# AERODYNAMICS COOLING OF DISC BRAKE ROTOR

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‘I admit that have read this work and in my opinion this work was adequate from the aspect scope and quality to award Ijazah Sarjana Muda Kejuruteran Mekanikal (Termal-Bendalir)

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“I declare that this report is done by my own exclude citation with the mentioned references for each.”

Signature :…………………………..

Author:……………………………...

Date:………………………………...

To beloved father and mother

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# ABSTRAK

Untuk mencipta sistem brek yang berkesan, pelepasan haba mestilah diambil kira kepentingannya. Udara sejuk dihasilkan untuk memastikan brek dapat beroperasi pada kadar masa yang panjang, oleh itu adalah amat penting untuk meningkatkan aerodinamik pada kawasan komponen brek. Projek ini dilaksanakan adalah untuk mendapatkan pemindahan haba melalui analisis terma pada rotor brek cakera. Simulasi aliran udara pada kawasan brek rotor telah dilakukan melalui teknik CFD. Keputusan kadar aliran yang digunakan dan pekali pemindahan haba telah didapatkan menggunakan perisian FLUENT 6.2. Nilai daripada keputusan tersebut dikaji dimana ia membantu kepada proses penyejukan brek melalui kesan aerodinamik.

# ABSTRACT

To create an effective braking system, the heat dissipation must be taken into accounts. Cooling air is generated to ensure that the brake can be operated in longer time so, the aerodynamics in the region of brake components is important to be developed. The project is done to obtain heat transfer through thermal analysis of disc brake rotor. Simulation of airflow at the region of the brake rotor is done using CFD techniques. The result of the flow rates and heat transfer coefficient is obtained using the software Fluent 6.1. The values from the results are reviewed to determine whether it can be helped to the brake cooling process trough effect of aerodynamics.

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# LIST OF SYMBOLS

$\mu$ = Coulomb friction

$M$ = Mass

$V$ = Velocity

$t$ = Time, s

$r$ = Radius

$Q$ = Rate of heat transfer ,Watts(W)

$h$ = Convection heat transfer coefficient ($W/m^2$ k)

$A$ = Area

$T$ = Temperature

$D$ = Aerodynamic Drag

$\rho$ = Density

$C_d$ = Non-dimensional Drag Co-efficient

$Z$ = Number of vanes

$D$ = The mid diameter of the rotor

$w$ = The flow passage width

$t$ = Thickness of the vanes

$\omega$ = Rotational velocity (rad/s)

$R_{eff}$ = Effective radius (m)

$a_d$ = Deceleration rate ($rad/s^2$)

$I$ = Brake rotor inertia ($kg/m^2$)

$E$ = Total braking energy (kJ)

$q$ = Heat flux ( $kW/m^2$)

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# CHAPTER 1

# INTRODUCTION

## 1.1 Background of project

The braking system is undeniably the most important parts in a road vehicle. It must be able to remove the kinetic and potential energy of the vehicle to enable safe retardation. Friction brakes operate by converting vehicles kinetic and potential energy into thermal energy (heat). According to (Limpert, 1975), during braking a large amount of heat can be created and has to be absorbed by brake components in every short space of time. However the allowable temperatures of the brake and surrounding components limits the thermal energy a brake can store. According to (Day and Newcomb, 1984) the absorb heat must be effectively dissipated to achieve satisfactory performance of braking. According to (Day, 1988) high temperatures are responsible for most problems in vehicle braking system. If the heat is not dissipated effectively the temperature in the brake and surrounding components become too high. This circumstance will lead to excessive component wear, squeal and complete failure of the brakes. To reduce the problems and to create safer vehicles transport, the improvement to the cooling characteristics of braking system is extremely needed.

The friction between the brake rotor and lining pad generates the heat which will be absorbed by rotor and other joint components. As braking continues, heat dissipated through convection to the atmosphere and also from conduction and radiation to nearby components. Convection to the atmosphere plays an important role of heat dissipation from the brake rotor; therefore the airflow must be controlled and must be directed to the appropriate region since airflow or cooling air give major assist to convection heat transfer.

## 1.2 Significant of project

The significant of this project is to provide better understanding of aerodynamics brake cooling. The purpose of this project is also to recommend methods of improving aerodynamics heat dissipation. The result of the project will serve information onto aerodynamics improvement that can be made to automotive brake cooling. By improving brake cooling, the weight of the brake and associated component maybe reduced. The thermal brake failure (brake fade and fluid vaporization) also can be reduced as well as noise and cost.

## 1.3 Objectives

The objectives of this project are:

- To understand the working principles, components, standard and theories through a literature studies
- To understand the working principles of CFD software (FLUENT 6.1)
- To understand the fundamental of heat transfer through airflow of disc brake rotor
- To study the airflow of disc brake rotor and provide the cooling effect through heat transfer.
- To clearly justify the result and conclusion

## 1.4 Scope of project

This study is primarily focus on:

a) Literature review on the working principles, components, standard and theories.

b) Construction of 3D model of disc brake rotor.

b) To do an analysis with the disc brake rotor using Computational Fluid Dynamics (CFD).

c) Final justification and conclusion.

## 1.5 Problems statement

According to (Hunter et al, 1998) if the temperatures reached in braking become too high, deterioration in braking may result, and in extreme conditions complete failure of the braking system can occur. It can be difficult to attribute thermal brake failure to motor vehicle accidents as normal braking operation may return to the vehicle when the temperatures return to below their critical level. One of the most common problems caused by high temperatures is brake fade; other problems that may occur are excessive component wear, rotor deterioration. Heat conduction to surrounding components can also lead to damaged seals, brake fluid vaporization, as well as wheel bearing damage, while heat radiated to the tyre can cause damage at tyre temperatures as low as (93°C), (Limpert, 1975). Therefore, the study on aerodynamics cooling will give an input to heat dissipation of disc brake rotor. The result of the project will shows the information on how and where aerodynamics improvements can be made to automotive brake cooling.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Overview of disc brake

Large thermal stresses always occurred during routine braking and larger thermal stresses happened during hard braking. Typical passengers vehicle can generate as high as 900°C which may produce two possible outcome that are surface crack or large amount of plastic deformation. T.J. Mackin et al.(2000) had studied on thermal cracking that happens in disc brakes. Their findings said that the cracks fall into two categories: a series of heat cracks that partially penetratre the surface of the disc and thru cracks that completely pass through the disc wall.

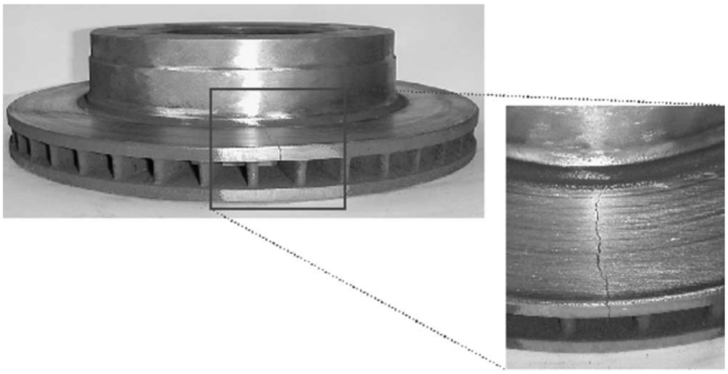

Figure 2.1 Picture of a failed front brakes disc rotor (Source: T.J. Mackin et al, (2000))

According T.J. Mackin et. al. (2000) there are three ways to eliminate thermal cracking in brake rotors: first increase the yield and fatigue strength of the rotor material; second decrease the braking temperature; and third redesign the hub-rotor unit to eliminate constraint stresses. New brake materials have been identified that can operate at higher temperature but this leads to a need for heat shielding around the brakes. Designs that incorporate cooling also difficult to achieve. The best way is to eliminate constraint brought about by rotor-hub.

## 2.2 Friction Braking Systems

Friction brakes happen by converting the vehicles kinetic, and sometimes potential energy into thermal energy (heat). Heat is created due to friction at the interface between a rotor (disc or drum) and (pads or shoes). During braking, a large amount of heat can be created and has to be absorbed by the rotor. The rotor and surrounding components effectively act as temporary thermal storage devices, and sufficient cooling of these components is essential to achieve satisfactory performance of the braking system, (Day and Newcomb, 1984). It is therefore vital that heat is effectively dissipated for the successful operation of a braking system.

## 2.3 Types of Friction Braking Systems

Two main types of automotive brakes exist, drum and disc. Drum brakes operate by pressing shoes radially outwards against a rotating drum (rotor), while disc brakes operate by axially compressing pads (stator) against a rotating disc (rotor). A more advanced form of the disc brake is the ventilated or vented disc, where internal cooling is achieved by air flowing through radial passages or vanes in the disc.

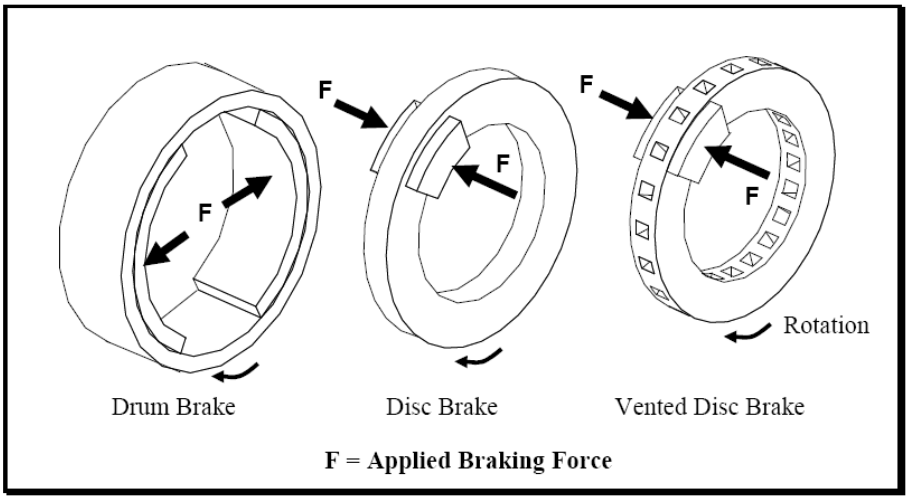

Figure 2.2: Schematic view of drum and disc brakes, (Source: Baker A.K., 1986)

The disc brake gain broad advantages against drum brakes in passenger's cars and light duty truck.

The advantages of disc brakes are:

a. The rubbing surfaces that contact with disc brakes are exposed to the atmosphere resulting better cooling and minimizing the possibility of thermal failure.
b. Disc brake adjustment is achieved automatically while for drum brake adjustment can be achieved only when frictional material wears.
c. Disc brakes are less sensitive to high temperatures and can operate safely at temperatures of up to 1000°C. Drum brakes due to their geometry and effects on their friction co-efficient should not exceed 500-600°C, (Limpert, 1999). Brake discs (solid and vented) are generally cast from an iron alloy and machined to the required finish.

## 2.4 Brake Fluid Vaporization

Most braking systems are hydraulically actuated, with the exception of heavy-duty trucking. If temperatures reached during braking exceed the boiling point of the hydraulic fluid then brake fluid vaporization will occur. A vapour lock will then form in the hydraulic circuit, and as gas is more compressible than liquid the pedal stroke is used to compress this gas without actuating the brakes. Brake fluid is hydroscopic causing it to absorb water from the atmosphere over time; this may result in a reduced boiling temperature of the fluid, (Hunter et al., 1998). Therefore it is usually recommended by vehicle manufacturers to replace brake fluid periodically.

## 2.5 Brake Fade

Brake fade is a temporary loss of braking that occurs as a result of very high temperatures in the friction material. The high temperature reduces the coefficient of friction between the friction material and the rotor, and results in reduced braking effectiveness and ultimately failure. Generally fade is designed to occur at temperatures lower than the flame temperature of the friction material to reduce the possibility of fire at extreme temperatures. Normal braking will usually return when temperatures drop below their critical level.

## 2.6 Excessive Component Wear

High temperatures in the braking system can form thermal deformation of the rotors leading to uneven braking, accelerated wear and premature replacement. The life of the friction material is also temperature dependent, at higher temperatures chemical reactions in the friction material may cause a breakdown in its mechanical strength, which reduces braking effectiveness and causes rapid wear. The wear of frictional material is directly proportional to contact pressure, but exponentially related to temperature, (Day and Newcomb, 1984); therefore more rapid wear will occur at elevated temperatures.

## 2.7 Dissipation of Heat from Disc Brakes

The rise in temperature of the brake disc in any braking operation will depend on a number of factors including the mass of the vehicle, the rate of retardation, and the duration of the braking event. In the case of short duration brake applications with low retardation, the rotor and friction material may absorb all of the thermal energy generated.

As a result very little heat dissipation occurs as the temperature rise in the rotor is minimal. In extreme braking operations such as steep descents or repeated high speed brake applications, sufficient heat dissipation becomes critical to ensure reliable continued braking. As the rotor temperature rises it begins to dissipate heat, at steady-state conditions heat generated through braking equals heat dissipation and no further heating occurs. If the heat generation is greater than the dissipation then the temperature will rise, the rate of this rise value will depend of the relative quantities of each. If sufficient heat dissipation does not occur the temperature of the rotor and friction material can reach critical levels and brake failure may occur.

Heat dissipation from the brake disc will occur via conduction through the brake assembly and hub, radiation to nearby components and convection to the atmosphere. At high temperatures heat may create chemical reactions in the friction material, which may dissipate some of the braking energy. However research conducted by (Day and Newcomb, 1984) indicated this to be less than two per cent of the total energy dissipated. While conduction is an effective mode of heat transfer it can have adverse effects on nearby components. Such effects include damaged seals, brake fluid vaporization, as well as wheel bearing damage. Radiation heat transfer from the rotor will have its greatest effect at higher temperatures but must be controlled to prevent beading of the tyre, (Limpert, 1975). It is estimated that the amount of heat dissipation through radiation under normal braking conditions is less than 5% of the total heat dissipated, (Noyes and Vickers, 1969; Limpert, 1975).