A Simulation Study Of Tubercles Effect Of Aerodynamics Performance On Car Rear Spoiler

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Abstract. The tubercle effect is a recently discovered phenomenon where the sinusoidal pattern ‘bumps’ on the leading edge of an airfoil can improve the aerodynamic performance. This effect was inspired by looking at the humpback whale pectoral flippers that give an exceptional acrobatic manoeuvrability in the water such as somersaults, also allowing for easier capture of prey. The objective of this research is to study the effect of implementing the tubercles concept on the car spoiler in order to see whether it bring advantage or disadvantage in the aerodynamic performance of a car. The design and simulation process are done by using Solidworks. The design of airfoil spoiler based on Selig S2091 (low Reynolds number airfoil) with sinusoidal pattern leading edge were computationally used. The Airfoil spoiler with 270 mm of the chord length (C), 1200 mm wingspan (L) and angles of attack of -5°, 0°, 5°, 10°, 15°, 20°, 25°, 30° were improvised with tubercles at 40 mm amplitude of bumps (h) and the distance of the wavelength between peaks (λ) of 1200 mm, 240 mm and 133.33 mm. The simulation was tested at 40 m/s. The investigation shown that the tubercles can improve the aerodynamic performance of car rear spoiler where the tubercles are able to increase the lift coefficient but has a significant decrease in drag only at 20° and above angle of attack.

1. Introduction
Tubercles referred to the rounded protuberances at the leading edge of airfoils with a sinusoidal pattern shape that can provide improvement in performance under certain condition. It is inspired by humpback whale pectoral flippers that give exceptional acrobatic manoeuvrability such as somersaults; an accomplishment that is novel among Baleen whales [1].

Several of numerical and experimental analysis have been performed to achieve more quality information and better understanding on tubercle concept [2-4]. According to the past studies, the researchers have exposed that the principle impact of leading-edge tubercles on wing performance is softening and delaying of stall [5-6], resulting in the reduction of drag as well increase lift at high angles of attack. The results found able to justify the fact that how enormous animal such as humpback whale can possibly able to manoeuvre so athletic and execute tight turns [5].

The detailed simulation revealed that at 15° angle of attack, the similarity of the streamwise vortices at the midsection of both flippers completely vanishes, instead the scalloped flipper displays a largestreamwise vortex that aligned with the tubercles compared to smooth flipper that shows no such structures. The development in the detachable area of the flipper is clear. More momentum energy
possesses in the region where the flow gone through over the scalloped flipper which resulting in the delays of the separation [7].

Technically, tubercles may be a half oval shape, but it can be modified in modern engineering technology application in order to improve the performance. There are several types of tubercles shapes available and an experimental had been conducted to reveal a better design pattern inspired from the tubercles shape [8].

Car rear spoilers on the vehicle are known as wings. One of the design goals of the implementation of the rear spoiler is to “spoil” unfavourable air movement across a body of a vehicle in motion, usually described as turbulence or drag. Recent investigation on 2011 revealed that a vehicle fitted with several real spoiler configurations did induce less turbulent dispersion that will affect in aerodynamic drag reduction compared to similar vehicle without spoiler [9].

From the investigation have done, it can be observed that configuration of car without spoiler shows two different flow separations (above rear window and behind vehicle) while car with spoiler shows only one flow separation which is behind vehicle. The transitions of the airflows from roof to the rear window need to be smoothed (laminar flows) to avoid bad flow separation [10] because it also can create additional amount of drag to the vehicle. The same research shows the simulation result on drag coefficient based on two configuration which is car without spoiler and car with spoiler [11].

Based on the result, it is also observed that significant change in terms of drag force (decrement in 17.2%) can be distinguish between these two configuration (cases) and so did the negative lift-force over the vehicle body; it additionally builds negative lift by decreasing the lift coefficient from -0.222 to -0.239, which is 7% lift reduction [11].

However, the investigation on implementing leading edge tubercles by existing researchers are so limited to the airfoil wings rather than car rear spoiler. From the inspiration of the humpback whale flipper’s wings, the concept of leading-edge tubercles being used in this simulation research from designing the tubercles configuration in order to identify the effect of aerodynamic drag reduction on car rear spoiler and to study the flow pattern on the tubercles.

2. Methodology
The simulation uses the same base car design that was made using Solidworks CAD software. The only changes in design that was made is in terms of the design of the spoilers them selves. Each spoiler has a chord length of 270mm and a wingspan of 1200mm. The design of the spoilers are based on the Selig S2091 airfoil. Four spoiler designs that was made with the spoiler M0 designated as the baseline design with no tubercles. The spoiler design with a single peak was designated as M1, the spoiler with 5 peaks was designated as M2, and the spoiler with 9 peaks was designated as M3. Each sinusoidal tubercles pattern has a peak of 40mm. The designed car and their respective spoilers can be seen if Figure 1-4.
As for the simulation process, a virtual air-chamber has been made around the car models (Figure 5), which represents the virtual wind tunnel in order to match the condition of a real-life situation. The overall size of the virtual wind tunnel is length = 40 m, height = 10 m and the width = 20 m. The space of the virtual air at the rear side of the car is more than at the front side in order to capture the flow behavior behind the vehicle because the interested in analyzing the “wake of vehicle” phenomenon.

The windspeed for the simulation was set at 30m/s and the spoilers was tested for their lift and drag generation at angles of attack; -5°, 0°, 5°, 10°, 15°, 20°, 25°, and 30°. The turbulence model used for the simulation was the Spalart-Allmaras turbulence model.
3. Results and discussion

As seen in Figure 6, it can be observed that at most angles of attack, the values of the generated drag is similar with the spoilers with tubercles have slightly lesser drag compared to the M0 model. However, at later coefficient (above 20°) the decrease in generated drag for the tubercles spoilers is significant. In terms of the differences between the tubercles designs however, while only slightly, M3 spoilers seems to generate the most drag at lower angles of attack (below 20°) but has the lowest generated drag at higher angles of attack (above 20°). This shows that the usage of different design is suitable for different angles of attack.

For lift coefficient, Figure 5 shows that, almost values of M1, M2 and M3 observed to have a higher lift generation than M0. This is true for all angles of attack. In terms of the effect of different tubercles, it can be observed that with increasing number of tubercles, the lift generation seem to increase. M1 has the least generated lift at all angles of attack followed only slightly by M2 and M3 has a significant increase in lift with an average increase of 1.771% above M0 for all angles of attack.

The Figure 8-11 shown a velocity contour different model. For M0 and M3, there are three regions where the concentrated blue colour exist. However, for M1 and M2, the concentrated blue colour can be seen significantly only at the back of the car. This explained the occurrence of turbulent dispersion whereas the velocity at that region became zero.
Two whirlpools of the air flow streamline created at the end of the car back for M3 shown the turbulent dispersion of this model is the worst compared to the others. For M1, the flow separation behind the spoiler is better compared to others because it produced less turbulent dispersion and can be easily identified with the concentrated of the blue colour.

4. Conclusion
The configuration of tubercles on car rear spoiler was proved in term of aerodynamics performances such as drag reduction. The configuration of tubercles also improved in flow pattern behind the car rear spoiler which is the flow separation is better compared to base spoiler because it produced less turbulent dispersion. Overall, the implementation of tubercles on the rear car spoiler can reduce the drag and the lift coefficient with the M3 showing the clearest improvement of lift.

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