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INVESTIGATION OF BUOYANCY FORCE AND LIFT OF NACA SERIES HYDROFOIL FOR WATER TURBINE

Azri Hamim Ab. Adzis [1], Mohd Azamuddin Mokhlis [2]

[1,2] Senior Lecturer, Mechanical Engineering Section, Universiti Kuala Lumpur Malaysia France Institute Section 14, Jalan Teras Jernang, 43650 Bandar Baru Bangi, Selangor, Malaysia

Email: [1] azri@unikl.edu.my, [2] mazamuddin.mokhlis@s.unikl.edu.my

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ABSTRACT

Hydropower is an economically viable source of renewable energy. The water turbine is one of the methods to generate hydropower. Hydrofoil creates lift force as when water flows through the hydrofoil it will exert an upward force on the foil. Lift force generates the kinetic energy of the water turbine and the kinetic energy is transformed into mechanical energy. This project focused on the investigation of buoyancy force and lift of NACA series hydrofoil for water turbine applications. The main problem of normal hydrofoils is when it approached the water surface the lift and drag force reduced and the velocity at which cavitation first emerged on the hydrofoil increased. Thus, this project simulated the lift and buoyancy force to generate by NACA series hydrofoils. The first objective of this project is to stimulate the value buoyancy and lift force during flow over typical NACA hydrofoils for water turbine applications. Next, this project compared the lift force produced by the NACA series hydrofoils water turbine applications. And lastly, the problems or causes that affected the lift force generated by the NACA series hydrofoils were determined. This project shows the improvement bring by NACA series hydrofoils to the value of buoyancy and lift force. This project focused on the simulation method using the software. NACA 0012 is the best NACA series hydrofoil for water turbine applications. The results were validated before being able to use them.

1. Introduction

Water turbine works when water flows through the blades of the turbine, creating force on the blades. The mechanical power generated from the rotating turbine shaft depends on the water volume and water pressure in the turbine blades. The water turbine blades shape is an important parameter for the water supply pressure and the type of impeller selected. Hydrofoils are the main part of the water turbine component. Hydrofoils must be correctly designed to improve the turbine performance and provide sufficient strength to the blade structure [1]. To rotate and gain the optimum energy from the water, the turbine blades are used to generate a lift force. The edges of the blades are round to reduce the drag force and produce a positive lift force. The hydrodynamic performance of hydrofoils functions differently on the rotating turbine. Once the rotor is in motion, the blade section starts enduring a relative component of tidal current velocity depending on blade parameters at variable angles of attack. A different force is also acting on the hydrofoil section.

NACA series hydrofoils are developed by the National Advisory Committee for Aeronautics (NACA). The shape of the NACA hydrofoils is described using a series of digits. NACA series hydrofoils have been discovered to be subjected to a high camber and high lift coefficient. NACA series hydrofoils have uniform pressure distribution because of its rounded edges and aerodynamics shapes [2]. The hydrofoil is described by the NACA numbers. The first digit describing the maximum camber as a percentage of the chord. The second digit describing the total camber length from the leading edge of the hydrofoil in tens of chord percentages. Last two digits describing the maximum hydrofoil thickness as a percentage of the chord.

The usage of mesh convergence in finite element stress analysis is necessary, and second if they converged to an acceptable level of accuracy. It must be ensured to obtain consistent results using the finite element method a suitable mesh for the shape and size of the elements is used [3]. To analyse the efficiency of hydrofoils, their lifting and drag coefficient must be compared. Angle attack is directly proportional to the lift force. As the angle of attack increases, the separation of water flow and pressure is more uniform thus it will increase the lift force generated by the hydrofoil blade for water turbine application [4].

2. Methodology

A. NACA Series hydrofoil

The NACA series hydrofoil that were used in this simulation are NACA 0012, NACA 23-018, NACA 63-215, NACA 63-424, and NACA 63-618. The first step is to set up the hydrofoil in the framework of Solidworks. Importing a curve created from a hydrofoil profile plot accomplished the first step. To import this data, Solidworks needs to be an XYZ data set. The data were obtained from the hydrofoil database. All hydrofoil model were generated from the Solidworks as shown inFig. 1

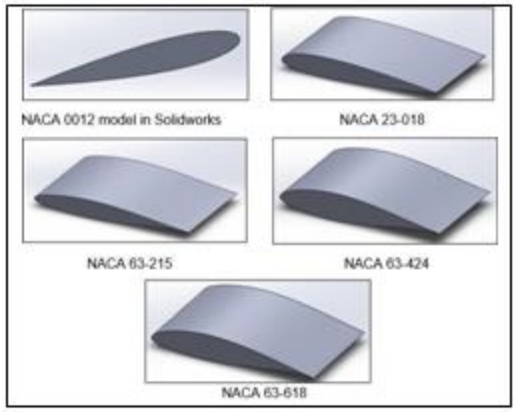

Figure 1: *NACA series hydrofoils*

B. Meshing

After the blade was designed, the model was saved in iges format and was imported into the ANSYS workbench. Ansys Fluid Flow (Fluent) was used to carry out this simulation.

Firstly, an enclosure box that covers the hydrofoil was created. The box acted as the surrounding water flow channel. The boolean effect was applied to both hydrofoil and the surrounding flow channel as shown in Fig. 2.

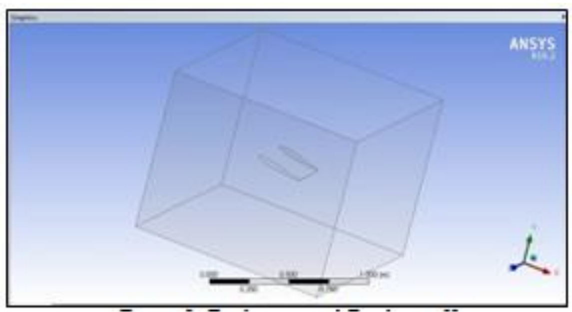

Figure 2: *Enclosure and Boolean effect*

After the geometry part has been done, the geometry has meshed. First, the direction of inlet velocity and outlet pressure was set. Next, the sizing of the mesh that we want to be was set. In this project, four mesh sizes were used from 0.1m to 0.13 m. After that, the meshing was generated as shown in Fig. 3.

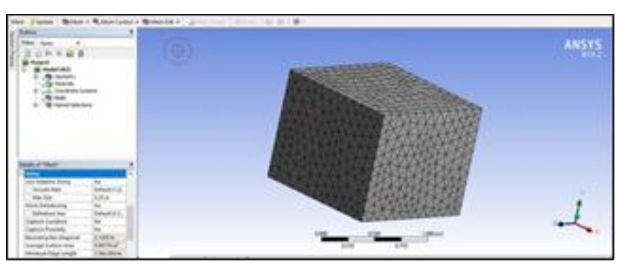

Figure 3: *Meshing*

C. Lift Force Simulation

To test the hydrofoil, some parameters were being set. First, the flow setting was set by choosing k epsilon viscous laminar flow. Then, water was chosen as the fluid material for the simulation. Next, the cell zone and boundary

condition were set. To keep our convergence tight, we start with some pressures and velocity. Then force in the x and y directions were used as well. Then, it was used to establish our lift and drag targets coefficient.
The value density of the fluid, the velocity, the normal and parallel force of the fluid flow, and the hydrofoil profile area were set. This allows us to describe the direction of flow with the angle of attack on the hydrofoil. Next, other parameters had been set such as pressure and temperature. After that, a report on lift force was generated by considering the wall of the surrounding flow channel as the wall zones. The number of iterations for the simulation was set and after all the data has been collected, the results were plotted and compared to theoretical values to validate the data.

3. Resulta And Discussion

A. Data analysis on the lift force and mesh convergence

When the hydrofoil produces lift, it will produce induced drag too. The value of drag will affect the value of the lift force. It is used in the drag equation where a lower drag coefficient means that there would be a less hydrodynamic drag on the object. The lift coefficient relates the lift produced by a lifting body to the fluid density around the body, the fluid velocity, and a reference area connected to it. So, a high lift coefficient will increase lift while a high drag coefficient causes a high drag force. Drag coefficient values are the lowest the lift coefficient can reach the maximum value [5].

TABLE 1: *Naca 0012 At Angle Of Attack 16 Degrees*

Mesh size (m)	NACA 0012			
	Lift(n)	Drag(n)	Cl	Cd
0.1	19 905	18 158	32397.16	90606.81
0.11	21 852	17 881	35561.78	84417.78
0.12	21 858	17 492	35557.8	75709.87
0.13	22 516	17 860	36638.35	78004.98

Table 1 showed that the lift increase from smaller mesh size to bigger mesh size. However, mesh size is not the factor of increasing lift force. For mesh size 0.13m, the lift force generated is the highest because the lift coefficient is the highest from other mesh sizes. At mesh size 0.12m, the value of drag is the lowest however the lift coefficient value is not high enough than others thus the lift force value is not too high.

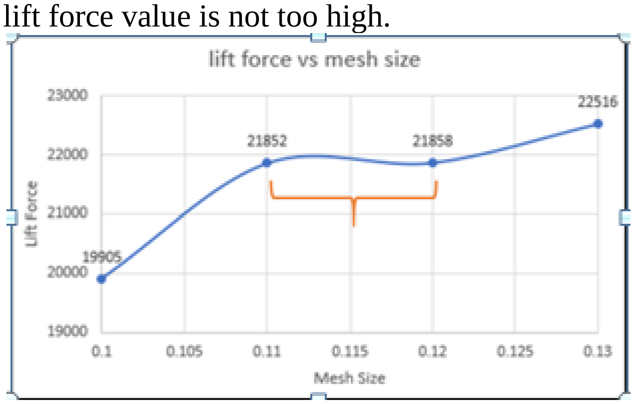

Figure 4. *NACA 0012 Lift Force vs Mesh Size graph*

Fig. 4shows that the mesh size equal to 0.11 and 0.12 the lift force value is nearly converged. Thus, the most accurate lift force for NACA 0012 is 21855 N. Mesh convergence is the best way to determine the best mesh that can be used to get the most accurate results [6].

TABLE 2: *Naca 23-018 At Angle Of Attack 16 Degrees*

Mesh size (m)	NACA 23-018			
	Lift(n)	Drag(n)	Cl	Cd
0.1	2596.41	9448.685	4220.557	77484.67
0.11	3264.697	9396.948	5307.204	67408.34
0.12	3354.78	9492.941	5464.723	73454.82
0.13	1595.333	9538.14	2583.74	85893.2

From table 2, at 0.12m mesh size, the lift force generated is the highest compared to 0.11m mesh size although it has a higher drag force because it has a higher lift coefficient. At 0.13m mesh size, the lift force produced is the lowest as it has the highest drag force and lowest lift coefficient.

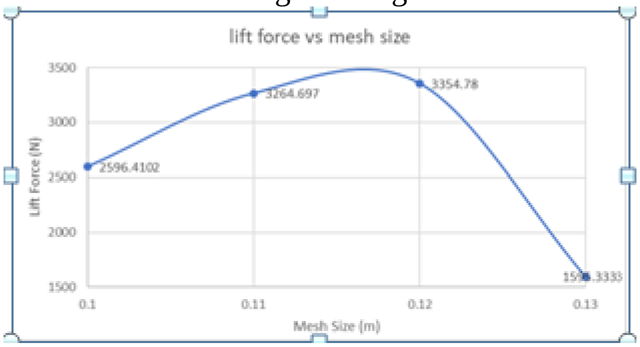

Figure 5: *NACA 23-018 Lift force vs Mesh Size*

From Fig. 5, at mesh size 0.11m and 0.12m the lift force value is nearly converged. Therefore, the most precise lift force for NACA 23-018 is 3309.74 N. Mesh convergence is necessary to get a consistent and precise result [3].

TABLE 3: *NACA 63-215 AT ANGLE OF ATTACK 16 DEGREES*

Mesh size (m)	NACA 63-215			
	Lift(n)	Drag(n)	Cl	Cd
0.1	6133.47	5504.62	10020.77	61486.65
0.11	5804.74	5722.84	9474.131	80722.97
0.12	4759.85	5452.30	7761.109	68980.81
0.13	5959.76	5646.60	9725.923	60450.71

Table 3 shows that at mesh size 0.1 m, the lift force generated is the highest as the lifting coefficients also higher than other mesh sizes. Drag coefficient recorded from mesh size 0.1 m is also among the lowest thus it can generate a higher lift force than other mesh sizes.

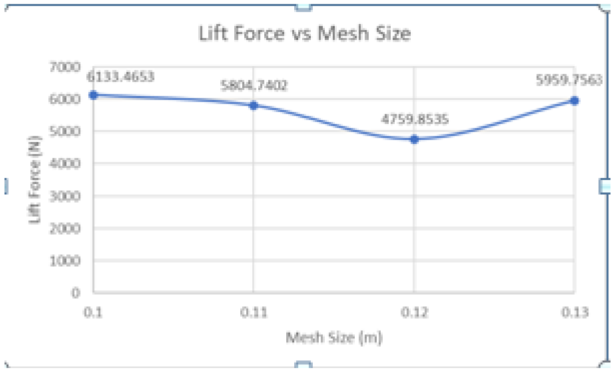

Figure 6: *NACA 63-215 Lift force vs Mesh Size*

In the Fig. 6, we can see the lift force value almost converges at all mesh sizes except at 0.12 m mesh size. The most accurate value of the lift force for NACA 63-215 is 5969.10 N.

TABLE 4: *NACA 63-424 AT ANGLE OF ATTACK 16 DEGREES*

Mesh size (m)	NACA 63-424			
	Lift(n)	Drag(n)	Cl	Cd
0.1	12779.47	14284.36	0.002559	0.011358
0.11	13692.3	14295.49	0.002742	0.011213
0.12	13680.49	14067.25	0.002739	0.009617
0.13	14343.41	14338.54	0.002873	0.010483

From table 4, 0.1 m mesh size recorded the lowest value of lift force as it has the lowest values of lift coefficient and the highest value of the drag coefficient. Although 0.12 m mesh size has a lower drag coefficient than 0.11 m, the lift force generated at 0.11m is higher because it has a higher lift coefficient than at 0.12m.

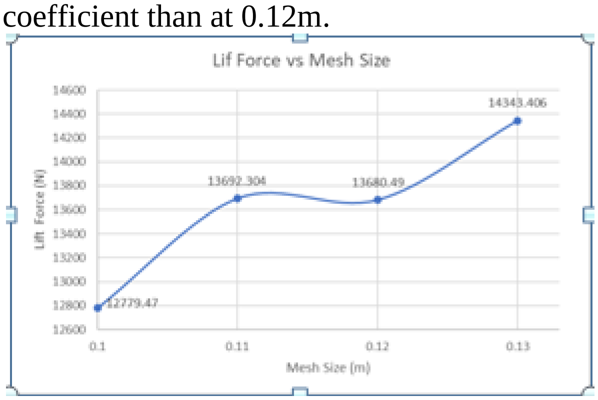

Figure 7: *NACA 63-424 Lift force vs Mesh Size*

Fig. 7 shows that the lift force value generated at all mesh sizes are not too far from each other. However, at 0.11m and 0.12 m the lift force value is nearly converged. Thus, the most accurate lift force value for NACA 63-424 is 13686.40 N.

TABLE 5: *Naca 63-618 At Angle Of Attack 16 Degrees*

Mesh size (m)	NACA 63-618			
	Lift(n)	Drag(n)	Cl	Cd
0.1	18334.36	14519.2	29911.16	82104.82
0.11	20711.26	14595.29	30149.76	81109.62
0.12	19184.15	14903.38	30024.13	81306.17
0.13	17951.93	14642.71	29285.72	88604.23

From table 5, the lift coefficient at 0.11 m mesh size is the highest and the drag coefficient is the lowest, so the lift force generated is higher than other mesh sizes.

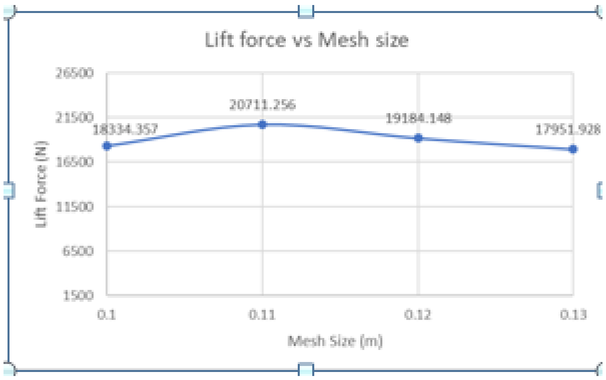

Figure 8: *NACA 63-618 Lift force vs MeshSize*

As shown in fig. 8, the value of lift force for NACA 63-618 for all mesh sizes is quite a difference. The least difference and nearly converge occur between 0.12 m and 0.13 m mesh size. Thus, the best value of the lift force for NACA 63-618 is 18568.04 N.

TABLE 6: *Naca 0012 With An Angle Of Attack 18 Degree*

Mesh size (m)	NACA 0012			
	Lift(n)	Drag(n)	Cl	Cd
0.1	21259.43	17984.84	34604.11	90882.34
0.11	21985.23	18006.65	35781.36	87336.95
0.12	23758.03	18552.24	38643.72	75727.77
0.13	22701.93	18345.49	36925.93	79245.31

Table 6 shows that at 0.1 m mesh size, the value of the lift coefficient generated during the simulation is the lowest.Thus, the lift force generated is also the lowest as the drag coefficient is the highest among all mesh sizes.

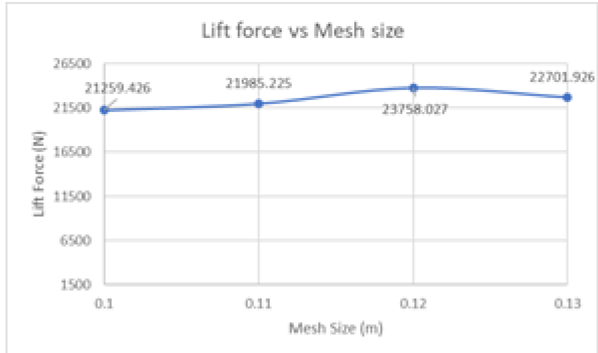

Figure 9: *NACA 0012 Lift force vs Mesh Size*

As shown in the Fig. 9, between mesh sizes of 0.1 m and 0.11 m, the value of lift force is nearly converged. So, the most precise value of lift force for NACA 0012 at angle attack 18 is 21622.33 N.

TABLE 7: *Naca 23-018 With An Angle Of Attack 18 Degree*

Mesh size (m)	NACA 23-018			
	Lift(n)	Drag(n)	Cl	Cd
0.1	3338.149	9899.161	5417.915	88765.91
0.11	3649.603	9661.998	5920.992	80684.22
0.12	3756.954	9729.211	6038.071	78864.45
0.13	2647.097	9495.098	4321.341	77222.57

Comparing the value of the drag coefficient at 0.1 m and 0.13 m mesh size in table 7, 0.1 m has a higher value of the drag coefficient. However, the value of the lift force generated at 0.1 m is higher because the value of the lift coefficient produced at 0.1 m mesh size is slightly higher than at 0.13 m mesh size.

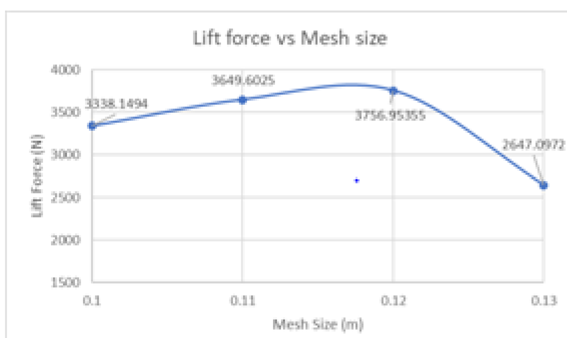

Figure 10: *NACA 23-018 Lift force vs Mesh Size*

Fig. 10 shows that the value of the lift force at 0.13 mesh size has high differences compared to other mesh sizes. So, the mesh convergence occurs between 0.11 m and 0.12 m mesh size. Thus, the most accurate value of the lift force for NACA 23-018 is 3703.28 N.

TABLE 8: *Naca 63-215 With An Angle Of Attack 18 Results*

Mesh size (m)	NACA 63-215			
	Lift (N)	Drag (N)	Cl	Cd
0.1	6817.587	5705.196	11134.07	78660.86
0.11	6126.785	5682.186	10011.01	65517.75
0.12	5591.643	5666.847	9135.379	72075.09
0.13	6306.213	5647.889	10283.51	64245.87

From Table 8, the highest drag coefficient generated is at 0.1 m mesh size but the value of lift force generated is also the highest because of the high value of the lift coefficient.

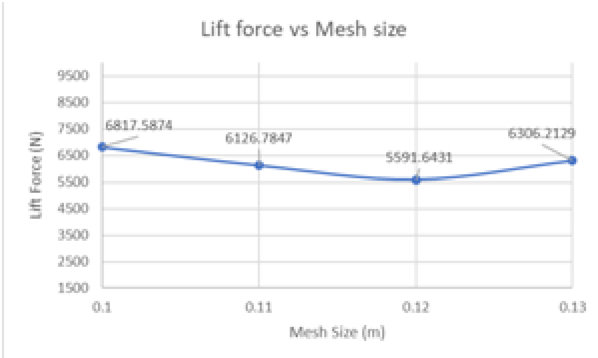

Figure 11: *NACA 63-215 Lift force vs Mesh Size*

In the Fig. 11, the value of the lift force NACA 63-215 at all mesh sizes isnearly converged. However, between 0.11 m and 0.12 m mesh size is the slightest difference than others. Thus, mesh convergence occurs between the two sizes. The most precise value of lift force for NACA 63-215 is 5859.21 N.

TABLE 9: *Naca 63-424 With An Angle Of Attack 18 Degree*

Mesh size (m)	NACA 63-424			
	Lift (N)	Drag (N)	Cl	Cd
0.1	13283.15	14048.92	21697.97	95946.81
0.11	15089.36	14191.86	24612.77	88811.13
0.12	14513.21	14044.11	23696.34	87746.66
0.13	15312.18	14187.56	24995.75	86618.23

The table 9 shows that at 0.11 m the drag force generated is higher than at 0.1 m and 0.12 m but the lift force is higher than the two mesh sizes. This is because at 0.11 m the lift coefficient is higher than the other two mesh sizes. If the lift coefficient is high and towards the maximum value, the force, power, and energy can be increased [7].

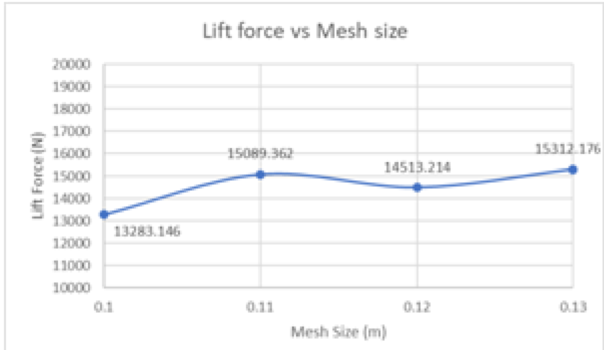

Figure 12: *NACA 63-424 Lift force vs Mesh Size*

From the Fig. 12, at 0.11 m and 0.12 mesh sizes, the value of the lift force is nearly converged. Thus, the most accurate value of the lift force for NACA 63-424 is 14801.29 N.

TABLE 10: *Naca 63-618 With Angle Of Attack 18 Degree*

Mesh size (m)	NACA 63-618			
	Lift (N)	Drag (N)	Cl	Cd
0.1	19468.46	14708.17	32901.27	80156.34
0.11	21581.64	14761.91	35207.7	80350.77
0.12	19850.67	14607.79	33615.64	78953.39
0.13	18400.07	14705.79	30018.03	76750.08

As can be seen in the table 10, at 0.13 m the value of the lift force generated is the lowest although the value of the drag coefficient is the lowest. However, the lift coefficient is also the lowest, so the lift force generated is not high.

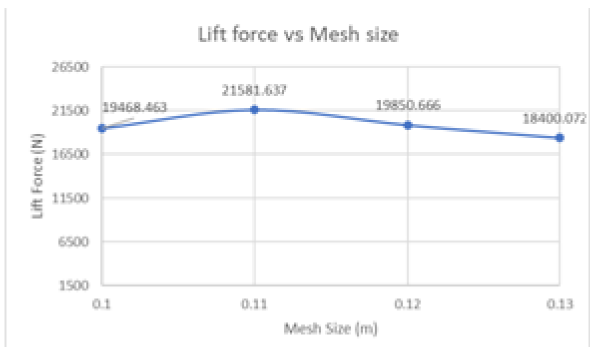

Figure 13: *NACA 63-618 Lift force vs Mesh Size*

From Fig.13, the value of the lift force for all mesh sizes are consistent. However, the value between 0.12 m and 0.13 m has the slightest difference and nearly converged. Thus, the best value of the lift force for NACA 63- 618 is 19125.37 N.

B. Comparison of the angle ofattack

TABLE 11: *Lift Force Comparison Based On The Angle Of Attack*

Meshsize (m)	Lift Force (N)			
	NACA 0012		NACA 63-215	
	Angle of attack 16	Angle of attack 18	Angle of attack 16	Angle of attack 18
0.1	19 905	21259.426	6133.4653	6817.5874
0.11	21 852	21985.225	5804.7402	6126.7847
0.12	21 858	23758.027	4759.8535	5591.6431
0.13	22 516	22701.926	5959.7563	6306.2129

From the table 11, the value of the lift force is directly proportional to the angle of attack. As the angle of attack increases, the value of the lift force also increases. The maximum values of the lift force can be obtained if the angle of attack increased. Furthermore, if drag coefficient values are the lowest the lift can reach the maximum value [5]. Thus, to compare the best NACA series that generate lift force for water turbine application data from a higher angle of attack will be used.

TABLE 12: *Comparison On The Angle Of Attack And Meshconvergence*

Angle of attack	Lift Force (N)				
	NACA 0012	NACA 23-018	NACA 63-215	NACA 63-424	NACA 63-618
16	21855	3309.74	5969.1	13686.4	18568.04
18	21622.33	3703.28	5859.21	14801.29	19125.37

Theoretically, the lift force will increase if the angle of attack also increases. However, from the table 12, the value of lift force at mesh convergence for NACA 0012 and NACA 63- 215 at an angle attack 18 degrees is lower than at angle attack 16 degrees. This is because the lift force values were chosen based on convergence and not the highest value. The value at mesh convergence is the most accurate so we neglect the highest value. The usage of mesh convergence in finite element stress analysis is necessary, and second if they converged to an acceptable level of accuracy [3].

C. Comparison between the NACA series hydrofoil

TABLE 13: *Comparison On Lift Force For Naca Series Hydrofoil*

Angle of attack	Lift Force (N)				
	NACA0 012	NACA 23-018	NACA 63-215	NACA 63-424	NACA 63-618
18	21622.33	3703.28	5859.21	14801.29	19125.37

At angle attack 18 degrees, the value of lift force generated is higher than at 16 degrees. Thus, the value of lift force at 18 degrees angle of attack will be used to compare the NACA series hydrofoil performance. From the table 13, the value of the lift force generated by NACA 0012 is the highest compared to other hydrofoils. NACA 0012 has 12% thickness to chord length ratio.

This series does not have the highest thickness, but it can generate the highest lift force. This is because the first 2 digits 00 from NACA 0012 means that the hydrofoil does not have a chamber and it is symmetrical. So, the hydrofoil has the same upper and lower region and the pressure distribution is normal. Non-symmetrical hydrofoil may have the best lift-drag ratio however the high value of drag effect the lift force generated. NACA0012 is more suitable since it generates higher force at the upper rotor region than the NACA2412 [8]. NACA0012 hydrofoil is a better choice and, more effective when the acoustic behavior of the hydrofoil is a significant design criterion [9].

The NACA 63-424 foil is a NACA foil of 6 series. The 3 displays the chordwise place of minimum stress in tenths of the chord from the leading edge, the 4 after the dash provides the design lift coefficient in tenths, and the last two numbers 24 show thickness in percent chord again [10]. There are three 6 series NACA series in this simulation. NACA 63-618 generates a higher lift force compared to NACA 63-424 and NACA 63-215. NACA 63-215 has the lowest thickness so the lift force generated is also low.

Although NACA 63-424 has a higherthickness than the NACA 63-618, NACA 63-618 design has a higher lift coefficient that increased the value of lift force generated by the hydrofoil. For NACA 23-018, it generates the lowest value of lift force as it has the lowest design lift coefficient.

4. Conclusion

The first objective of this experiment is to simulate the lift force produced by the NACA series that run in shallow water or specifically for water turbine applications. In this project, 100 m/s water velocity was used as the parameter. Next, water was chosen in the Ansys Flow Fluent as the moving fluid. This project was run in Ansys Flow Fluent that shows the most similar perspective towards the real situation of water turbine application.

All five hydrofoils that have been used in this project consist of 4 series,5 series, and 6 series of NACA series hydrofoils. Then, the results obtained for all hydrofoils are compared to find the best NACA series for water turbine applications that have the highest value of lift force generated. NACA 0012 is the best NACA series hydrofoil.

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Azri Hamim Ab Adzisis a technical lecturer in Universiti Kuala Lumpur. His background is in pneumatics, hydraulics and engineering simulations.

Mohd Azamuddin Mokhlis wasa final year students in the Bachelor of Mechanical Engineering with Honours, Universiti Kuala Lumpur and currently a practicing engineer in Malaysia