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# Improving Aerodynamic and aeroacoustic performance of the propeller by synchronic wavy tubercles

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**ABSTRACT:** One of the effective methods in improving the performance of propellers is the use of tubercles on blades inspired by nature and the basis of passive flow control. In this research, the effectiveness of an innovative idea has been investigated from an aerodynamic aspect with computational fluid dynamics analysis and from aeroacoustic aspect with experimental testing. This idea has been studied by creating wavy simultaneous tubercles on leading and trailing edges with a wavelength of 6 mm and an amplitude range of 3 degrees in pitch direction from near the root to tip of the blade. Improvement of aerodynamic efficiency has been done by numerical simulation using the rotating reference frame method, and improvement of static aeroacoustic efficiency has been done with experimental tests resulting from the calibration of microphone sensors. Computational fluid analysis using the finite volume method based on finite elements and solving Reynolds averaged Navier-Stokes equation with K-Omega-SST model has been validated from reference experimental test. By studying the independence of results, the appropriate computing domain and grid for numerical simulation of flow has been determined. Results show an increase in aerodynamic efficiency of 7.5% in advance ratio equivalent to maximum efficiency and an increase of 22% in others. Reduction of maximum sound intensity in frequency equivalent to the main harmonic of the propeller, 1.4% in the area near the rotor plate and 3.8% in the area behind the plate, shows improvement of aeroacoustic performance.

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## 1- Introduction

Propellers, as one of the main propulsion components, play an important role in the performance of flight in subsonic regimes. Meanwhile, the use of flow control methods has significantly improved the performance of profiles related to fluid passage. Passive flow control methods are more interesting than active methods due to the lack of energy consumption for their setup and ease of use and maintenance [1]. The use of profile edge tubercle as an effective method of passive flow control was inspired by the natural shape of humpback whale fins [2], beached dolphin's bill [3], and harbor seal hair [4]. The creation of these tubercles in whale wing leading edge areas increases its mobility despite its large dimensions [5]. The impact of fluid on the raised leading edge will create vortices to increase momentum, improve aerodynamic performance, and prevent flow separation. Studies carried out in using passive flow control patterns and also creating optimal cutting area based on the ideas in nature are limited to creating tubercles on the leading and trailing edges of the propeller blade separately.

In this research, using the innovative idea of synchronic raised edges on the leading and trailing edge of wave-shaped blades, its advantage in aerodynamic and aeroacoustic optimization has been achieved. To increase the aerodynamic efficiency, especially in higher advance ratios, it has been used to create a tubercle in the direction of the blade pitch. The investigation of parameters on wavelength and amplitude by computational fluids analysis using the finite volume method based on the finite element with the commercial software Ansys CFX has been determined in the value of the trust factor to the power factor in the advance coefficients. The simultaneous profile of the bulge with the bulge wavelength is equal to the distance between the two sections of the airfoil with the increase of the pitch angle to the amount of the amplitude of the bulge. Finally, the propeller with a wavelength of 6 mm and an amplitude range of 3 degrees is made of wood for aeroacoustic testing in static conditions.

## 2- Methodology

The tubercles created in the leading and trailing edge regions of the blade are shown in Figure 1. The wavelength parameter is in the span direction and the amplitude parameter is in the blade pitch direction.

In the analysis of computational fluid dynamics, according to the effect of the dimensions of the computational field according to Figure 2 on number of elements, as well as

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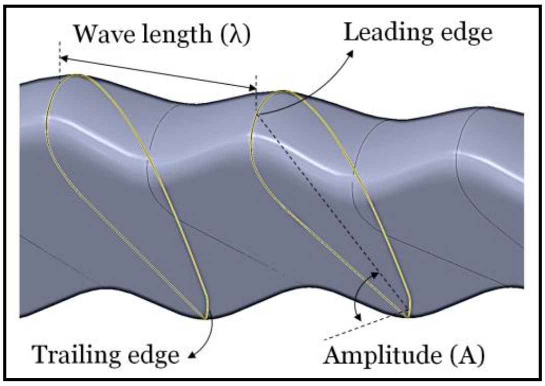


Fig. 1. Design parameters of wavy blade

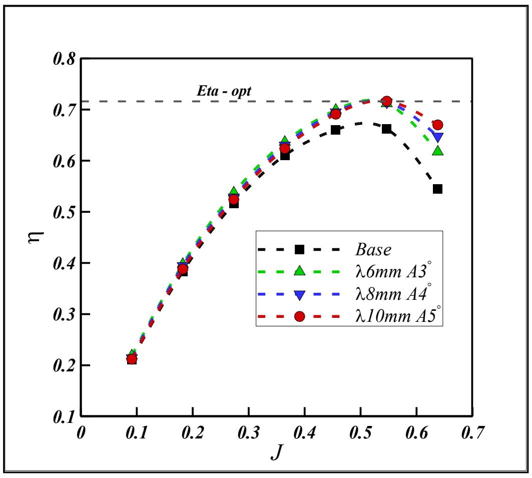


Fig. 3. Numerical aerodynamic efficiency result

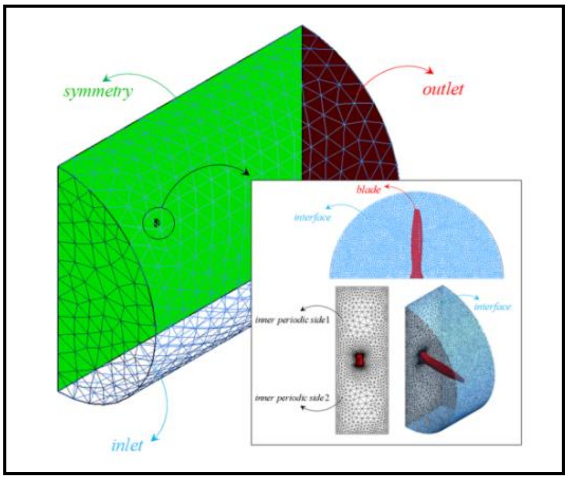


Fig. 2. Computational domain

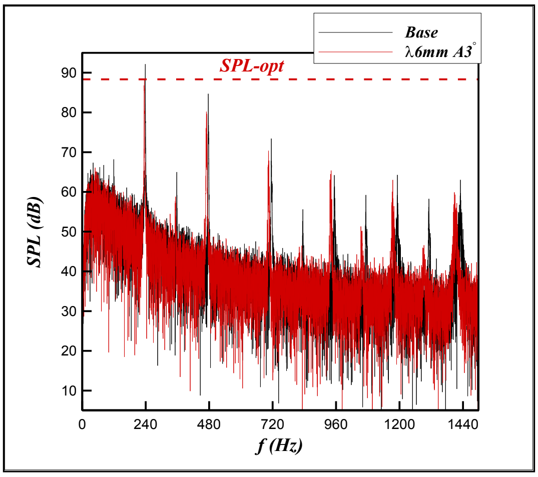


Fig. 4. Sound intensity in rotor plate

different ranges of dimensions of each area, results changes have been reported in relation to number of computational grid field elements. More changes in force and torque values on the propeller compared to the upstream internal dimensions field show the high sensitivity of this parameter to other computing dimensions fields. Also, in examining the importance of computational element size, grid dimensions in the areas including blade wall, boundary layer near wall, and the interfaces are of great importance.

For propeller noise data in static conditions, a semi-anechoic chamber with inlet and outlet ducts of air flow, sound insulation foams, microphone sensor, rotational speed sensor, data collection system, motor, and its required components have been used. Due to the need to reduce engine noise and the ability of brushless motors to provide power along high rotation speed, XM motor is used. The noise measurement caused by rotation and the wake emitted from the propeller was done by two microphone sensors at radial distance from the center of rotation in the vicinity of the rotor rotation plate and behind the rotor plate.

## 3- Results and Discussion

Due to the increase in blade pitch in the tubercle sections, there is an expectation of an increase in thrust coefficient. Because the increase in power factor of the propeller is such that it increases the efficiency ratio, the tubercles increase the aerodynamic efficiency according to Figure 3.

Examining the level of sound intensity in the main harmonic equivalent to the frequency in the range of 240 Hz shows a decrease of 1.4 percent compared to the base propeller from the value of 92.1 dB to the value of 88.3 dB in the wavy propeller in Figure 4. The amount of tonal noise in the first harmonic corresponding to the area outside the rotor plane according to Figure 5 is 77.1 dB for the base propeller and 70.7 dB for the wavy propeller. As a result, in this area, the reduction in noise intensity compared to the base propeller is 8.3%.

## 4- Conclusion

This research has investigated the improvement of the aerodynamic and aeroacoustic performance of the

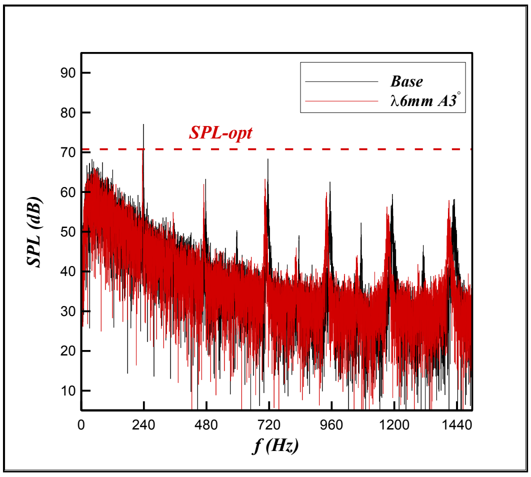


**Fig. 5. Sound intensity behind the rotor plate**

wooden propeller by presenting an innovative flow control pattern with simultaneously raised edges in a wavy shape. Aerodynamic analysis by computational fluid dynamics method using Ansys CFX commercial software and rotating reference frame method has answered conservative equations in fluid flow by discretizing the finite volume based on the finite element. Examining the wavelength of the tubercle has shown an increase in aerodynamic efficiency in all propeller advance ratios. This value has been increased by 7.5% in the advance ratio equivalent to the maximum aerodynamic efficiency compared to the base propeller and further up to 22%. Measurement and comparison of the emitted noise in the aeroacoustic test have shown a reduction of 1.4% of maximum noise in the vicinity of the rotor plate and a reduction of 3.8% of maximum noise in the area behind the rotor plate at the main harmonic frequency compared to the base propeller.

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