The Aerodynamics of Ventilated Disk Brakes

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The brake is the utmost important component of a vehicle regardless of it shape, size and weight. A brake system is akin to the reaction force for any action force. The action force would be the engine's performance. A brake system needs to be as good as the brake's horse power for safety and exceptional handling qualities.

The history of the brake disk revolution was recorded from the early 20th Century by Newcomb (Newcomb, 1981). The development of the brake started from the dog cart automobile where contemporary bicycle or carriage brakes were used. Within a century, the braking technology has evolved tremendously. One specific contribution in the ventilated brake disk design is the aerodynamic improvement of the disk brake blade design which is highlighted in this article.

Lanchester had patented one of the earliest spot-type brake disk in 1902 (Newcomb, 1981). The vented passage concept in the brake rotor is to increase the level of heat convection. Limpert, R. 1975, stated that convective heat transfer of the vented disk is almost double that of the solid disk (Johnson, 2003). However, very little research has been done on the optimisation of the ventilated blade design.

Throughout the development of the brake technology, the ventilated brake disk is the state-of-the-art technology in automobile brake system. Vehicle designs have mostly concentrated on vehicle aerodynamics, thus the importance of proper brake systems is often disregarded. The brake system normally consists of the ventilated brake disk, which function as a means of storing energy and dissipating it quickly during braking. The braking process is a very quick process; therefore, the brake disk has to be able to dissipate the energy quickly and efficiently.

The brake disk has a fan-like effect, allowing air to flow through it smoothly. There are three means of transferring heat, namely, by conduction, convection and radiation. Conduction is the transfer of heat through the brake disk to its mating component, convection is the transfer of heat through the atmosphere, while radiation is the transfer of heat to the atmosphere and its adjacent components. There was a limited number of work done in past years on the flow characteristics of the ventilated brake disk and its related blade designs.

An arbitrary design of a race car's brake disks was chosen in this flow investigation as shown in Figure 1. The conventional blade design for a race car's ventilated brake disk normally has blunt leading and trailing edges with sharp corners for manufacturing convenience. A blade design modification to improve the disk brake aerodynamics by streamlining can be seen in Figure 1. Both designs are simulated using computational fluid dynamics by solving the flow equations governing the flow field.

The parameters, such as the mass flow through the ventilated blades and the surface heat transfer coefficient, are calculated and compared for the two designs. The ventilated blade designs for the conventional and streamlined brake disks are illustrated in Figure 1. Both brake disks have 48 blades and the only difference between the two designs is the blade profile.

The flow is periodical in the circumferential direction, thus only 1/48th of the geometry is modelled. The computational grid is generated by the Geometry and Mesh Building Intelligent Toolkit (GAMBIT) and simulated in the FLUENT proprietary software, by Fluent Inc. Appropriate boundary conditions (periodical, wall and symmetry) were determined. The RNG k-e two-equation model is assumed for the turbulence transport equations as validated by the experiment above and as used by Rahman and Faghri, 1992, in their CFD simulation. The code uses the Launder-Spaulding law-of-wall for wall treatment.

A segregated solver was chosen since the flow is relatively low speed and the pressure correction method is used for the flow field calculation. The whole flow field is set to be in a rotating frame of reference. Both brake disk designs are simulated with a design rotational speed of 147 rad/s, which is equivalent to a road speed of 100mph. Two off-design cases are simulated for both designs at 73 rad/s and 220 rad/s rotational speed, which are equivalent to a road speed of 50mph and 150mph respectively.

The flow through the ventilated blade is drawn symmetrically around the mid-span of the blade, thus only one half of the brake disk ventilated blade geometry is modelled. The plane is defined as a symmetric boundary. The second order upwind spatial discretization scheme is used for the solver. The brake walls are set to be isothermal at 300°C.

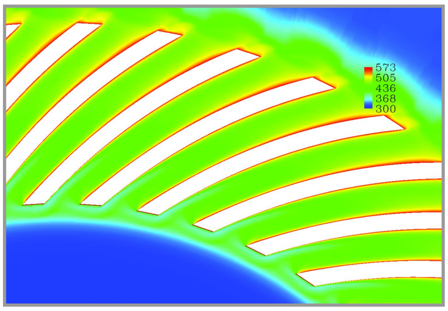
A structured H-type mesh is used for the simulation of a conventional brake disk design due to the rectangular shape of the blade. However, unstructured and structured C-type mesh near the wall is used for the streamlined ventilated brake disc design due to the curved shape at the leading edge. The number of cells or the computational nodes involved is approximately 250,000. A grid dependency study has been carried out and the optimal numbers of grid points are chosen to give a satisfactory compromise between accuracy and computational time.

The convergence criteria of the third order residuals reduction were fulfilled for all rotational speed calculations. However, the simulation continued until stable values of the wall heat flux of the blade were obtained. The mass flow rate through a pair of ventilated blades and the ventilated blade wall heat flux are extracted from the results of the Computational Fluid Dynamics. The parameters between the conventional and the streamlined brake disk design were compared.

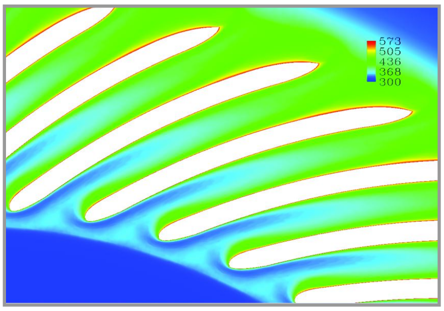
The flow induced by the rotational motion of the brake disk causes the through-flow inside the ventilated blades. The dominant forces in thin film flow near the rotating disk are friction exerted by the disk, centrifugal and coriolis forces due to rotation and inertia from the incoming fluid stream. This creates an induced flow. In other words, the brake disc acts like a centrifugal fan and, hence, will improve the heat transfer via convection.

The raw results show that the mass flow and surface heat transfer increase by at least 30% from the conventional design for all three road speed. Figure 1 shows the temperature distribution of the ventilated brake disks for both designs. The conventional design has a higher air temperature near the pressure side of the blade, whereas for the streamlined case, the temperature distribution is smoother from the inlet of the blade throughout the whole blade flow passage. This would explain the mass flow increment. The increase in the mass flow is more effective in cooling, giving higher heat transfer coefficients.

An innovation in the aerodynamics of brake disk design has predicted a significant improvement in the cooling of the brake disk. A simple streamlining of the ventilated disk blade can have a significant effect on brake disk cooling, by reducing the incidence angle of the rotational flow around the blade and increasing the mass flow. In turn, the increment in the mass flow results in the improvement of the heat transfer coefficient. The analysis also shows similar improvements for all three rotational speeds studied. From the simulations, both the mass flow and heat transfer rates increase linearly with the rotational speed. Simple streamlining is predicted to be worthwhile in displaying substantial improvement in ventilated brake disc performance. ■



a) Conventional disc at 100mph



b) Improved disc at 100mph

Figure 1: Two dimensional cut of the temperature distribution (Kelvin) for a few road speed simulation configurations