An experimental study on the influence of tubercles on aerodynamics performance of car rear spoiler

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Abstract. In this study, the aerodynamic performance of a car spoiler with tubercles configurations that was inspired by Humpback whale flipper morphology was investigated. This was done by producing three (T0, T3, and T9) spoiler designs where, tubercles sinusoidal protrusions pattern was applied at the leading edge of the spoiler. T0, is a base line spoiler that has no tubercles, T3, that contains three tubercles protrusions, and T9, contains nine tubercle protrusions. The baseline spoiler design was based on the Selig s2091 spoiler and the spoiler has a chord length (C) 100mm and 290mm wingspan. The spoiler was tested angle of attack from -20 to 30º and at Reynolds number 60000 in an open circuit subsonic wind tunnel. The aerodynamic performance of the spoiler was measured by the recorded time averaged lift and drag. From the recorded it was observed that at certain angles of attack, the presence of a tubercle pattern can bring a significant aerodynamic improvement.

1. Introduction

Bio-inspiration is an ideation technique that uses the observed phenomenon found in nature as a template of inspiration for mechanical applications. In this study, a bio-inspiration technique was used by taking inspiration from the humpback whale (Megaptera novaengliae) flipper. The humpback whale flipper contains patterns called tubercles that was proven to be able to improve the aerodynamic performance of Underwater Vehicles [1], Aircrafts [2], and Turbine Blades [3]. This study aims to implement the use of tubercles on the design of a automotive vehicle. This is due to the issue of rising fuel prices and the effects of air pollution give a rise in the need of a more efficient and clean automotive design. Improving the aerodynamic performance of a automotive vehicle can be vital because it was found that 25%-35% in drag reduction can contribute to a significant reduction of fuel consumption by 10% to 15% [4].

There are several previous works that focuses on improving the aerodynamic performance of an automotive vehicle [5-11]. A 3D CFD simulation where a framework was attached to the upper part of the back window that was able to decrease the drag by 17% [5]. This is because of the role of the rear spoiler in reducing the drag of the vehicle [8]. This is because with the application of the rear spoiler that induces less turbulent dispersion that will then effect in a decrease in terms of drag [9]. This proven more in a different previous work where a car without a spoiler create two different flow separation; one above the rear window and one behind the vehicle while with the addition of a spoiler only one flow separation is observed, behind the vehicle. The car spoiler plays a role in smoothing the flow transitions
from the roof of the car to the rear window and thus avoiding flow separation on the car and inducing drag [10, 11].

The car spoiler does not only play a role in decreasing drag but also helped in generating negative lift. Negative lift is important because it allows for the better transference of kinetic energy from the moving tyres to the movement of the vehicle itself, and thus creating a more efficient vehicle. A previous study has also shown that the addition of a spoiler can increase the generated negative lift of a vehicle by 7% [11]. With all of the benefits of the car spoiler it is useful to improve them by increasing their performance in these two aspects, the drag and the negative lift. This study aims to improve the aerodynamic performance of a car spoiler by implementing a sinusoidal protrusions pattern on the leading edge of the car spoiler called tubercles, which is inspired by the patterns found in the flippers of a humpback whale.

2. Methodology

2.1. Spoiler Design

The computer aided design (CAD) software Solidworks 2016 software was used to produce the spoiler designs. The shape of the designed spoiler itself was unchanged but the differences lies in only the presence and configuration of tubercles. As seen in figure 1, all spoiler designs were based on the Selig s-2091 Air foil, and the main dimensions of the air foil is kept constant with the chord length (C) was kept at 100mm and the wingspan was kept at 290mm (as seen in figure 2). Three different spoiler designs were made. The designs were named; T0, T3, and T9. T0 has no tubercles associated with it which will act as a base line design for the study. T3 spoiler contains three tubercle protrusions and T9 contains nine tubercles. Dimensions of the different spoiler designs can be seen in table 1, and the fabricated spoiler designs can be seen in figures 3, 4, and 5.

![Figure 1. Base design of Selig airfoil s-2091.](image1)

![Figure 2. Schematic Diagram of Tubercles Configuration on Spanwise.](image2)

| Model          | Wavelength Between Two Neighboring Peaks (λ), (mm) | Number of Tubercles | Dimensionless Amplitude of Bumps (h), (mm) |
|----------------|-----------------------------------------------|---------------------|------------------------------------------|
| Base Model (T0)| None                                          | None                | None                                     |
| Tubercles (T3) | 90                                            | 3                   | 20                                       |
| Tubercles (T9) | 30                                            | 9                   | 20                                       |

Table 1. Tubercles configuration.
Figure 3. Fabricated base model spoiler (T0).

Figure 4. Fabricated three tubercles spoiler (T3).

Figure 5. Fabricated nine tubercles spoiler (T9).

Figure 6 shows the experimental setup that was used for the study where a sub sonic wind tunnel was used, and a strain gauge balance was used to measure the generated aerodynamic forces. The signal from the strain gauge was processed by a Kyowa data acquisition system PCD-300A and then fed into a computer. Figure 7 shows the schematic diagram of the experimental set up.

Figure 6. Experimental setup for spoiler with tubercles performance test (Open Circuit Wind Tunnel) base design of selig airfoil s-2091.

Figure 7. Schematic diagram for experimental setup (Open Circuit Wind Tunnel).

3. Results and discussion
The main objective of this study is to investigate the effect of tubercles on the aerodynamic performance of an automotive spoiler by measuring the lift and drag at angles of attack -200, -100, 00, 50, 100, 150, 200, 250, 300 and at a fixed Reynolds number, Re=60000. As seen in Figure 8, for all spoiler designs, as the angles of attack decreases, the lift decreases until at angle of attack 250, where the lift begin to increase. All spoilers begin to generate negative lift at around 00. In terms of the effect, all spoiler design generates around the same lift at early angle of attack, but the values begin to differ at around angle of attack 50. Beyond this point just the presence of tubercles the spoiler generates greater negative lift. T3 model generates the greatest negative lift followed by the T9 model. This shows that while the presence of tubercle has an effect, larger number of tubercles does not generate greater negative lift. It is possible that there is an optimum number of tubercles for spoiler design before the negative lift generation begins to deteriorate.
In terms of generated drag, figure 9 shows that as the angle of attack increases, the generated drag decreases until angle of attack 250 where the generated drag begins to increase. Also, at early angles of attack, the generated drag is similar until angle of attack 50 before there is an observable difference between the spoilers with tubercles and the base model spoiler, with the spoiler with tubercles generating less drag. From angle of attack 50 to angle attack 150 the T9 generate the least drag. But, at angle of attack 200 and above, T3 generates the least drag.

Figure 8. Graph of $C_L$ vs AoA at Re=60000.  
Figure 9. Graph of $C_D$ vs AoA at Re=60,000.

4. Conclusion
From the observed results, it can be concluded that the tubercles do have an improvement on the aerodynamic performance of the spoiler where the spoiler is able to generate the most negative lift and the least drag. In general, both lift and drag decreases with increasing angle of attack until angle of attack 250 before the generated lift and drag increased. It is also observed that at later angles of attack, 200 and beyond, the T3 has the best aerodynamic performance with the greatest negative lift and the least drag. The best observed result in this study is the T3 at angle of attack of 250. This study proves the concept of the role of tubercles on the aerodynamic performance and can be used as a basis for further optimisation process for spoiler design.

Acknowledgments
Authors wishing to acknowledge assistance or encouragement from colleagues, special work by technical staff or financial support from organizations should do so in an unnumbered Acknowledgments section immediately following the last numbered section of the paper.

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