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Flow Separation Evaluation on Tubercle Ship Propeller

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ABSTRACT

Propeller design for ship propulsion is important based on efficiency and power output. Advanced propeller design has been proposed in recent research, such as the tubercle propeller. The modified propeller on the leading edge with a tubercle-like design has been improved. Moreover, some evaluation has been studied on the design and performance. In the present study, the tubercle design on the leading edge is evaluated, which focuses on the flow separation effect developed by the tubercle shape. A computational fluid dynamic (CFD) model is compared between the normal and tubercle leading edge. The flow total pressure, Reynold number velocity, and power surface acoustic are evaluated. The flow separation is generated in the leading edge due to the tubercle shape. Moreover, the tubercle shape reduces the total pressure at the propeller blade, especially at the edges. It also increases the Reynold number velocity at the surface due to the flow separation. However, the flow separation decreased the power acoustic surface, which means it lost some power on the propeller.

1. Introduction

The ship propeller has a significant role in the ship propulsion system. The propeller has the power to rotate from the shaft, which is from the main engine. Thus, the propeller has a thrust to move the ship hull against the ship resistance between the ship and the fluid around. The water flows through the propeller during the ship's operation. The propeller moves the water with the thrust due to the propeller shape with blade and pitch. However, the blade configuration has a critical effect on the thrust generated by the propeller, such as the number and type of the blade. Propeller blade has a lot of types for ship propulsion [1-3]. Most merchant ships use a B-Screw propeller for propulsion due to the performance and efficiency of its simple shape [4].

The shape of the propeller blades is based on the pitch and usually based on Bernoulli law which on the face side has a longer surface than on the backside. Thus, the flow characteristic is important for the application, which affects the velocity and the pressure. It affects the overall propeller performance, such as propeller thrust, torque, and efficiency. Sometimes, propeller blade

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modification is needed to employ better performance of the propeller [5,6]. Many studies are conducted to achieve high propeller performance by modifying the blade shape formation. Many studies also proposed Tubercle-like propellers to modify the flow characteristics of the blades [7-9]. The tubercle-like propeller has a tubercle shape at the leading edge, forming a wavy shape [10].

Recent studies indicated that the tubercle-like propeller has a less significant effect on the propeller performance [11-13]. Meanwhile, it has a different flow characteristic than the propeller without a modification but is less discussed. However, it indicates that it has other effects on the propeller's works than the performance. Thus, this study aims to identify the flow characteristic. The flow characteristic is identified using a CFD model comparing the unmodified with the modified leading edges. The pressure, Reynold number velocity, and power surface acoustic are identified using low fluid velocity on the surface.

2. Methodology

The B4-50 propeller is used to identify using unmodified and modified leading edges. The focus of this study is to identify the flow characteristics of those unmodified and modified leading edges. The identification uses the same fluid velocity on the propeller with advance ratio variation $J = 0.2$. The calculation of the advance ratio variation is on the equation which V_a is the speed advancing, n is the rotational speed, and D is the propeller diameter.

$$J = \frac{V_a}{nD} \tag{1}$$

2.1 Propeller Design

The detail of the propeller design is presented in the other study by Arifin and Felayati [14], while in this study, only a brief explanation is presented. Unmodified or normal propeller design characteristic is shown in Table 1. The type of the propeller is B4-50 which means a B-series propeller with four blades and 50% surface ratio. The pitch is 1.37, and the diameter is 1.96 m, with a pitch to diameter ratio of about 0.7. The propeller is applied at 395 rpm. Moreover, the modified propeller is modified using a tubercle shape on the leading edges. The tubercle shape uses amplitude of about 2.5% of the chords, with the wavelength is about 20% of the propeller radius. The design comparison between unmodified and modified propellers is shown in Figure 1.

Table 1
Unmodified propeller specification

Type	Db (m)	Pitch	P/Db	n (RPM)
B4-50	1.96	1.37	0.7	395

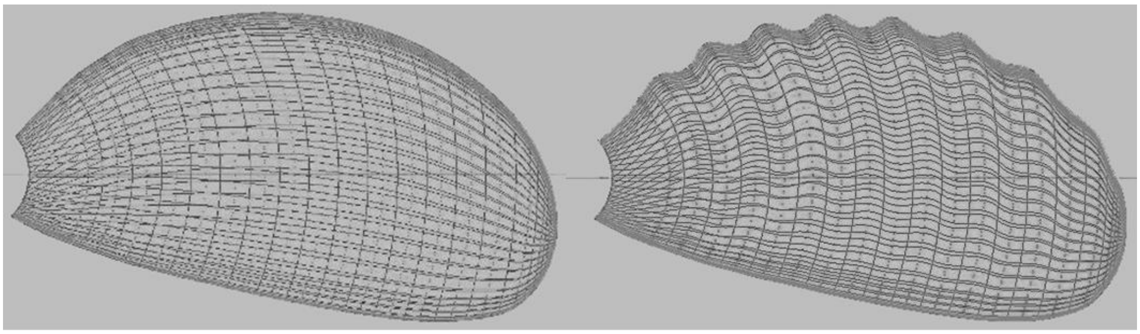


Fig. 1. Unmodified and modified propeller shape

2.2 Numerical Study

The numerical model for this study uses software for designing the unmodified and modified propeller. Then, CFD software is used for the flow simulation on the propeller using those variations. Two boundaries are developed on the CFD modeling, an inner boundary, and an outer boundary. The propeller is inside the inner boundary, and the inner boundary is inside the outer boundary [15,16]. The inner boundary is performed as a rotating boundary, and the outer boundary is performed as a fixed boundary. The propeller position is on the 2/3 outer boundary length from the inflow side. Moreover, a multiple reference frame (MRF) is used for this simulation with a coarse mesh type for the propeller. The boundary setup is shown in Figure 2.

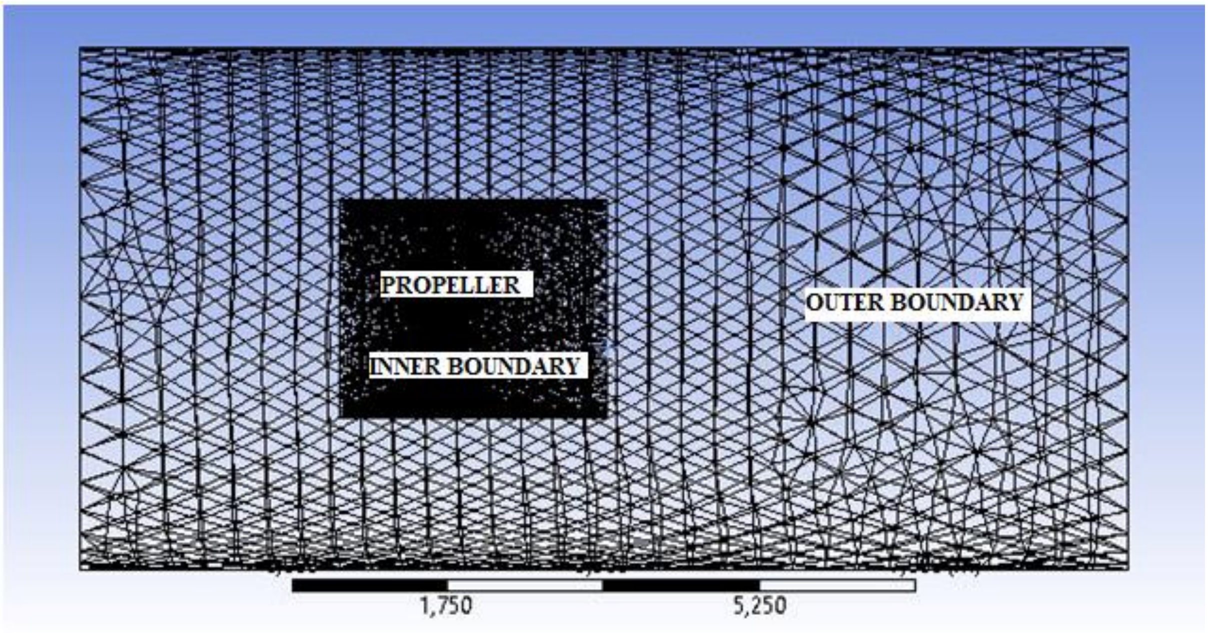


Fig. 2. CFD boundaries setup

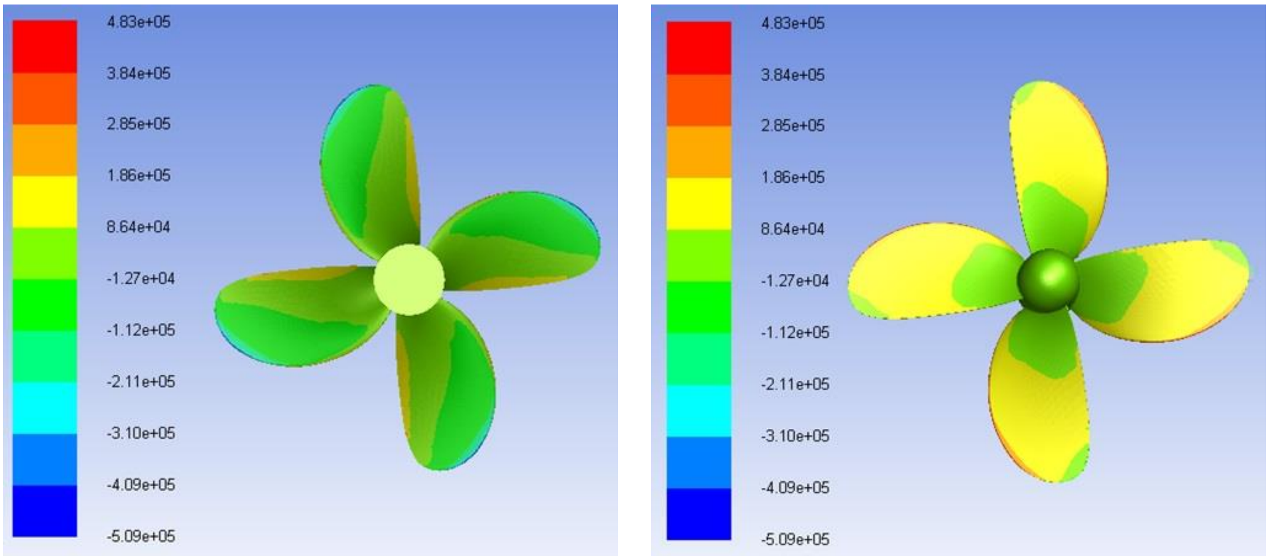
3. Results

This section discusses flow characteristics by comparing the unmodified with modified propeller blades. As mentioned before, this study used a low advanced ratio variation which indicates that the flow velocity through the propeller is low. However, the flow characteristics discussed in this section are based on the surface pressure, Reynold number velocity, and power surface acoustic velocity.

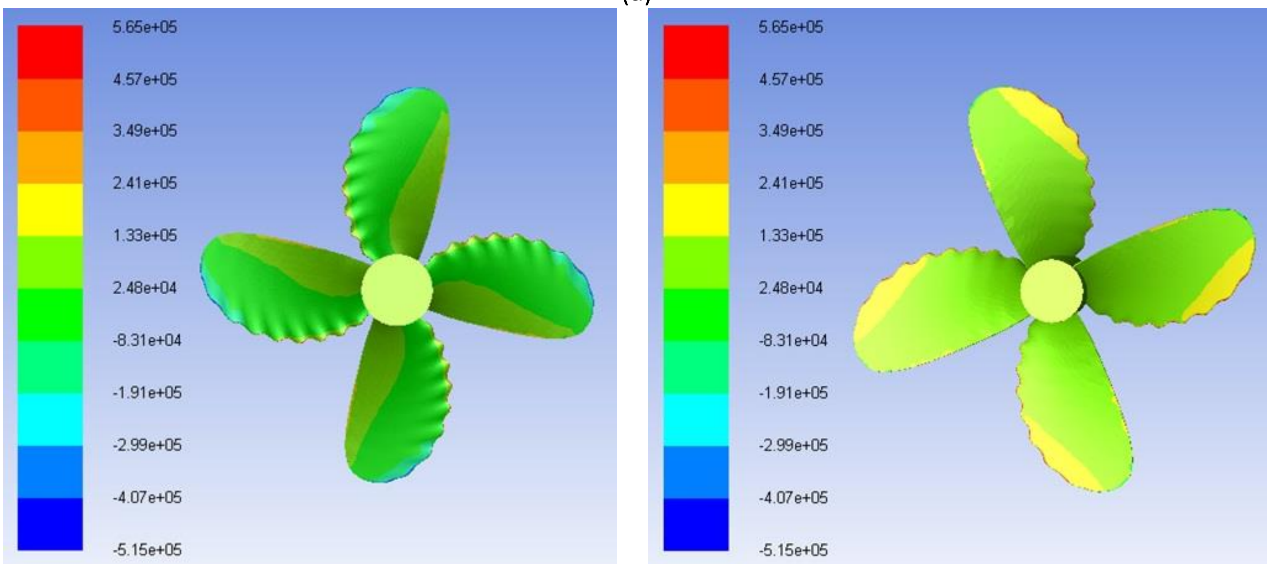
3.1 Surface Pressure Characteristic

Figure 3 shows the comparison of the surface pressure between the unmodified and modified propeller on the back and face surface. It shows that modifying the leading edge on the propeller to be like a tubercle affects the pressure surface. However, it is due to the tubercle shape on the leading edge, which is identified before, that the tubercle shape on the leading edge causes the flow separation. The water flow after the leading edge is divided by the shape amplitude [17]. The flow on the peak of the tubercle concentrates to the depth of the tubercle; thus, the pressure lowers on the surface due to the lower surface that flows by water. On the back surface (Figure 3), it shows that the tubercle-like shape on the leading edge slightly affects the pressure contour in the blade surface. However, it is obvious that the pressure gradation is clearly different between the unmodified and the modified propeller on the back surface. In the modified propeller, the gradation of the pressure on the surface becomes simpler and lighter. Moreover, it shows that the pressure in the trailing edges is lower in the modified propeller than in the unmodified propeller. On the face surface (Figure 3), the modified propeller also has a lower pressure surface than the unmodified propeller. The tubercle-like shape clearly is lower, almost the entire surface of the modified propeller. The highest-pressure surface is identified only on the tail of the leading edge. On the unmodified propeller, the lower surface pressure is only on the center and tail of the propeller.

It is a better condition for the water flow that easily flows through the surface; nevertheless, it might cause a power loss due to the lower resistance [7]. As reported before, the tubercle shape on the propeller is lowering the torque, and it should be considered for the design. However, it should be observed in more detail propeller conditions to elaborate on the best conclusion.



(a)

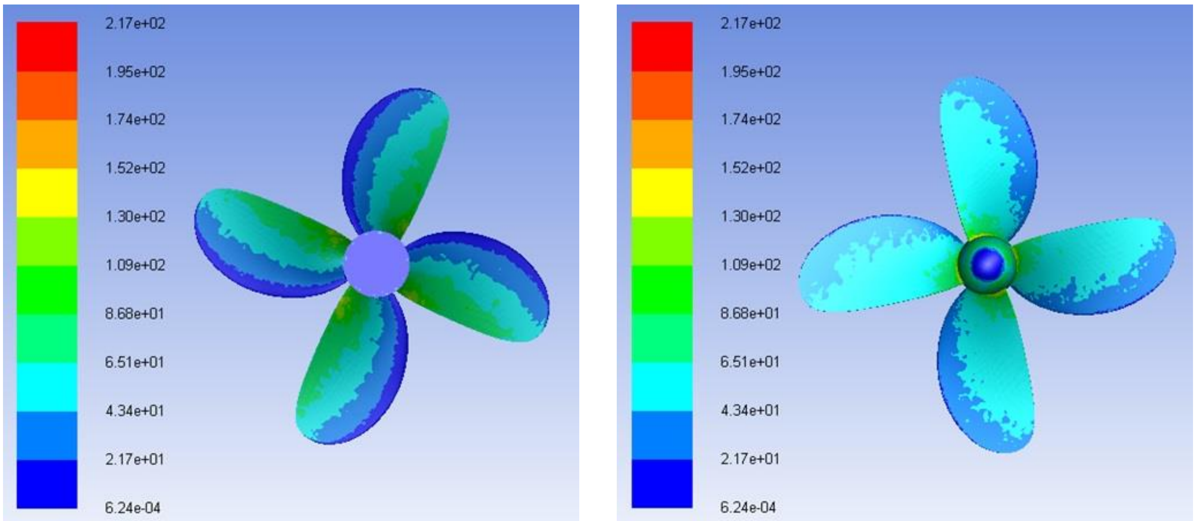


(b)

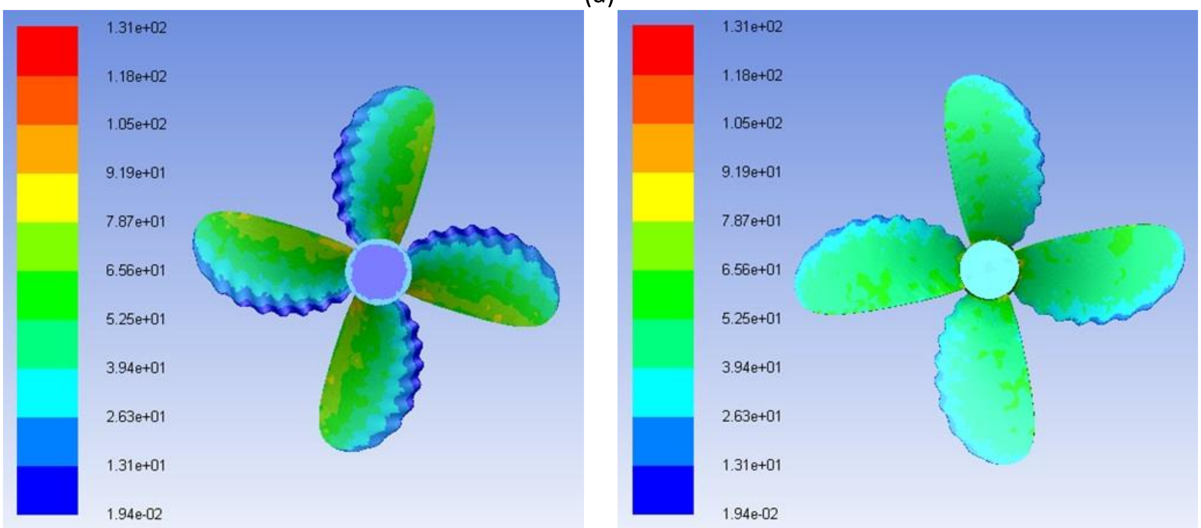
Fig. 3. The surface pressure on the back surface (left) and face surface (right). (a) Unmodified propeller, (b) Modified propeller

3.2 Surface Reynold Number Velocity Characteristic

Figure 4 shows the comparison of Reynold number velocity between the unmodified and modified propeller surface. It also shows the comparison between the back surface and the face surface. Overall, it shows that the Reynold number velocity on the modified propeller with the tubercle-like leading edge is higher than the unmodified propeller. However, the lower zone of the Reynold number velocity on the surface is only identified on the leading edge with the wider area on the unmodified propeller. The higher Reynold number velocity on the surface indicates that the water flow on the propeller surface tends to be more turbulent [18,19]. Thus, the modified propeller increases the turbulent flow on the blade surface. It is obvious due to the flow separation. It shows in the modified propeller that the higher Reynold number velocity is started at the peak of the tubercle-like shape on the leading edge. It proves that the flow separation due to the tubercle-like shape on the leading edge affects the fluid flows to the depth of the shape. The flow which is still flowing through the peak tends to be turbulent. Increasing turbulent flow on the propeller blade means increasing the vibration, which might cause multiplier effects on the propulsion.



(a)

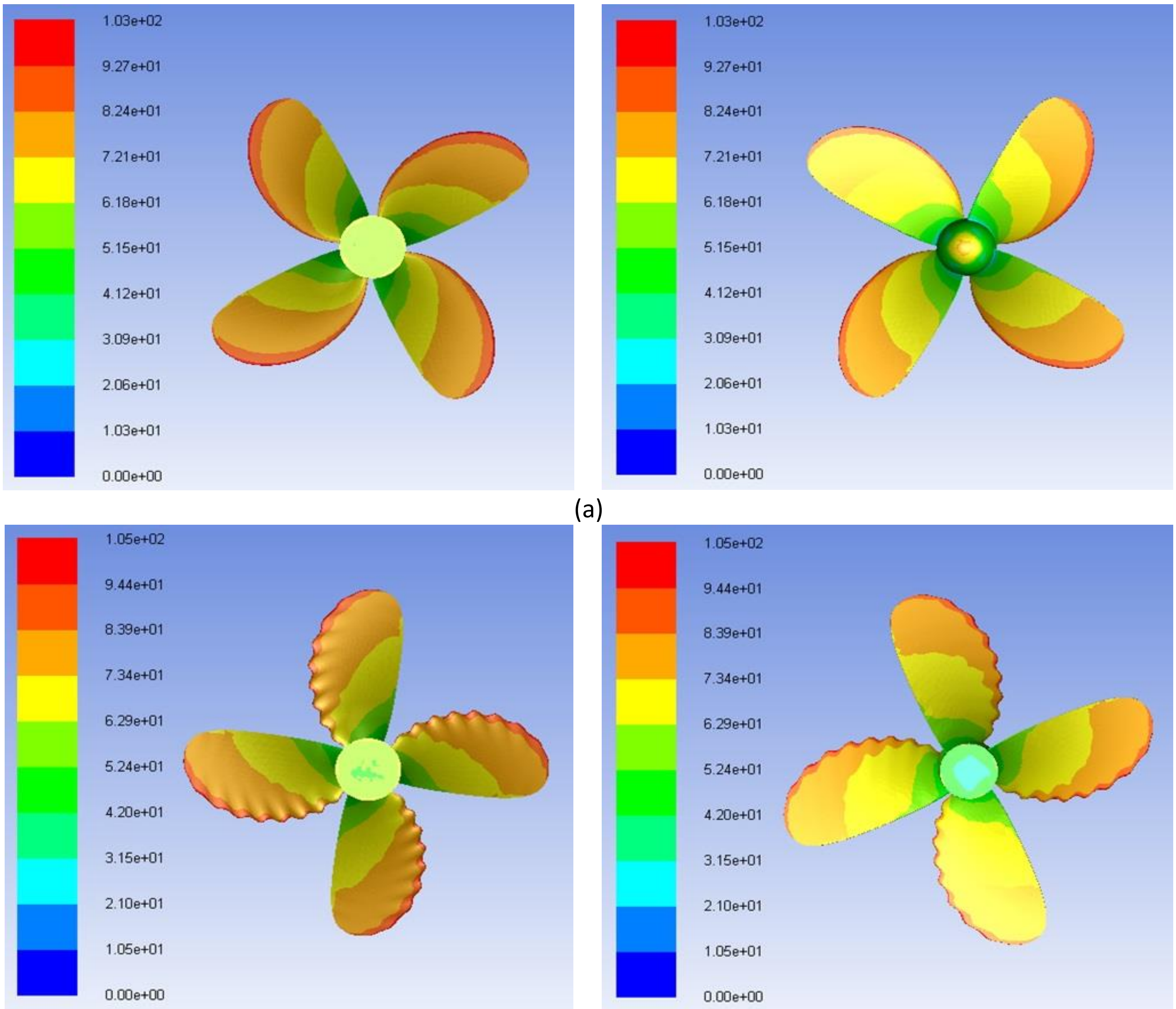


(b)

Fig. 4. Surface Reynold number velocity on the back surface (left) and face surface (right). (a) Unmodified propeller, (b) Modified propeller

3.3 Power Surface Acoustic Characteristic

Figure 5 shows the power surface acoustic of the propeller between the unmodified and modified leading edge shapes. Moreover, it also shows the comparison between the back and face surface of the propeller about the power surface acoustic contour. Overall, the tubercle-like leading edge slightly affects the power surface acoustic on the blades. However, almost all of the contours are the same, and the only difference is caused by the tubercle-like shape. The power surface acoustic on the modified propeller has an unstable contour than the unmodified propeller. It is due to the turbulent flows from the leading edge that are forced to the blades. As shown in Figure 5, the back surface of the propeller has a significant difference between the unmodified and modified propeller. In the leading edge is the highest power surface acoustic level produced. Nevertheless, in the modified propeller, the level of the power surface acoustic is lower than in the unmodified propeller. It means that the modified propeller has less noise generated by the flow through the propeller [7,20]. However, it might cause a power loss during the rotation, which might cause lower power performed by the propeller.



(b)

Fig. 5. Power surface acoustic on the back surface (left) and face surface (right). (a) Unmodified propeller, (b) Modified propeller

4. Conclusions

The flow of the tubercle-like propeller has been identified in this study. The tubercle-like propeller has an additional flow separation on the leading edge. However, that shape decreases the pressure, increases the turbulence, and lowers the noise. Decreased pressure on the surface leads to lower torque. Moreover, increased turbulence on the surface leads to higher vibration on the propeller. In addition, the lower noise due to the tubercle-like shape of the propeller leads to the lower power output from the propeller. Overall, the tubercle-like shape of the propeller has a significant effect on the flow on the surface, which tends to affect the propeller performance.

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