International Journal of Electrical Engineering & Emerging Technology, Vol. 05, No. 01, JAN-JUN 2022, pp 42-44

Three-dimensional analysis of tubercle leading edge airfoil with varying amplitude of tubercles

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[**Received on:** 17/05/2022 **Accepted on**: 30/05/2022 **Published on:** 07/06/2022]

***Abstract* — The design of tubercle wings inspired by humpback whales has sparked interest in the recent decade. Study showed that tubercle wings had a great impact on performance when compared to baseline models. By altering the amplitude, wavelength, Reynolds number, wing planform, and airfoil thickness, the aerodynamic performance of a wavy wing is extensively examined. Modifying tubercle amplitude has yet to be investigated in terms of its effect on the leading edge of the finite wing. The current research focuses on the performance of the finite tubercle wingspan in the stall zone with changing waviness amplitude. The tubercle models are DU06W200 airfoil designs that have had their amplitude increased or decreased from the wing root to the wing tip. The experiment is carried out in a subsonic wind tunnel with a constant Reynolds number of 120,000. The spanwise waviness on an aircraft wing is only advantageous in the pre-stall regime, according to the experimental data. It was also shown that increasing waviness amplitude from the root to the tip enhances aerodynamic performance more than reducing it near the tip.**

***Index Terms*— L/D.**

I. INTRODUCTION

Global energy consumption is increasing, and climate change makes it more difficult to rely on fossil fuels. Researchers are eager to work on green energy resources as a long-term solution to global issues. One of the most important resources in green energy solutions is wind energy. Mechanical components are required to extract the energy from the wind and transform it into mechanical or electrical energy while using wind energy. Wind turbines are installed with airfoil wings that generate lift by creating a pressure difference across their wing surface [1] and drive the shaft of the turbine using Bernoulli's principle. Wind turbine performance has been enhanced by studying the airfoil wings and modifying the wing geometry. The existence of wavy structure on the leading edge of the wing [2], as shown in fig 1, is one of the major geometrical modifications in airfoil wings.

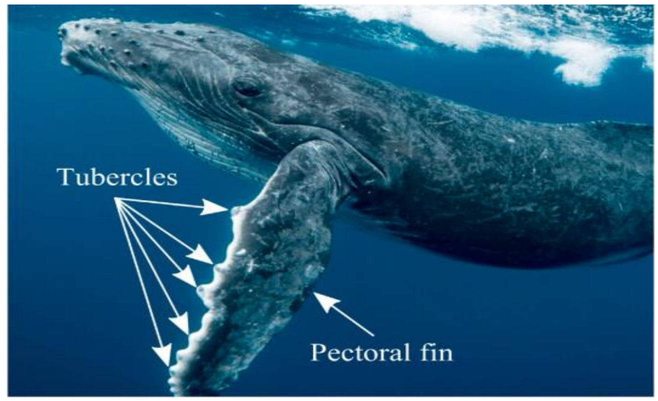

Fig 1: Humpback Whale Flippers

Experimental inquiry done for greater aerodynamic and hydrodynamic advantage, inspired by humpback whale pectoral flippers for high agility and maneuvers. Wavy wings offer greater performance towards the stall regime, according to research. Different hydrodynamic [3] and aerodynamic turbines [4] are examples of wavy wing applications for enhanced stall performance. [5] To configure the tubercle, six different tubercle models were applied to the baseline airfoil, each with a different amplitude and wavelength. [6] Numerical simulations were used to determine the efficiency of the improved propeller. [7] worked on eight different airfoils with different wavelengths and discovered that the tubercle increased performance on the NACA 65-021 airfoil more than the NACA 002 airfoil. The goal of this study is to explore how changing the wing waviness amplitude impacts the aerodynamic efficiency of a wing in the pre- and post-stall regime. The airfoil utilized in this study has a thickness of 20% and a camber of 0.88 percent, resulting in a 5% increase in low-speed turbine efficiency over the NACA series, making it appropriate for VAWT applications [8]. Furthermore, compared to the standard NACA series, airfoil is more effective at low tip speed ratios [9].

II. METHODLOGY

The case under study is modelled using Solid Works CAD software, and the experiment is carried out in a subsonic wind tunnel. This covers all of the phases required for this aspect of the research, including modelling of airfoil wings, 3D printing, and testing in a subsonic wind tunnel. During the modelling process to create wavy tubercles on the leading edge, the tubercles' amplitude is calculated with relation to chord length, ranging from 2.5 percent to 12.5 percent of chord length, depending on the parameter of the whale wing structure. The amplitude of each tubercle valley is calculated by altering the percentage of the chord length in between the prescribed range, and the position of each tubercle valley is computed by setting the wavelength at 25mm and dividing the wingspan into 8 equal parts. The variation of waviness amplitude results in two modified baseline wing models, namely, increasing the amplitude model from the root to the tip of the airfoil wing and decreasing the amplitude model from the root to the tip of the airfoil wing. The amplitude variation of the tubercle geometry of the DU06W200 baseline airfoil increasing and falling in size from the root to the tip of the wing. The updated airfoil wings CAD model created in Solid Works 2019 program for high to low and low to high amplitude models is displayed in the figures below.

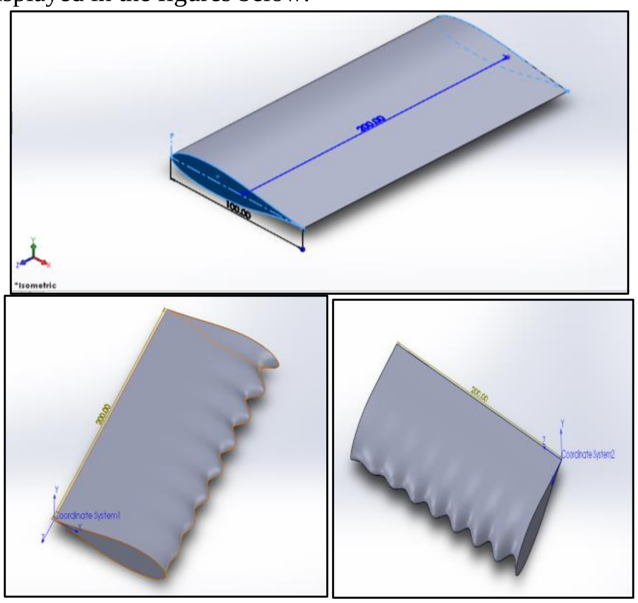

Fig 2: CAD Model of DU06W200 and its modified models (a) Baseline Model (b) Low to High (b) High to Low

The three-component balance attached with the test section of the wind tunnel measures the readings of the lift and drag forces acting on the airfoil at respective angle of attack. The readings are shown in the table I.

TABLE I: Measured Lift and Drag Forces.

α	Baseline Model		High to low		Low to high	
	Lift	Drag	Lift	Drag	Lift	Drag
10	5.609	0.809	5.269	0.728	5.269	0.721

The lift and drag coefficient were calculated using the data in table I and equation 1.

$$C_{L,D} = \frac{2L}{\rho A V^2} \qquad (1)$$

Where $C_{L,D}$ represents coefficient of lift and drag, ρ is the air density at STP, A is the wing planform area and V denotes air velocity.

III. Results and Discussion

To compare the wings, the lift coefficient and drag coefficient values of each model are compared at various angles of attack. Considering the results of the experiment's measurements and formulating them using equation 1 leads to following observation shown in bar charts.

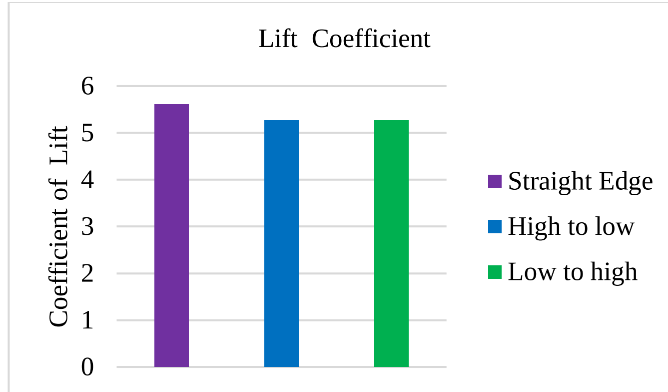

Fig 3: Coefficient of Lift at α=10°

The lift coefficients for the baseline and modified models are shown in Fig 3 at α=10° angle of attack. The results were shown in a bar chart using the experimental subsonic wind tunnel sensor. In terms of lift coefficient, the graph likewise indicates the baseline model's supremacy over the wavy model. During the trial, the baseline model lift coefficient value remains greater than the modified models.

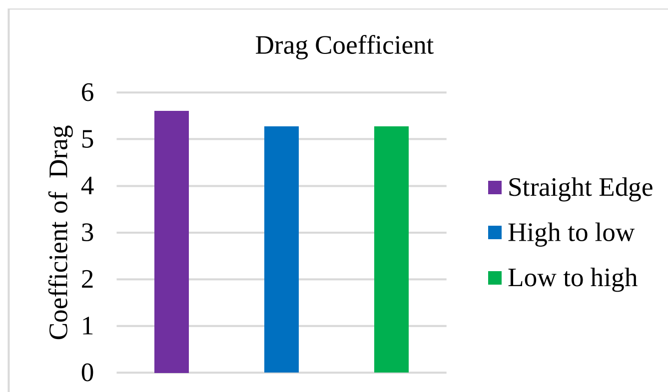

Fig 4: Drag Coefficient at α=10°

The coefficient of drag for the current investigation is shown in Figure 4 for each of the three models. The graphical relationship shows that the drag coefficient of the baseline model with straight edge is much greater than that of the tubercle model. It's the explanation behind the tubercle model's waviness, which has a lower drag value than the baseline model. The low drag appearance in the modified model indicated the impact of the leading-edge modification positive impact on the drag performance.

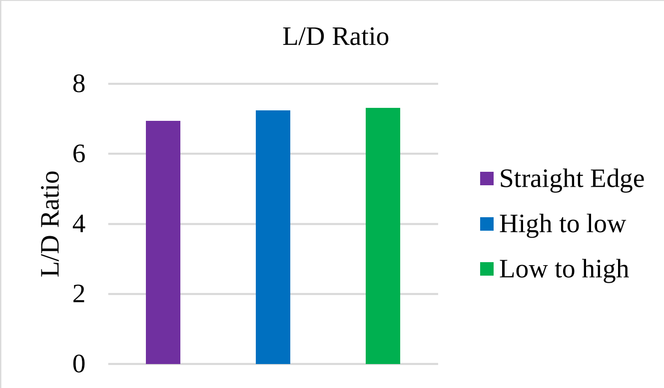

Fig 5. Lift/Drag at α=10º

The baseline model and its two additional modified models' aerodynamic properties are compared in the Fig 5 bar chart. The L/D ratio forecasts the wing's performance at various angles of attack. This graph shows that the wavy model wings for the airfoil DU06W200 are more effective for the pre-stall phase than the baseline models because they have a higher L/D ratio. It may also be determined that the root-to-tip low-to-high amplitude model has the best performance indication at $\alpha = 10^o$. When the L/D ration of the modified modes is examined, the low to high amplitude tubercle modified model outperforms the high to low amplitude tubercle model. Because updated models have a rough structure, they have a lower drag value, which means the wing's performance has improved.

IV. Conclusion

Various tubercle airfoils were designed in Solid Works program and tested in the subsonic wind tunnel during this study. By delivering a high L/D ratio, the alternative tubercle airfoil DU06W200 with elliptical bumps at the leading edge gave greater pre-stall performance. These sorts of alternative tubercle models may be used to improve the stall characteristics of the wings, according to the examination of these two alternative models. When exposed to subsonic flow with constant Reynolds number, the distinct tubercle amplitude variations demonstrate this. It is concluded that the modified tubercle model has superior aerodynamic qualities than the straight Edge baseline model at $\alpha=10^o$. It demonstrates that the higher performance of the tubercle model is due to a lower drag value. While the combination of tubercles appears to be favorable, it significantly enhances the airfoil's pre-stall performance, according to our findings.

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