Computational Fluid Dynamics (CFD) investigation onto passenger car disk brake design

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Abstract. The aim of this study is to investigate the flow and heat transfer in ventilated disc brakes using Computational Fluid Dynamics (CFD). NACA Series blade is designed for ventilated disc brake and the cooling characteristic is compared to the baseline design. The ventilated disc brakes are simulated using commercial CFD software \textsuperscript{TM} using simulation configuration that was obtained from experiment data. The NACA Series blade design shows improvements in Nusselt number compared to baseline design.

1. Introduction
The brake is the most essential part of a vehicle regardless of it physical properties because brake system are considered as a safety control of a vehicle during emergency or any other normal conditions usage [1]. Efficient braking system enables a vehicle to stop smoothly during driving on condition that the vehicle provide essential braking torque to the wheel and at the same time dissipate heat generated by friction between the brake rotor and the pad [2].

As a result of demand on increasing vehicle speed, weight and acceleration, the necessity for brake disc cooling is also increasing [3]. Efficiency of the disc brake need to be achieved in order to full fill customers demand. Firstly, the cause of this problem should be identified. During braking, vehicles kinetic and potential energy are converted into thermal energy by the friction between brake pads and rotor faces. When the brake disc temperature rises, the braking performance reduce which may lead to deformation, judder, squeal, increased wear and complete damage of brake. Larger amount of heat generated will be absorbed by brake parts in a very short period of time during braking. As a result, the brake disc must store and dissipate energy quickly during braking process [4]. Therefore, ventilated disc brake is becoming more essential for better cooling efficiency as it consume a larger area to dissipate heat [5]. Ventilated disc brake help to improves the convection cooling by separating the braking surfaces using air passages. The rotor acts as a centrifugal fan to draw cool air from the inboard side, passing through the rotor passages and exhausting at the outer diameter. Other than that, ventilated disc brake help in storing energy and dissipating it quickly and efficiently during braking since braking process occur very fast [6].

2. CFD Simulation of Flow and Heat Transfer.
The baseline design is a commercial-vehicle ventilated cast iron disc and this design has 36 equally spaced blades. The design of this blade is done in two dimensional and the commercial CFD software
**FLUENT**™ is used for simulation. The simulation configuration is tabulated in Table 1 below as boundary condition to CFD model.

The flow is periodical model consist of 55188 computational mesh for baseline design and 66790 computational mesh for NACA Series design. A mesh dependency test was carried out to make sure that the selected mesh will generate a mesh independent result. The RNG k-ε turbulent model with standard wall treatment is employed. The disc is simulated with six different velocity and rotational speeds. The brake wall is set to be isothermal at 300°C to simulate the braking heat.

**Table 1.** The simulation boundary condition

| Velocity in (m/s) | Rotational Speed (rad/s) | Pout  |
|------------------|--------------------------|-------|
| 2.46             | 67.34                    | 0 gage|
| 2.89             | 84.18                    | 0 gage|
| 3.28             | 101.01                   | 0 gage|
| 4.00             | 117.85                   | 0 gage|
| 4.41             | 134.68                   | 0 gage|
| 5.54             | 168                      | 0 gage|

Figure 1 compares the Nusselt number for both baseline and NACA Series design blade design. Both Nusselt number increases as the rotational speed increases and NACA Series blade design disc brake has higher Nusselt number than baseline design disc brake. The NACA Series blade design has cooling improvement of Nusselt number approximately by 14.4% compared to baseline design disc brake. Figure 2 illustrates about the temperature contour of both designs in the highest rotational speed. NACA Series design shows a better temperature distribution near the blade than the baseline design. This proofs the finding of the Nusselt number above.
3. Conclusion
The investigation concludes that the NACA Series design is superior in cooling compared to the baseline design ventilated disc brake. From CFD simulations, the Nusselt number coefficient increases as the rotational speed increases for both designs.

References
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