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Analysis of Leading Edge Protuberances on Fully Submerged Hydrofoil of 15 m Pilot Boat

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Analysis of Leading Edge Protuberances on Fully Submerged Hydrofoil of 15 m Pilot Boat

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Abstract: Resistance greatly affects on selection of the main engine and ship fuel consumption. To achieve the speed of the ship, the ship must be prepared to overcome resistance in the waters to be passed by choosing the right engine according to the needs of the ship. In the last few years there have been many studies on biomimetics or the use of systems in nature to be applied in a technology. Such as the use of Leading edge protuberances. Despite its large size and stiff flexibility, the humpback whale has a good maneuver even when chasing prey compared to other animals of its size. This study aims to obtain the highest lift force result and the smallest resistance with a hydrofoil model configuration of leading edge protuberances which resembles a humpback whale fin (megaptra novaengliae). The Computational Fluid Dynamics (CFD) is applied to analyse lift faorce and ship resistance of all models variation. The results indicates that from all variation of models at the Fn 1.356, the model has 5 ° angle of attack were able to reduce the total resistance value of Pilot Boat by 35.13%.

1. Introduction

In a previous study based on the results of the analysis of variations in the shape of a 15 meter step hull pilot boat, the total resistance value was scaled down to 16.96%, this condition occurred in variation of step hull with angle 180° at a speed is 26 knots [1]. In the analysis of the addition of a hull vane in 15 meter pilot boat can increase the lift value by 26.529 kN and reduce the total resistance of the ship by 35% in the hull vane model with an angle of attack of 2° with a depth of 100% T [2]. Then in the analysis of the addition of foil on the 15 m pilot boat with a variation of the swept foil angle model, the value of the total resistance value decreased to 38.021% than the original ship for angle of attack's variation 4° and swept 10 degrees Fn 1.356 [3].

On hhydrofoil supported catamaran (Hysucat), the use of hydrofoil on catamarans makes the lift force on the ship higher which causes the ship's draught to be reduced, so that reduce in total resistance. In the analysis of calm water conditions it is proven to reduce the resistance value of the catamaran model sample by 30% to 50% [4, 5]. In other studies, the use of hydrofoil on catamaran vessels was proven to reduce the value of ship resistance by 35% at Fn > 1.8. [6, 7].

In the last few years there have been many studies on biomimetic or the use of systems in nature to be applied in a technology, such as the use of Leading edge protuberances. Leading edge protuberances is the shape resembles a humpback whale fin (Megaptera novaengliae) [8]. Despite its large size and stiff flexibility, the humpback whale has a good maneuver even when chasing prey compared to other animals of its size.

Watts and Fish uses the panel method on the NACA foil series 634-021 with a second aspect ratio at the angle of attack α = 10 °, there is an increase in lift by 4.8% on the baseline wing and a 10.9% decrease in induced drag [9]. Humpback whale flipper model has able to increase lift force about 6% when is fitted in aeroplane wing and also increase stall angle about 40% [10]. Drag force also decreases up to 32% on angle of attack over the range of 10,3° to 11,8° when protuberances is used.

In this study, the variations used consisted of variations in wavelengths of 0.5c and 0.25c and amplitudes of 0.025c, 0.05c and 0.12c with the angles of attack 2.5° and 5°. The selection of amplitude and wavelength is based on the value associated with the characteristics of humpback whales [11]. The purpose of this study was to determine the lift and resistance of each design of the leading edge protuberances.

2. Method of Research

The Pilot Boat hull model is created using Rhinoceros v 6.0 software student version. The scaled ship model was generated by 1: 30. The tandem foils is applied on the pilot boat that the position of these foils on the ship are fitted at 4.5 m from LCG aft and 4.3 m from LCG front. Figure 1 shows the result of 3D boat modeling with foils.
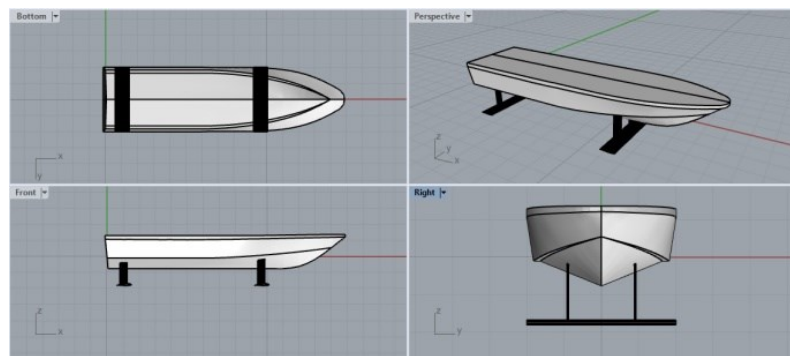

Figure 1. Pilot Boat 3D Modeling with foils

The models is varied based on its wavelength and amplitude of leading edge. In addition, the variation also varied with two variations of angle of attack of 2.5° and 5°. Detail of model variation of leading edge protuberances are shown in Table 1 and Figure 1.

Table 1. Parameter of model variation

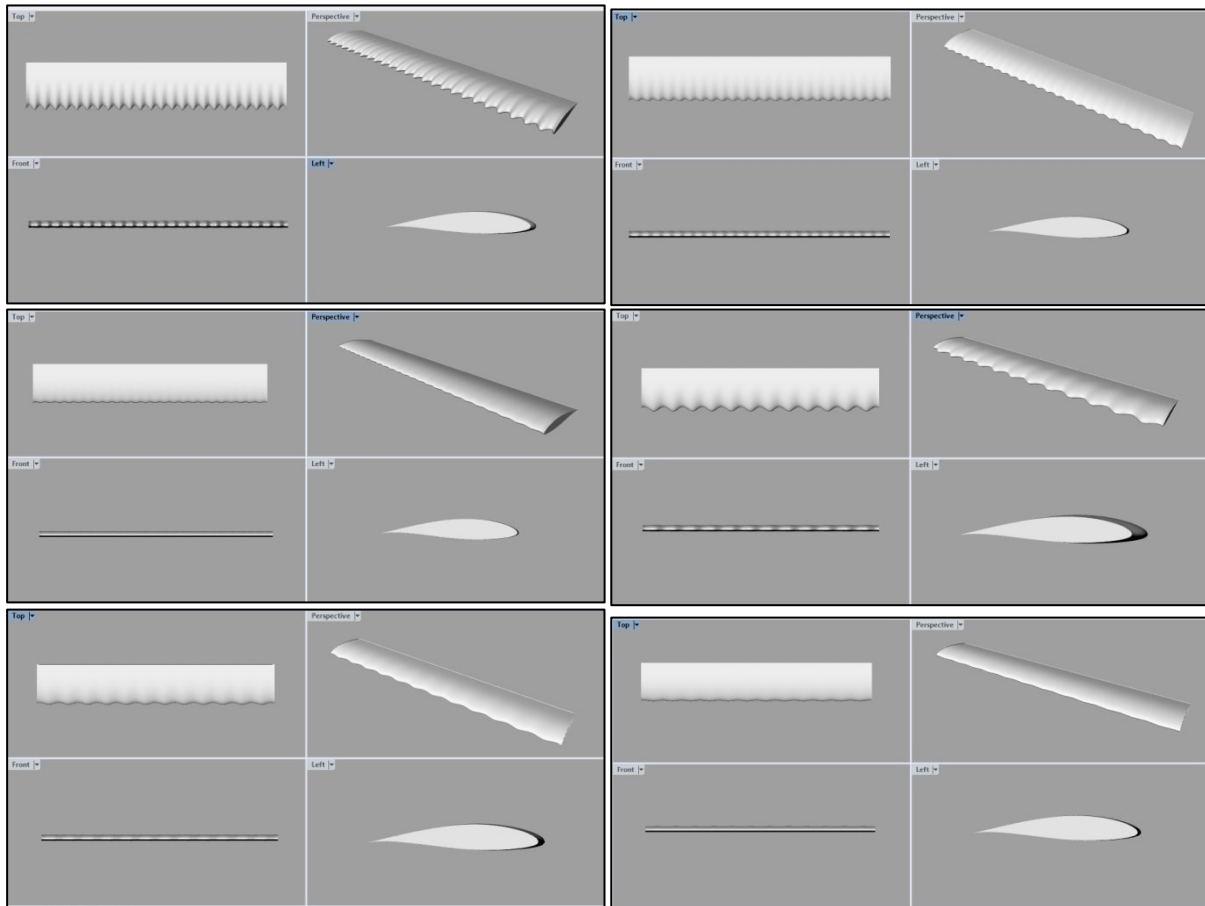| Model	Wavelength	Amplitudo	Angle of Attack
8L	0.25c	0.12c	2.5°& 5°
8M	0.25c	0.05c	2.5°& 5°
8S	0.25c	0.025c	2.5°& 5°
4L	0.5c	0.12c	2.5°& 5°
4M	0.5c	0.05c	2.5°& 5°
4S	0.5c	0.025c	2.5°& 5°

Figure 2. Model variation of leading edge protuberances
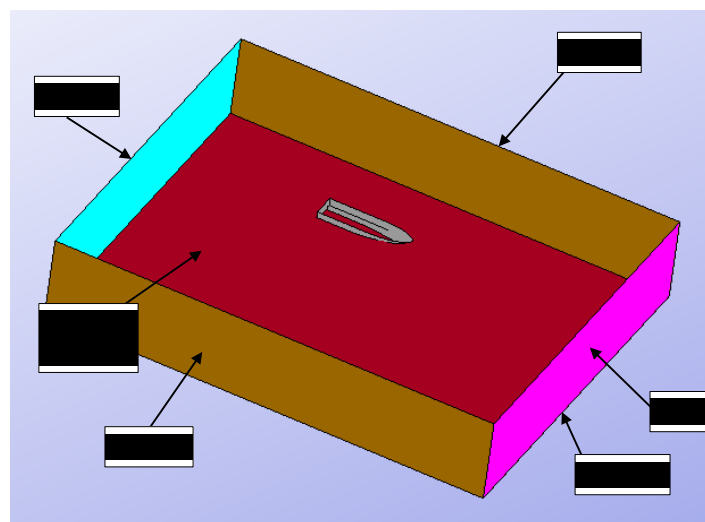
Figure 3. Boundary layer of Pilot Boat domain

CFD method is applied in this study to analyse total resistance when the ship is modified using leading edge protuberances. Figure 3 shows all boundary layer on domain box is required to CFD analyse. Top boundary is opening type with zero gradient turbulence. Bottom and wall boundary is free slip. Velocity of fluid flow is applied in inlet, while static pressure is applied in outlet. Turbulence model using SST.

3. Result and Discussion

It takes two running stages to get the total resistance value of the hydrofoil craft, the first running stage is used to obtain the lift force, trim moment and heave, then the second running stage is done when the ship has been lifted and the trim and heave values are in accordance with calculation of equation (2) and (3) is inclined with the equilibrium condition when the ship moves at each speed.

Table 2. Lift force Angle of Attack 2.5° (kN)

Model	Lift (kN)		
	Fn 0.904	Fn 1.130	Fn 1.356
8L	121.238	172.494	232.283
8M	125.015	171.655	223.816
8S	115.773	180.427	189.766
4L	128,293	183.313	249.264
4M	133.704	186.829	270.837
4S	117.709	177.862	209.611

Table 3. Lift force Angle of Attack 5° (kN)

Model	Lift (kN)		
	Fn 0.904	Fn 1.130	Fn 1.356
8L	151.440	217.115	256.767
8M	136.220	212.533	261.511
8S	152.833	212.174	259.629
4L	148.645	216.237	310.041
4M	146.858	236.638	290.277
4S	141.288	232.,831	247.544

Table 2 and Table 3 show the lift value using the CFD analysis with variations in the leading edge protuberances model. The highest lift value is 270.837 kN for the 4M model angle of attack 2.5˚ and 310.041 kN for the 4L model angle of attack 5˚, each of these values occurs on Fn 1.356 with a Tandem configuration. Whereas in the same froude number, the smallest lift value is a 8S angle of attack 2.5˚ model with a value of 189.766 kN and 4S angle of attack 5˚ with a value of 247.544 kN.

The total resistance on ship is the sum of several other resistance components such as viscosity resistance and wave resistance. The other important thing that has a big influence on the total resistance value on the ship is Wetted Surface Area (Table 4 and Table 5). The increasing of WSA, the total resistance value on the ship will also increase.

Table 4. Wetted Surface Area with Angle of Attack 2.5° (m^2)

Model	Wetted Surface Area (m^2)		
	Fn 0.904	Fn 1.130	Fn 1.356
Original	34.728	32.736	35.915
8L	40.000	30.548	21.666
8M	38.605	31.036	22.527
8S	39.362	29.266	27.727
4L	37.829	29.393	18.870
4M	37.374	28.428	14.958
4S	38.169	29.727	24.455

Table 5. Wetted Surface Area with Angle of Attack 5° (m^2)

Model	Wetted Surface Area (m^2)		
	Fn 0.904	**Fn 1.130**	**Fn 1.356**
Original	34.728	32.736	35.915
8L	35.000	24.008	17.858
8M	36.986	24.123	16.593
8S	34.014	24.343	16.629
4L	35.047	23.925	13.195
4M	35.159	20.424	13.359
4S	35.876	20.942	18.447

Table 6 shows that the result of total ship resistance on Fn 1.356 has closed value betwen CFD method and analytical method (Blount & Fox, and Savitsky). It means that the CFD setup is liable to be applied to analyse other modification of leading edge protuberances on fully submerged hydrofoil of Pilot Boat.

Table 6. Validation for Ship Resistance on Fn 1.356

Fn	v (m/s)	Method	Total Resistance (kN)	Error (%)
1.356	2.817	CFD	35.39	-
1.356	2.817	Blout & Fox	36.60	4.077
1.356	2.,817	Savitsky	34.30	2.478

In Table 7 and Table 8 show that the total resistance value of ships using foil becomes smaller than original ship model, specificly in the froude number 1.356 had biggest decreased of resistance than the lower froude number.

The total resistance which had biggest reduction occured on angle of attack of 5° with a reduction in total resistance of 35.13% for the 4L model of the total resistance of the original ship. The variation of 4L foil models had the biggest reduction in drag caused by having the greatest lift force so that it can lift the original ship completely from the water surface.

Table 7. Total Resistance Foil Angle of Attack 2.5° (kN)

Model	Total Resistance (kN)		
	Fn 0.904	**Fn 1.130**	**Fn 1.356**
Original	17.010	22.084	35.386
8L	23.069	24.907	25.877
8M	22.580	26.145	26.635
8S	23.251	24.383	30.553
4L	19.813	25.109	26.877
4M	19.793	23.766	23.625
4S	20.559	25.457	28.976

Table 8. Total Resistance Foil Angle of Attack 5° (kN)

Model	Total Resistance (kN)		
	Fn 0.904	**Fn 1.130**	**Fn 1.356**
Original	17.010	22.084	35.386
8L	20.473	24.105	25.371
8M	21.229	24.439	25.472
8S	20.790	24.317	24.120
4L	20.210	21.756	22.955
4M	19.820	21.558	23.484
4S	20.220	21.281	25.570

The lift value on the hydrofoil leading edge protuberances is always inversely proportional to the total resistance value of the ship. In Figure 4 taking a model with a variation of 0.5c wave length, namely 4L and 4M models at an angle of attack 5˚ showed the higher the lift value, the smaller from the total resistance. The 4L and 4M models on the Fn 1.356 had the highest lift forces, each worth 310.041 kN and 290.277 kN and had smallest total resistance respectively 22.955 kN and 23.484 kN.

In Figure 5 and Figure 6, showed the original model had sharper wave pattern color than 4L model at the same vulnerable wave elevation. In the 4L model the wave patterns that occur are only caused by strut and foil which are still below the surface of the water. In the final results of this study it appears that the angle of attack value is same to the value of the lift. At the Fn 1.356 the lift values of all models with an angle of attack 5° are bigger than all models with an angle of attack of 2.5°.
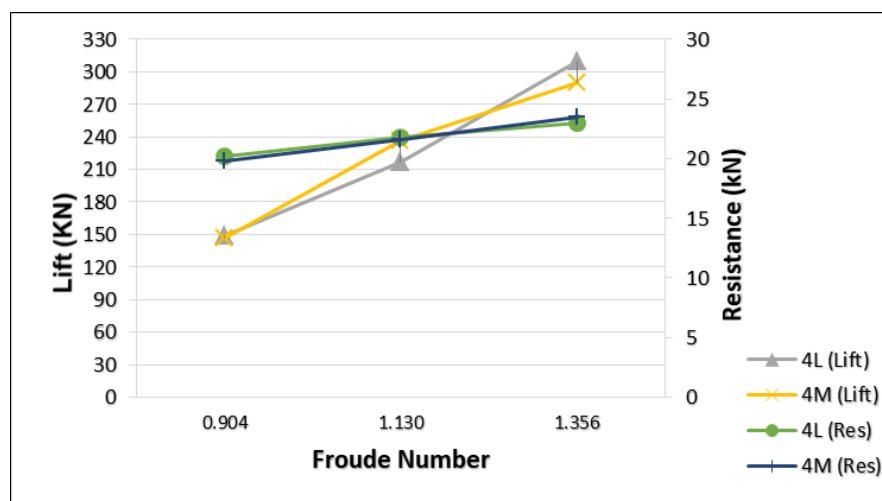

Figure 4. Comparation between Lift and Total Resistance Model 4M & 4L Leading Edge Protuberances Foil with Angle of attack 5˚
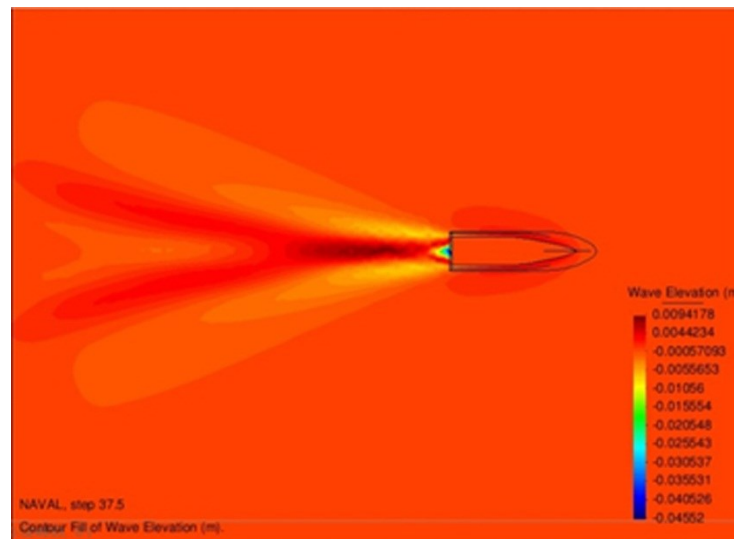
Figure 5. Wave Pattern of the Original Model Fn 1,356
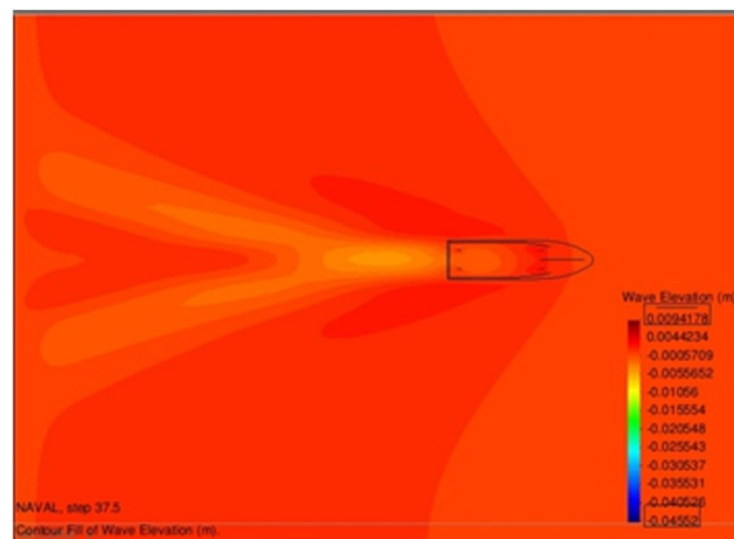

Figure 6. Wave Pattern of the 4L Foil angle of attack 5° Fn 1,356

4. Conclusion

The highest lift value is generated by the 4L model in Fn 1,356 at a 5° angle of attack of 310,444 kN. The lowest lift value occurs in the 8S model at Fn 0,904 at 2.5° angle of attack is 115,773 kN.

The lowest total resistance value is resulted by the 4L model in Fn 1,356 at angle of attack 5° with a decrease of 35,13% from the total resistance of the original ship. In the 4L and 4M foil models the hull is already above the surface of the water, so the Wetted Surface Area value is getting smaller which results in a total resistance generated at Fn 1,356 also getting smaller.

The leading edge protuberances model variation had a effective lift force to reduce the total resistance value of the 15 meter Pilot Boat is a 4L model variation or a model with a wavelength of 0,5c and an amplitude of 0.12c with angle of attack of 5°.

The variation of the leading edge protuberances model that most influences the ship's performance is the wavelength variation. The greater value of the wavelength, the foil will tend to produce a greater lift force and greater resistance reduction. Amplitude variation also affected at the value of lift and

decrease in ship resistance, the bigger the amplitude value, the lift force will tend to increase and the resistance of the ship will decrease bigger.

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