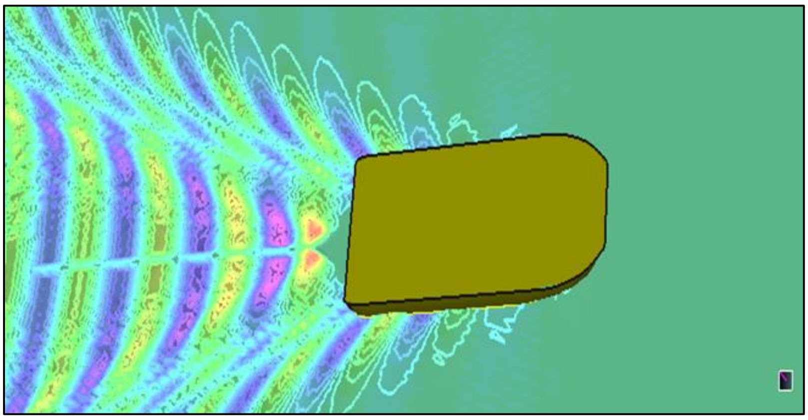

Figure 7 AWI @ design draught 1.5 degrees trim

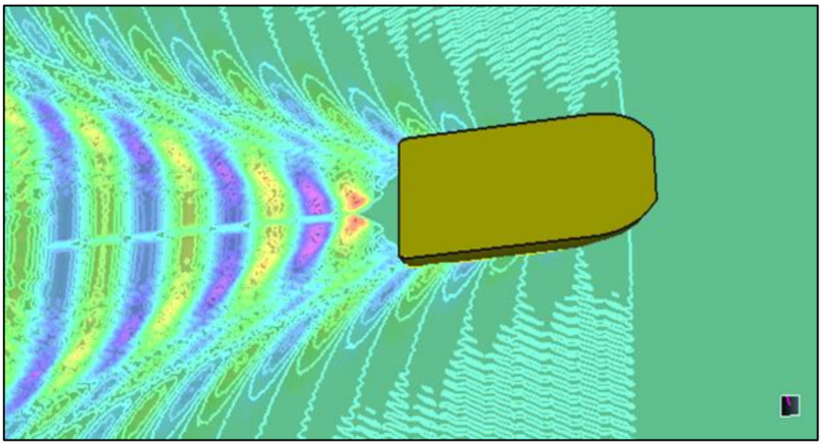

Figure 8 AWI at design draught @ 2 degrees trim

The airboat AWI for two-degrees trim indicates that at the boundary between the air and water surrounding of the airboat shows another unique presentation in the formation of the wave pattern different from the 1 and 1.5 degrees of trim. The interaction between the air and water at the interface when operating and maneuvering shows that the wave generated is reflective in nature and spreads feather away from the bow when compared to the same vessel and speed without the trim. The trim gave a slight rise of the bow and reduced the turbulence at the bow which gave a circular wave pattern from the bow to the aft and regular cylindrical wave form behind the boat. So, the wave generated by the airboat is connected to the volume displacement of the boat, the resistance of the vessels, the angle of trim of the airboat and the hull form of the vessel. This shows that displacement, resistance, trim angle, and the hull form will influence the wave generated especially for the planning craft vessels like the airboat.

3.2. The Air-Water Interface (AWI) simulation result for the airboat at speed of 3.35m/s

Figure 9 to 11 shows the simulation result for the AWI simulation for design draught, ballast draught and mid draught respectively at the speed of 3.35m/s of the model airboat. Figure 9 shows the aerial view of the AWI of the model vessel at the design draught of 0.020m at the speed of 3.35m/s.

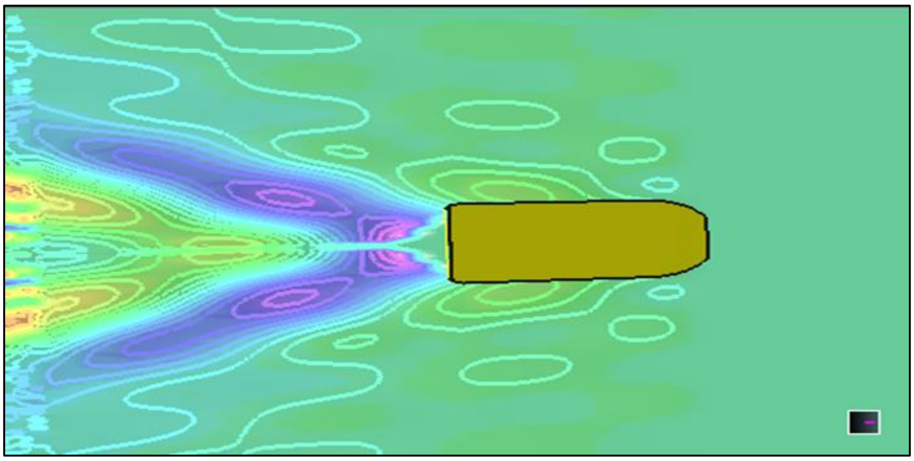

Figure 9 AWI at design draught

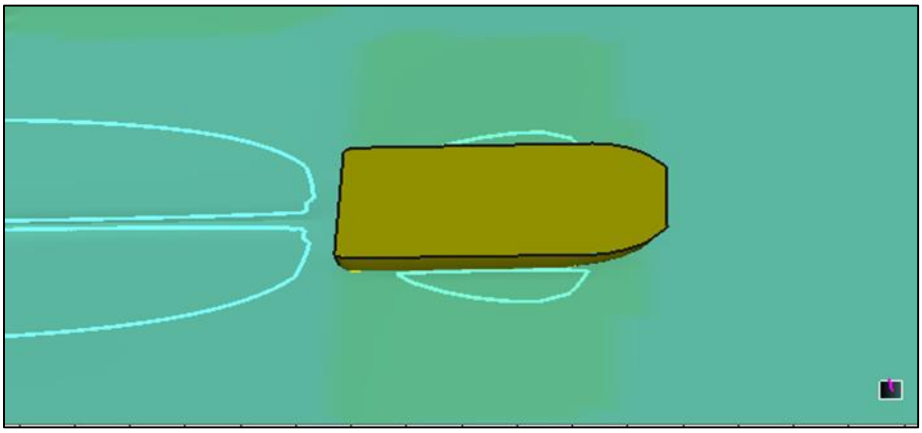

Figure 10 AWI at Ballast draught

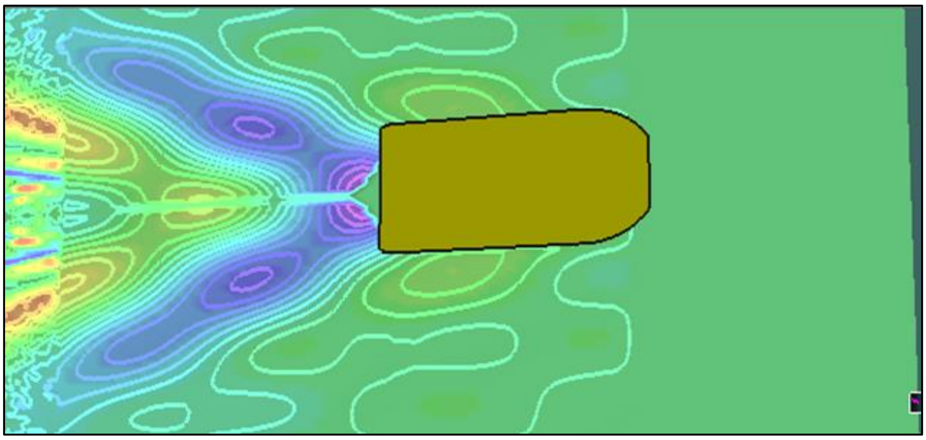

Figure 11 Air-Water Interface at mid draught

At the speed under consideration, the airboat is operating as a planning craft. The propeller of the airboat at the aft pushes the air backward and displaces significant amount of air while in operation at the maximum speed of the vessel, this displaced air that is directed downward towards the water surface creates a high-pressure region below the airboat and forms a cushion of air between the boat's hull and the water. It is observed that the cushion of air allows the airboat to move on top of the water, reducing the frictional drag between the boat and the water. It is also clear that the bow is wholly out of the water and the generated wave is seen at the aft of the vessel, no turbulence is seen at the bow during planing but a little spay of the wind and the water interaction. Furthermore, it is observed that the propeller blade directed at the water surface generated a considerable wave pattern behind the propeller.

Figure 12, 13 and 14 shows the aerial view of the AWI of the model vessel at the design draught of 0.020m, at the speed of 3.35m/s and trim angle of 1, 1.5 and 2 degrees respectively. The airboat AWI for one-degree trim indicates that at the boundary between the air and water surrounding of the airboat shows the unique interaction between the air and water at the interface during maneuvering. It is observed that the wave generated is reflective in nature more at the aft when compared to the same vessel and speed without the trim. The airboat at the planing stage has lifted the bow considerable from the water, so the trim gave a further rise of the one side of the bow than the other and reduced the turbulence drastically at the raised bow which gave little or no wave at the bow and regular cylindrical wave form behind the boat. So, the wave generated by the airboat is connected to the volume displacement of the boat, the resistance of the vessels, the angle of trim of the airboat and the speed of the boat.

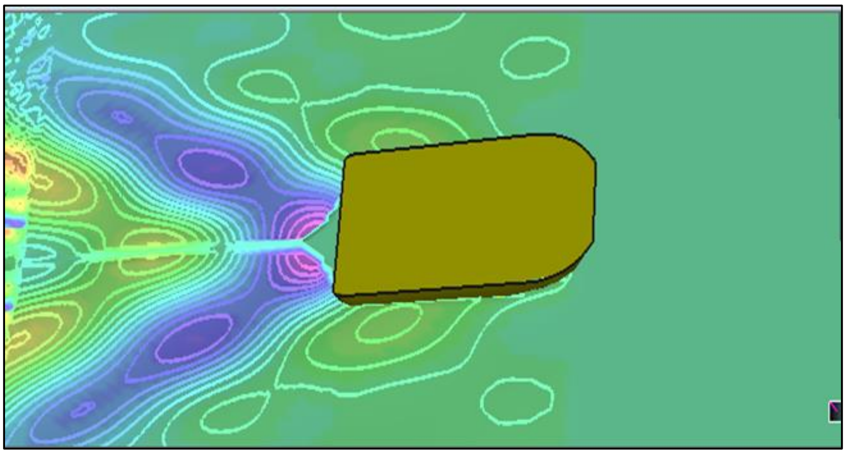

Figure 12 AWI at design draught @ 1degree trim

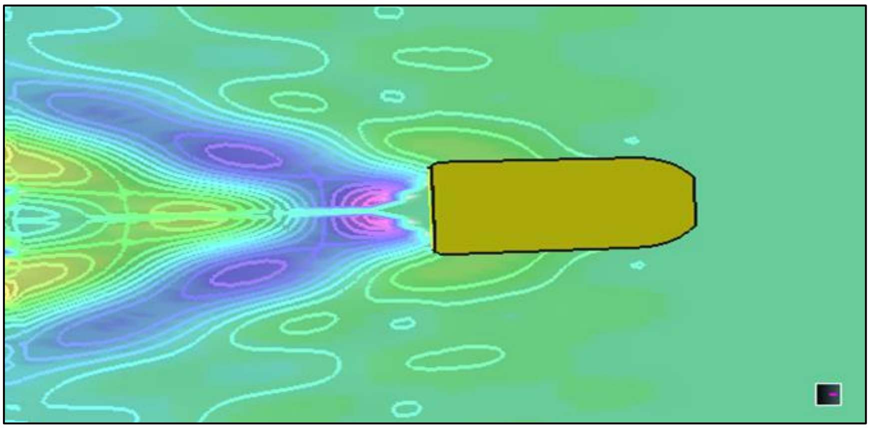

Figure 13 AWI at design draft @ 1.5 degrees trim

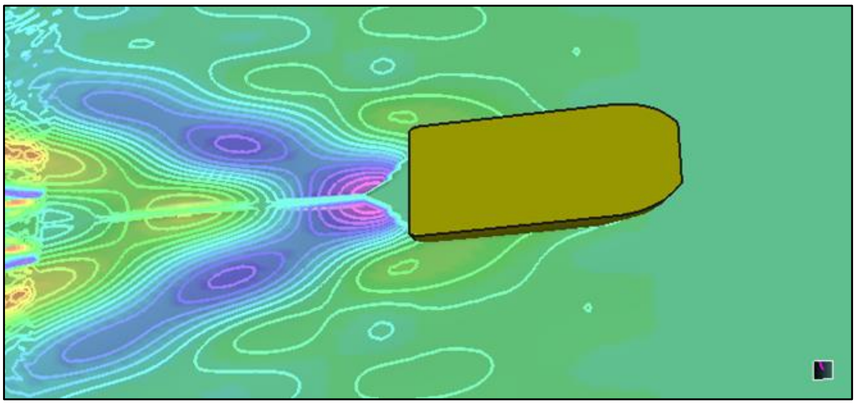

Figure 14 AWI at design draft @ 2 degrees trim

The airboat AWI for two-degrees trim indicates that at the boundary between the air and water surrounding of the airboat shows another unique presentation in the formation of the wave pattern different from the 1 and 1.5 degrees of trim. The interaction between the air and water at the interface when operating and maneuvering shows that the wave generated is reflective in nature and spreads feather away from the bow when compared to the same vessel and speed without the trim. The trim gave a slight rise of the bow and reduced the turbulence at the bow which gave a circular wave pattern from the bow to the aft and regular cylindrical wave form behind the boat. So, the wave generated by the airboat is connected to the volume displacement of the boat, the resistance of the vessels, the angle of trim of the airboat, the hull form of the vessel and the speed of the boat. This shows that displacement, resistance, trim angle, the hull form and the speed of the boat will influence the wave generated especially for the planning craft vessels like the airboat.

4. Conclusion

The numerical simulation of the AWI of the airboat plays a critical and crucial role in the operation and performance of the airboat, which will enable the unique ability to navigate shallow waters and challenging operation terrains which is obtained with good representation for the airboat under consideration. The simulation result of the ANSYS for the airboat help us to understanding and gain insight into the fundamental principles that govern the functioning of the airboat and their efficient maneuverability across diverse aquatic environments. The analysis involves change in speed, draught, trim, the AWI at design, mid and ballast draughts with zero, 1 degree, 1.5 degree and 2 degrees trim at the speed of 1.01m/s and 3.35m/s. The wave generated at various trim angle will also create or generate unique wave even at the same speed and draught with a change in trim. The difference in wave formation is seen not to be the same with the change in trim as shown below and these changes are observed at the bow and the aft of the vessel. This is also connected to the volume displacement of the boat, the resistance of the vessels, the angle of trim of the airboat and the hull form of the boat. This shows that displacement, resistance, angle of trim and hull form of the boat play critical and crucial roles in wave formation especially for the planning craft vessels.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] Daniel Tamunodukobipi, Ibelema Faango, Nitonye Samson, Ogbonnaya Ezenwa (2017), Design, Fabrication and Rotodynamic Performance Analysis of Airboat Propulsion System for application in Amphibious Planning Crafts. Nigerian Oil and Gas Industry Content (NOGIC) Research and Development Journal, Vol. 1, No1, 41-48. www.ncdmb.gov.ng

[2] Tamunodukobipi, D.T.; Ogbonnaya, E.A.; Koumako, K.E.E. (2009). Characteristic Behavior of High-Speed Craft at transition from Bow-wetting to full planning. Journal of Engineering and Applied Sciences 4(3) 189-196

[3] Daniel Tamunodukobipi, and Ibelema K. Faango (2017), "Hydrodynamic Characterization and Structural Design Analyses of an Airboat." American Journal of Mechanical Engineering, vol. 5, no. 5: 199-204. doi: 10.12691/ajme-5-5-2.

[4] Abdullah, M. N., Yek, P. N., Hanmdan, S., Junaidi, E. and Kuek, P. (2010). An airboat for riverine transportation and mangrove marine environment applications. International Journal of Research and Review in Applied Science IJRRAS, 2(3):211-222.

[5] Carlos Rivera-Solorio, Alejandro J.-Garcia-Cuellar and Abrud Flores (2013). Design and Construction of a Boat Powered by Solar Energy with the Aid of Computational Tools. International Journal of Engineering Education. 29(2):380-387.

[6] Srinivas A., Chandra Sekhar V. and Syed Altaf Huisain (2012). International Journal of Modern Engineering Research IJMER. (2(5):2975-2980. Online. Available from: www.ijmer.com. (Accessed: 1st June 2015)

[7] Hui Wang, Renchuan Zhu, Le Zha, Mengxiao Gu, (2022) Experimental and Numerical Investigation on the Resistance Characteristics of a High-Speed Planing Catamaran in Calm Water, Ocean Engineering

[8] Guan Guan, Lei Wang, Jiahong Geng, Zhengmao Zhuang, Qu Yang. (2021), Parametric automatic optimal Design of USV hull form with respect to wave resistance and seakeeping, Ocean Engineering

[9] Guan Guan, Qu Yang, Yunlong Wang, Shuai Zhou, and Zhengmao Zhuang. (2020), Parametric design and optimization of SWATH for reduced resistance based on evolutionary algorithm. Journal of Marine Science and Technology

[10] Guangsheng S., Hailong S., and Yumin S. (2020) Numerical Prediction of Hydrodynamic Performance of Planing Trimaran with a Wave-Piercing Bow, Journal. Marine. Science. Engineering, 8(11), 897; https://doi.org/10.3390/jmse8110897

[11] Emre K, Silvia P and Huseyin Y. (2021), Numerical Evaluation of Hydrodynamic Characteristics of Planing hulls by using a hybrid method. Proceedings of the Institution of Mechanical Engineers, Part M: Journal of Engineering for the Maritime Environment,

[12] Biran, A. B. (2003). Ship Hydrostatics and Stability. Burlington: Butterworth Heinehann.

[13] Nitonye, S. & Adumene S. (2014). Numerical and experimental analysis for the stability of a 2500 tonnes Offshore Work Boat. International Journal of Applied Science and Engineering, 3 (6), 1041-1053. (http://www.ijaser.com)

[14] Nitonye, S., Ogbonnaya, E. A., & Ejabefio, K. (2013). Stability analysis for the design of 5000-tonnes Offshore Work Barge. International Journal of Engineering and Technology, 3 (9), 849-857. (http://www.ijet.journal.org)

[15] Anders Rosén, Ermina Begovic, Mikael Razola, and Karl Garme (2017) High-speed craft dynamics in waves: challenges and opportunities related to the current safety philosophy, Proceedings of the 16th International Ship Stability Workshop, 5-7 June 2017, Belgrade, Serbia, https://kth.diva-portal.org/smash/get/diva2:1275215

[16] Anders R., Ermina B., Mikael R, and Karl G. (2017) High-Speed Craft Dynamics in Waves: Challenges and Opportunities related to the Current Safety Philosophy, Proceedings of the 16th International Ship Stability Workshop, 5-7 June 2017, Belgrade, Serbia, https://kth.diva-portal.org/smash/get/diva2:1275215

[17] Anders R, Karl G, Mikael R, Ermina B, (2020), Numerical Modelling of Structure Responses for High-Speed Planing Craft in Waves, Ocean Engineering, Volume 217, 1 https://doi.org/10.1016/j.oceaneng.2020.107897

[18] Naga V. R. N, Lokeswara R. P. and Anantha S. V. I. (2020), Simulation of Air–Water Interface Effects for High-Speed Planing Hull, Journal of Marine Science and Application 19:398–414, https://doi.org/10.1007/s11804-020-00172-0

[19] Sasan T, Rasual N B, Simone M, Fabio De L, Abbas D. (2020), Dynamic of a planing hull in regular waves, Comparison of experimental, numerical, and mathematical methods. Ocean Engineering

[20] Dong Jin Kim, Sun Young Kim, Young Jun You, Key Pyo Rhee, Seong Hwan Kim and Yeon Gyu Kim, (2013) Design of high-speed planing hulls for the improvement of resistance and seakeeping performance, International Journal of Naval Architecture and Ocean Engineering 5(1):161-177, DOI: 10.3744/JNAOE.2013.5.1.161, https://www.researchgate.net/publication/273688084

[21] Garme, K., Improved Time-Domain Simulation of Planning Hulls in Waves by Correction of the Near-Transom Lift, Submitted for publication, 2004

[22] Shuo Wang* , Yumin Su, Xi Zhang and Jinglei Yang (2012), RANSE Simulation of High-speed Planning Craft in Regular Waves, J. Marine Sci. Appl. 11: 447-452 DOI: 10.1007/s11804-012-1154-x, https://www.researchgate.net/publication/257760487

[23] Savitsky D, DeLorme M.F., Datla R., (2006), Inclusion of Whisker Spray Drag in Performance Prediction Method for High-Speed Planing Hulls, Technical Report SIT-DL-06-9-2845, Presented at Meeting of New York Metropolitan Section. The SNAME

[24] Savitsky, D and Koelbel, J.G. (1979) Sea-keeping Considerations in the Design and Operation Hard Chine of Planing Hulls," Marine Technology, 32(3). Pp 115-127

[25] Xiaosheng Bi, Jiayuan Zhuang, Yumin Su. (2020), Seakeeping Analysis of Planing craft under large wave height, Water

[26] Xiaosheng Bi, Hailong Shen, Jin Zhuo, Yumin Su. Numerical Analysis of the Influence of fixed hydrofoil installation position on Seakeeping of the Planing craft, Applied Ocean Research Water 2019

[27] Faltinsen, O. M., Holden, K. O., Minsaas, K. J., (1991), Speed loss and operational limits of high-speed marine vehicles, In Proc. IMAS'91 – High Speed Marine Transportation, pp. 13–21, London: The Institute of Marine Engineers.