# THE CHARACTERISTICS OF THE IN-CYLINDER FLUID FLOW OF THE 660cc PETROL ENGINE



# UNIVERSITI TEKNIKAL MALAYSIA MELAKA

# THE CHARACTERISTICS OF THE IN-CYLINDER FLUID FLOW OF THE 660cc PETROL ENGINE

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# UNIVERSITI TEKNIKAL MALAYSIA MELAKA

### DECLARATION

I declare that this project report entitled "The Characteristics of the In-Cylinder Fluid Flow of The 660cc Petrol Engine" is the result of my own work except as cited in the references



#### APPROVAL

"I hereby declare that I have read this report and in my opinion this report is sufficient in terms of the scope and quality for the award of Degree of Bachelor of Mechanical Engineering."



# DEDICATION

"I hereby dedicate this final year report for my beloved father and mother"



#### ABSTRACT

Two major challenges for modern engine in the industry of automotive is continuous increase of fuel price and strict emission regulations. Numerous research and development on air flow during the intake stroke and air flow in the engine cylinder are done. This is because in-cylinder fluid flow has significant effect on the in-cylinder mixture preparation, combustion performance and engine response. This is all towards cleaner emissions and high fuel efficiency. Introduction of new engine technologies such as spark controlled compression ignition (SPCCI) that is use in Mazda Skyactiv-X engine also contribute to increasing of attention on in-cylinder charge motion. In-cylinder fluid flow in an engine are air flow going into the engine cylinder with a swirl or tumble motion of air. The fluid flow enhances fuel vaporization and fuel-air mixing process for combustion. Therefore, the aim of this project is to study in-cylinder fluid flow of 660cc, petrol engine under steady state condition. Parameters of in-cylinder fluid flow that going to be study are air flow rate into the cylinder that is then translated into coefficient of discharge, Cd, swirl speed and tumble speed during intake stroke using a Superflow® SF-1020-SB flow bench machine. The experiments were done on cylinder 2 of the engine at 25" H<sub>2</sub>O test pressure. Cd and swirl speed were measured at various intake valve lift per diameter ratio, L/D. Tumble speed was measured at intermediate and maximum L/D at various cylinder head orientation,  $\theta$ . Result from all the test done was recorded and discussed in the report. Cd increase gradually with L/D and the maximum Cd was 0.33. Swirl speed also increase with L/D but the trend is more random. Maximum swirl speed is 1770rpm at 0.35L/D. Maximum tumble speed obtained was 2250rpm at 0.35L/D. And the orientation that produce high tumble speed at both intermediate and maximum L/D is at 0°.

#### ABSTRAK

Dua cabaran utama untuk enjin moden dalam industri automotif adalah kenaikan berterusan harga bahan api dan peraturan emisi yang ketat. Banyak penyelidikan dan pembangunan pada aliran udara semasa strok masukan dan aliran udara dalam silinder enjin dijalankan. Ini adalah kerana aliran cecair dalam silinder mempunyai kesan ketara ke atas penyediaan campuran dalam silinder, prestasi pembakaran dan tindak balas enjin. Ini semua ke arah emisi yang lebih bersih dan kecekapan bahan api yang tinggi. Pengenalan teknologi enjin baru seperti Spark Controlled Compression Ignition (SPCCI) yang digunakan dalam enjin Mazda Skyactiv-X juga menyumbang kepada peningkatan perhatian pada gerakan cas silinder. Aliran cecair dalam silinder di dalam enjin adalah aliran udara masuk ke dalam silinder enjin dengan gerakan pusaran atau jatuh udara. Aliran cecair meningkatkan pengewapan bahan api dan proses pencampuran bahan api untuk pembakaran. Oleh itu, matlamat projek ini adalah untuk mengkaji aliran bendalir dalam silinder 660cc, enjin petrol di bawah keadaan keadaan mantap. Parameter aliran cecair dalam silinder yang akan dikaji ialah kadar aliran udara ke dalam silinder yang kemudiannya diterjemahkan ke dalam pekali pelepasan, Cd, kelajuan putaran dan kelajuan jatuh semasa stroke pengambilan menggunakan mesin bangku aliran Superflow® SF-1020-SB. Eksperimen dilakukan pada silinder 2 enjin pada tekanan ujian 25 "H2O. Kelajuan Cd dan pusaran diukur pada nisbah pengambilan injap pengambilan pelbagai, L / D. Kelajuan putaran diukur pada L / D pertengahan dan maksimum pada pelbagai orientasi kepala silinder,  $\theta$ . Hasil dari semua ujian yang dilakukan telah direkodkan dan dibincangkan dalam laporan tersebut. Cd meningkat secara beransur-ansur dengan L / D dan maksimum Cd ialah 0.33. Kelajuan berputar juga meningkat dengan L / D tetapi trendnya lebih rawak. Kelajuan putaran maksimum ialah 1770rpm pada 0.35L / D. Kelajuan maksimum jatuh ialah 2250rpm pada 0.35L / D. Dan orientasi yang menghasilkan kelajuan jatuh tinggi pada kedua-dua pertengahan dan maksimum L / D adalah 0°.

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# LIST OF SYMBOLS

SPCCI	-	Spark Controlled Compression Ignition
Cd	-	Coefficient of discharge
SI	-	Spark ignition
cc	-	Cubic centimeter
L	-	Liter
rpm	-	Revolution per minute
2VWALA	YSIA-	Two valve
4V		Four valve
SOHC	-	Single Overhead Cam
Kg	-	Kilo gram
hp	_	Horse power
mm	-	Mili meters
Rs	ahun	اوىيۇم سىتى ئىكە Swirl ratio
Rt		Tumble ratio
	SITI_TI	Swirl angular speed
ωt	-	Tumble angular speed
cfm	-	Cubic feet per minute
L/D	-	Valve lift per diameter ratio
$\Delta p$	-	Pressure drop
θ	-	Cylinder head orientation
دد	_	Inch

#### **CHAPTER 1**

#### **INTRODUCTION**

#### **1.1 Introduction**

Two major challenges for modern engine in the industry of automotive is continuous increase of fuel price and strict emission regulations (M. El-Adawy et al., 2017). Numerous research and development on air flow throughout the intake stroke and air flow in the engine cylinder are done. It has significant effect on the in-cylinder mixture preparation, combustion performance and engine response. This is all towards cleaner emissions and high fuel efficiency (M. El-Adawy et al., 2017, Mazda, 2017). Introduction of new engine technologies such as Spark Controlled Compression Ignition (SPCCI) that is used in Mazda Skyactiv-X engine (Mazda, 2017) have cause increasing of attention on in-cylinder charge motion. To overcome the challenges and produce an innovation, the dynamics of in-cylinder flow structures need to be understand thoroughly (A. Mohammad Ebrahim et al., 2013)

The reasons above act as a motivation of this study and the title of "The Characteristics of the In-Cylinder Fluid Flow of 660cc, Petrol Engines" is proposed. Characteristics of in-cylinder fluid flow are air flow in an engine cylinder that is swirl and tumble motion. Both of the two motions are rotational motion but on a different axis. Swirl is an air rotational flow in the cylinder on Z axis while tumble is a rotational motion on X and Y axis as shown in figure 1.1. Both swirl and tumble motions enhance the fuel vaporization and fuel-air mixing and results in better performance (C. Ramesh Kumar and G. Nagarajan, 2012, Saud A. Binjuwair B.Sc., M.Sc, 2013). Three parameters of in-cylinder

fluid flow of a small displacement spark ignition (SI) engine that is going to be study are coefficient of discharge, Cd (-), swirl speed (rpm) and tumble speed (rpm).



Air is needed for the combustion process. Because of that, air needs to flow into the cylinder. Coefficient of discharge (Cd) can be used to quantify an engine breathing potential or the air flow (N. A. Mohamad Shafie et al., 2017). Cd can be described as the air flow rate efficiency (Abdul Rahim Ismail and Rosli Abu Bakar, 2008) of the intake port of the 660cc, 3-cylinder, petrol engine going to be tested. Since the value of Cd shows the air flow rate efficiency, it can be concluded that, the higher the value of Cd, the more efficient the air flow of the intake port.

After air flow into the engine cylinder, fuel is injected to be ignited with the air. Swirl and tumble are required to mix the air and fuel to produce a mixture of air and fuel. If the mixture is homogenously mixed, the combustion will be more efficient. Swirl and tumble can be computed in term of tumble ratio and swirl ratio (Ujwal D. Patil, 2013, C. Ramesh Kumar and G. Nagarajan, 2012). Swirl measurements is usually used on two valves (2V)

and four valves (4V) diesel engines and two valves petrol engines, while normal tumble also referred as tumble is usually applied to a pent roof four valves petrol engines (M. El-Adawy, 2017)

In a single valve small displacement engine, in-cylinder fluid flow characteristics were expected to have a low value of swirl and tumble because there was only one valve for the intake port and exhaust port respectively. Hence, this study is to investigate the air flow, swirl and tumble motion of a small displacement engine and getting the exact value of the variables stated above using a flow bench machine.

This study was strictly to know the air flow performance of a 'Perodua Kancil' engine that is Daihatsu EF-CL SOHC I3. The cylinder head of the engine going to be tested using the flow bench machine or more specifically the Superflow® SF-1020-SB Flow bench machine and the port that was tested is the intake port. The flow in the intake port is measured as the coefficient of discharge(Cd). A wide variety of inlet port geometry patterns will affect the amount of air entered the port. Swirl and tumble motion of air can be examined with the additional equipment that is a swirl meter.

#### **1.2 Problem Statement**

For a car performance enthusiast, engine modification is a popular option but with a tight budget cylinder head modification is a brilliant option. In an internal combustion engine, the cylinder head has an important role in the engine performance. It closes in the top of the cylinder, forming the combustion chamber. This joint is sealed by a head gasket. In most engines, the head also provides space for the passages that feed air and fuel to the cylinder, and that allow the exhaust to escape.

Air flow in a cylinder head port can be used as an important factor to know the engine performance. Valve and port design determines the discharge coefficient (Cd) of the port and consequently the volumetric efficiency of the engine. Discharge coefficient describes the behavior of all real flows contract in an area as they pass through any restriction. Since the performance of the engine is dependent on the amount of air entering the combustion chamber, this study is aimed to determine the flow. The effect of boundary layer development on backpressure also needs to be studied because pressure drop may affect the Cd value.

Swirl motion is expected will occur in the cylinder because of the direct port design (Ujwal D. Patil, 2013, John B. Heywood, 1988). But how it was generated and what are the swirl speed of a 660cc engine is unknown. For the tumble motion, a single valve is not considered to have tumble motion of air in previous studies. Tumble motion is usually measured in a pent roof 4 valve engine (M. El-Adawy, 2017). Hence, this study concerns on measuring the swirl and tumble motion in a 660cc, 3 cylinders, 6 valve engine.

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# **1.3 Objectives of the project**

The objectives of this project are: -

- To investigate the cylinder head coefficient of discharge at a range of inlet valve lift.
- To investigate the swirl motion and tumble motion of air at a range of inlet valve lift.

# **1.4 Scopes of Project**

The scopes of this project are: -

1) Studies the details of intake port cylinder head of a Perodua Kancil 660 cc,

Daihatsu EF-CL SOHC I3 engine.

 Operate the Superflow® SF-1020-SB Flowbench machine to determine the air flow through the intake port, determine the coefficient of discharge(Cd), swirl speed and tumble speed.

#### **CHAPTER 2**

#### LITERATURE REVIEW

#### 2.1 Overview

This chapter explains the spees of each component and apparatus that was used in this project, based research and reference done in this project. The function and the application for the component will be explained in this chapter. The information was obtained from journals, books and browsing through the internet. Automotive industries nowadays have enlarged in impressive ways. The internal combustion engine first developed in the year 1876 until now, the engines have continued to develop as the knowledge of engine processes has increased, where new technologies have been invented and available as the demand for new cars and new engine arose. Analysis of the cylinder head of Daihatsu EF-CL SOHC13 engine will be done using the Superflow® SF-1020-SB Flow bench machine with a swirl meter. The high flow of air-fuel mixture that can enter the cylinder head will determine the performance of the engine. The performance can be defined by the terms coefficient of discharge, Cd, swirl and tumble.

#### 2.2 Coefficient of discharge (Cd)

During the intake stroke, air is drawn into the cylinder through the intake manifold, intake port and intake valve. The air flow needs to be quantified to determine the performance of the cylinder head. One of the parameters for cylinder head performance is the coefficient of discharge (Cd). Port and valve design determines the discharge coefficient (Cd) of the port and consequently the volumetric efficiency of the engine. Discharge coefficient which is less than 1 describes the behavior of all real flows contract in an area as they pass through any restriction in the cylinder head (M. F. Samuri et al., 2015, Y. Cengel and J Cimbala, 2013). For example, Cd of venture meters are very high, it ranges from 0.95 to 0.99. And for flow with high Reynold number through an orifice meter, the Cd is 0.61 (Y. Cengel and J. Cimbala, 2013). This shows that the higher the Cd of an orifice the better the flow is.

The engines port flow coefficient of discharge for a particular flow can be defined as the ratio of actual discharge to ideal discharge. Mathematically, Cd can be translated as measured mass flow rate over the ideal mass flow rate or measured air flow over calibrated air flow as in equation 2.1 (C. Ramesh Kumar and G. Nagarajan, 2012). In term of the flow bench machine, Cd is Test Flow over Potential Orifice Flow as shown in equation 2.2 (SuperFlow Technologies Group, 2004).

In an engine surrounding, an ideal gas is considered an ideal discharge and the process to be free from friction and surface tension and other disturbance. Coefficients of discharge are used to monitor and determine the flow efficiency through various engine components and are quite useful in improving the performance of components tested (Abdul Rahim Ismail and Rosli Abu Bakar, 2008). From the previous study of Abdul Rahim Ismail et al (2008), results shown that, increasing the increase of valve lift increase the coefficient of discharge.

In this study, the value of Cd of the cylinder head is expected to be dependent on the boundary layer in the intake port. Boundary layer is the layer of reduced velocity region in fluids flow. Boundary layer is next to the intake port roof, wall and floor (Harold Bettes, 2010).

 $Cd = \frac{Measured Air Flow}{Calibrated Air Flow}$ 

#### (2.1)

= Test Flow Potential Orifice Flow

(2.2)

#### 2.3 In-cylinder Fluid Flow

Extensive knowledge of the in-cylinder fluid flow of an engine is important to optimize the air-fuel mixture preparation and the combustion process. The in-cylinder flow that occurs during the intake stroke can be categorized into two structure that is organized or unorganized structure. The unorganized structures are simply filling the cylinder with undefined flow moving. But the organized structures are the one that going to be studied. It has rotational flow structures that can be defined and it is generated by the inlet port design, inlet valves assembly and cylinder head and piston geometry. In addition, valve lift is considered to have an important role in the generation and development of in-cylinder flow motion (A-F M Mahrous et al., 2006). Two organized fluid flow is swirl and tumbles motion.

#### 2.3.1 Swirl

Swirl is the in-cylinder flow where the rotational axis of the flow is parallel to the cylinder axis as illustrated in figure 2.1 and figure 2.3. The air motion can be quantified by an impulse swirl meter or by a paddle wheel swirl meter (M. El-Adawy et al., 2017). Swirl motion can also be understood as an organized rotation resulting from the air-flow motion in the intake port. The significant of the swirl motion in an engine cylinder is to help to mix the fuel and air rapidly. The swirl motion generates according to the perimeter of the bore by tangential injection, helical port and contoured valve. The rotation will continue in the combustion chamber until the combustion or ignition process started (Willard W. Pulkrabek, 2004, Mohd Taufik Bin Abd Kadir, 2008).

Paddle wheel swirl meter is the instrument going to be used in this study to measure the circular motion of combustion air on a steady state flow bench. Engine research has shown that mixture motion improves combustion efficiency burn rate. Both of these trends improve engine power output and efficiency. Improved efficiency means that power can improve even if the engine's air flow does not improve. This is especially important in restricted classes of racing, where restrictor plates limit engine air flow.

Swirl coefficient is defined as the ratio of circumferential air speed in the cylinder to the axial speed of the air flow in the cylinder. Swirl ratio is a dimensionless parameter to quantify the rotational movement in the cylinder and can be define as angular speed of swirl,  $\omega_s$  over engine speed, *N*.

$$Rs = \frac{\omega_s}{N}$$

Even though substantial efforts have been made by many of the previous researchers to determine the most effective methodology for steady state flow tests, there are sizable diversities in the definitions of the technical terms and the best techniques used in the flow bench experiments (A. Mohammad Ebrahim et al., 2013). Hence, the setup of the flow bench can differ from user to user. Swirl speed (rpm) is the simplest parameters to quantify the swirl values. The value can be obtained directly by the swirl meter attached to the flow bench test setup.



Figure 2.1: Swirl motion in a cylinder (John L. Lumley, 1999)

#### **2.3.2 Tumble**

Tumble is the flow with an axis perpendicular to that of the cylinder (M. El-Adawy et al., 2017) as shown in figure 2.2 and figure 2.3. There are three axes of air motion where flow bench measurements are taken that are swirl, normal tumble or sometimes referred to as barrel swirl and side tumble. Tumble motion is secondary rotational flow generated by squish motion. This rotation occurs about a circumferential axis near the outer edge of the piston bowl (Ujwal D. Patil, 2013, Willard W. Pulkrabek, 2004).

Tumble is desired in an engine cylinder is because of the same reasons as the swirl motion that is to increase the in-cylinder mixture preparation and the combustion performance by increasing turbulence (Bidesh Roy et al., 2015)

Swirl measurement is most commonly applied to two valves (2 V) and four valves (4 V) diesel engines and to two valves gasoline engines, while normal tumble (referred to as tumble) is most commonly applied to pent roof four valves gasoline engines (M. El-Adawy et al., 2017). Tumble motion can be notified in term of tumble ratio that is the angular speed of tumble over engine speed (Willard W. Pulkrabek, 2004). From the previous study of M. El Adawy et al (2017), shows that increased valve lifts produce an increase of tumble motion.

$$Rt = \frac{\omega_t}{N} \tag{2.3}$$



Figure 2.3: Air motion axes (M. El-Adawy et al., 2017)

#### 2.4 660cc Petrol SOHC Engine

The Daihatsu E-series engine is a range of compact three-cylinder, internal combustion piston engines, designed by Daihatsu, which is a subsidiary of Toyota. The petrol-driven series has cast iron engine blocks and aluminum cylinder heads, and are of either SOHC or DOHC design, with belt driven heads. In this project, the engine type used is SOHC. SOHC represents Single Over Head Cam or Single Cam. In a SOHC engine, the camshaft is installed in the cylinder head and valves are operated either by the rocker arms or directly through the lifters.

The E series engine was a replacement for the two-cylinder AB engine used in Daihatsu's Kei cars previously. The engine was Daihatsu's second three-cylinder design Originally with two valves per cylinder, four-valve versions later appeared as did turbocharged versions. The engine is quite light, with the original EB-10 weighing in at 60–63 kg (132–139 lb) depending on transmission fitment.

The EF-series is a 659 cc (0.66 L) version designed to replace the EB series engine when Kei car regulations changed for 1990. It was first seen in the Daihatsu Mira when it was facelifted in March 1990. The bore is 68 mm (expanded from 62) and stroke is 60.5 mm. Having undergone a long development. Production ended in December 2007 when the new KF engine had replaced the EF series. The EF was nearly as light as its predecessor, with a 2004 EF-SE weighting in at 68 kg this with the added weight of modern emissions equipment and fuel injection. The same engine was also used in 660cc Perodua Kancil. The actual cylinder head used for this study was shown in figure 2.4.



Figure 2.4: Perodua Kancil's cylinder head

#### 2.5 Flow Bench SuperFlow SF-1020

Roughly, all flow benches whether commercial or homemade, operate on the same basic principles. They are a tool that is used to measure the amount of air, volumetrically, that passes through an air-flowing test piece in a given amount of time (Donald Heareth, 2008). The SuperFlow SF-1020 flow bench that can be seen in figure 2.5, is designed to measure the airflow resistance of an engine breathing parts such as the engine cylinder heads, velocity stacks, intake manifolds and restrictor plate that was used in racing cars like the Japanese SuperGT. For four-cycle engine and intake testing, air is drawn in through the cylinder head into the machine through the air pump and exits through the vents at each side of the flow bench. For exhaust testing, the path of the airflow is reversed by entering an exhaust flow range from the Control Panel. Schematic drawing of the flow bench machine was shown in figure 2.6. The number of flow displays in cubic feet per minute (cfm), liters per second (lps) or cubic meters per hour (cmh)based on user preference. For the best accuracy, a flow range that produces 70% reading of flow range during a valve full lift can be selected. By selecting different ranges either increasing or reducing the range, higher accuracy over a wide range

of flows can be obtained. The flow meter reads 5% to 100% of any selected flow range for intake and exhaust flow direction. (Abdul Rahim Ismail and Rosli Abu Bakar, 2008, SuperFlow Technologies Group, 2004).



Figure 2.5: SF-1020-SB Flowbench Machine



Figure 2.6: Schematic of flow bench layout (SuperFlow Technologies Group, 2004)

### 2.6 Swirl and Tumble Meter

The swirl motion flow in a steady state flow test is usually measured by the light paddle wheel as shown in figure 2.7 with low friction bearings, pivoted on the cylinder center line. In this study, the rotation rate of the paddle wheel is used as a measure of the air swirl and is reported as the swirl speed (rpm).

The Swirl Meter mounts between the bore adapter and the flow bench and it will record the gross axial, circular motion of the intake air flow in the cylinder adapter. The Swirl Meter does not produce a significant restriction on the flow, that is usually less than 1 cfm at 400 cfm flow (Performance Trends Inc, 2012). The Swirl speed (rpm) and the air flow rate (cfm) need to be recorded as the flow test on the intake process is running.



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#### **CHAPTER 3**

#### METHODOLOGY

#### 3.1 Overview

In this chapter, there will be explanations on the methodology used to achieve the research objectives and completing the *Projek Sarjana Muda (PSM)*. This chapter was done by referring to the information obtained from the literature review and with the guidance of a flow chart in figure 3.7. In addition, the parameters involved and the procedure of the flow bench test will also be explained in this chapter. Based on the procedure the test was done and the result was recorded. The selection of pressure drop and flow range was referred to tables in Appendix A1 and A2.

# اونيوم سيتي تيڪنيڪل مليسيا ملاك 3.2 Test Preparation RSITI TEKNIKAL MALAYSIA MELAKA

In this project, the head cylinder that was used to be tested was from a 'Perodua Kancil' engine that is Daihatsu EF-CL SOHC 13. Firstly, The Cylinder head specification that are valve diameter, stem diameter, valve maximum lift and bore diameter was taken. Figure 3.1 shows the process of measuring the intake valve. From the parameters recorded, the net valve area that is the valve area minus the stem area can be calculated.

Net valve area = 
$$0.785$$
 (valve diameter<sup>2</sup> – stem diameter<sup>2</sup>) (3.1)

Table 3.1: Specification of 660ccPerodua Kancil engine.

DESCRIPTION	SPECIFICATION
Valve mechanism	6V SOHC
Total displacement	659 cc
Bore	68 mm
Stroke	60.5 mm
Valve diameter	30 mm
Stem diameter	6.6 mm
Maximum valve lift	12 mm
Max output (/rpm)	23 kW (31 hp) / 6400
Max torque (/rpm)	49 Nm (5.0 kgm) / 3200
Fuel type	Petrol



Figure 3.1: Intake valve measurement

To make the experiment setup airtight, some gaskets for the cylinder head and for the head adapter itself was made. The dimension of the gasket was mocked from the test orifice plate but with a bigger hole diameter that was similar to the head adapter cylinder diameter. The gasket can airtight the experiment setup and reduce the leakage value.

#### **3.2.1 Steady Flow Test**

The experiment was set up based on the flow bench manual as shown in figure 3.2. The cylinder heads are mounted onto the SuperFlow Flowbench by a cylinder adapter. The adapter consists of a tube about 86 mm long with the same bore as the engine that is 70 mm and a flange on top and bottom end. The bottom flange is bolted to the flow tester and the upper flange is clamped to the test cylinder head. The flange has a gasket at the bottom ad upper flange to make an airtight seal. The adapter cylinder clearance may be 0.06 inch or 1.5 mm, larger or smaller than the actual diesel engine cylinder.

A valve opener was attached to the cylinder head as shown in figure 3.3 to open the valves to the various test positions. A 0 to 1" x 0.001 (20 mm x 0.1) dial indicator was mounted to the same fixture with its tip contacting the valve spring retainer to measure the amount of valve opening. In this test 0.04 rotation of the dial was equal to 1 mm valve lift. The standard valve springs were replaced with light springs for testing as it was easier to open the intake valve than the standard spring. Figure 3.4 shows the schematic diagram of the steady flow test.



Figure 3.2: Steady flow test setup



Figure 3.3: Dial gauge at valve opener.



Figure 3.4: Steady flow test schematic diagram.

At the intake port, a radius inlet guide was made from a yellow modeling clay to lead air straight into the head as shown in figure 3.2. In addition, the engine valve tests need to be performed at the same ratio of valve lift to valve diameter, or L/D ratio so that the flow efficiency of any valves can be compared, regardless of size. The valve diameter was multiplied by each of the seven L/D ratios (0.05, 0.10, 0.15, 0.20, 0.25, 0.30, 0.35) to obtain the valve lift test points.

$$L/D \text{ ratio} = \frac{\text{Valve Lift}}{\text{Valve Diameter}}$$
(3.2)

	L/D ratio	Valve lift (mm)	
	0.05	1.5	
	0.10	3	
	0.15	4.5	
	0.20	6	
W	LAYSIA 0.25	7.5	
2	0.30	9	
N.N.	0.35	10.5	
I LINGS AN			1
ملاك	ىنيكل مليسيا	يىرسىتى تيك	اونيو
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Table 3.2: Valve lift based on L/D ratio

#### 3.2.2 Swirl Test

Experimental setup for swirl test is similar to the flow test setup but with an addition of paddle wheel swirl meter that is shown in the previous chapter. It is used to measure the rotational speed of the paddle wheel that was rotated by the air swirl motion. The paddle wheel swirl meter was mounted under the cylinder adapter as shown in figure 3.5. The swirl meter will show the average rotational speed of the paddle wheel during the air flow is present. The schematic diagram of swirl test was illustrated in figure 3.6.





Figure 3.6: Swirl test schematic diagram.

#### 3.2.3 Tumble Test

The air tumble flow setup is different than the other two test. Tumble flow needs to be transformed into an artificial swirl flow so that it can be measured by the paddle wheel swirl meter (N. A. Mohamad Shafie et al., 2017). Cylinder or bore adapter and tumble fixture are the additional apparatus. In this experiment, the paddle wheel was mounted at the tumble fixture to change the paddle wheel center of rotation to X-axis. The tumble meter reads average tumble speed at 0.2 L/D and 0.35 L/D valve lift at every cylinder head orientation that are from 0° to 360°. Purpose of changing the cylinder head orientation is simply to find a position that produces the highest tumble speed. Schematic diagram of the tumble test was shown in figure 3.7.



Figure 3.7: Tumble test schematic diagram.

#### 3.3 Data Analysis

#### **3.3.1** Coefficient of discharge

For the analysis of the experiment results, corrected test flow or also read as Fbflow for each L/D ratio is measured by the flow bench. The corrected test flow can be compared to other experiments of a cylinder head with the same setup without further calculations. To obtain the test flow for each L/D ratio, it is necessary to calculate the flow in cubic feet per minute (cfm)/square inch (inch2) or liters per second (l/s)/square centimeter (cm2) of the valve area.



Next, to calculated the valve coefficient of discharge (Cd), the test flow per unit area is divided by the maximum potential or maximum potential orifice flow per unit area for the test pressure as shown in table 3.4.

$$Cd = \frac{\text{Test Flow}}{\text{Maximum PotentialOrificeFlow}}$$
(3.5)

#### 3.3.2 Swirl

Swirl characteristic can be measured by the swirl meter to obtain its angular velocity in revolution per minute (rpm). The data for each L/D ratio can be calculated to obtain the swirl coefficient or the swirl ratio. Swirl coefficient is defined as the ratio of circumferential air speed in the cylinder to the axial speed of the air flow in the cylinder.

Swirll coefficient(
$$C_s$$
) =  $\frac{\text{Circumferential Velocity}(C_u)}{\text{Axial Velocity}(C_a)} = \frac{\omega B}{V_B}$  (3.6)



$$(SR)_{1} = \frac{angularspeed}{enginespeed} = \frac{\omega}{N}$$
 (3.7)

$$(SR)_{2} = \frac{swirl \tan gentialspeed}{average piston speed} = \frac{u_{t}}{U_{p}}$$
(3.8)

### **3.3.3 Tumble**

Tumble characteristic can be measured by the paddle wheel swirl meter but at different position to obtain its angular velocity in revolution per minute (rpm). The data for each L/D ratio can be calculated to obtain the tumble speed. In other research, tumble ratio is used to quantify tumble and defined as the ratio of circumferential air speed in the cylinder to the axial speed of the air flow in the cylinder.

 $Rt = \frac{angular \ speed}{engine \ speed}$ 



# **3.4 Test Methodology**

# 3.4.1 Leakage Test Methodology

- i. The test orifice plate was removed from the flow bench and the test head was clamped onto the cylinder adapter as shown in figure 3.8, and a valve opener for the actual flow tests was installed. The dial indicator was set to read zero with the valve closed. The inlet guide was installed on the intake port.
- ii. The flow bench was set to Intake, Range 1 and 25" (60 cm) test pressure. The flow bench motor was turned on and the test pressure was observed and make sure that it reads correctly. The leakage flow with the valves closed was determine.
- iii. The leakage value was inserted on screen 3 and the motor was turned off.
- iv. The valve was open until it reach the final L/D ratio that was 0.35 = 10.5mm. Motor was turned on and the flow value was recorded.



Figure 3.8: Clamping cylinder head onto cylinder adapter

#### 3.4.2 Steady Flow Test Methodology

- i. The flow range was changed to intake, range 2 since the engine bore diameter is 68mm as shown in table 3.3.
- ii. The valve was readjusted to the first L/D ratio.
- Motor was turned on and the Fbflow value was recorded when the pressure reaches the test pressure of 25" (60 cm H<sub>2</sub>O). Motor was turned off.
- iv. The valve was adjusted to the next L/D ratio and step iii was repeated until the valve lift reaches the maximum L/D ratio.
- v. When the motor temperature reaches 100°C, the motor was turned off and let to cool down before resuming the test.

# 3.4.3 Swirl Test Methodology

i. Swirl meter was installed as in figure 3.9.

- ii. The flow range was kept constant as the steady flow test (range 2). UNIVERSITITEKNIKAL MALAYSIA MELAKA
- iii. The valve was readjusted to the first L/D ratio.
- iv. Motor was turned on and the Fbflow value and the swirl average speed was recorded when the pressure reaches the test pressure of 25" (60 cm H<sub>2</sub>O). Motor was turned off.
- v. The valve was adjusted to the next L/D ratio and step iii was repeated until the valve lift reach the maximum L/D ratio.
- vi. When the motor temperature reach 100°C, the motor was turned off and let to cool down before resuming the test.





# 3.4.4 Tumble Test Methodology

- i. Cylinder adapter and tumble fixture flange were mounted as in figure 3.10.
- ii. Paddle wheel swirl meter was installed as in figure 3.11.
- iii. The flow range was kept constant as the previous test (range 2).
- iv. The valve was readjusted to the intermediate L/D ratio (0.2 L/D).
- v. Motor was turned on and the Fbflow value and the tumble average speed at  $O^{\circ}$  cylinder head orientation was recorded when the pressure reaches the test pressure of 25" (60 cm H<sub>2</sub>O). Motor was turned off.
- vi. Step v was repeated for  $20^{\circ}$ ,  $40^{\circ}$ ,  $60^{\circ}$  until the cylinder head orientation reach  $360^{\circ}$ .
- vii. The valve was adjusted to the maximum L/D ratio (0.35L/D) and step v and vi was repeated.

viii. When the motor temperature reaches 100°C, the motor was turned off and let to cool down before resuming the test.



Figure 3.11: Paddle wheel swirl meter mounted on tumble fixture.

# **3.5 Testing Flow Chart**



Figure 3.12: PSM2 Flow Chart

#### **CHAPTER 4**

#### **RESULTS AND DISCUSSION**

#### 4.1 Overview.

This chapter consist of results from three test done and discussion for each results. Test was done to determine Cd, swirl speed and tumble speed. The experiments to determine Cd and swirl speed have been conducted at several intake valve lifts over valve diameter ratio (L/D) that is 0.05,0.1, 0.15, 0.2, 0.25, 0.3, 0.35. Tumble speed test was done at 0.20 and 0.35 L/D. The L/D ratios are equivalent to 1.5, 3, 4.5, 6, 7.5, 9, 10.5 mm respectively. All test being done on the flow bench at a pressure drops, 25" of H2O and calibrated air flow was based on the same test pressure. Swirl test was done with addition of swirl meter and tumble test was done with the addition of swirl meter and tumble fixture.

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#### 4.2. Coefficient of Discharge, Cd

The volume flow rate (cfm) represented by the corrected test flow obtained for each valve lifts were illustrated in figure 4.1. It can be observed that flow rate data measured for low valve lifts had a significant increment and the volume flow rate at high valve lift show insignificant increment. There is only a very small deviation at the top end of valve lift since the flow is more restricted at low valve lift (Ujwal D. Patil, 2013, John B. Heywood, 1988). The effective test flow (cfm) increases gradually with the increase of valve lift. The higher the valve lift the higher the air flow rate entering the intake port. Air flow into an engine is directly controlled by the intake valves and at higher valve lifts the flow peaks (SuperFlow Technologies Group, 2004).



Figure 4.1: Corrected test flow (cfm) versus valve lift, L/D (-).

From the flow bench test, the corrected flow (cfm) obtained were then tabulated into the data sheet (Appendix B1) for the calculation of discharge coefficient, Cd with the reference from the previous chapter. Another required parameter for calculating Cd is test flow

(cfm/sq.in). Results of Cd was then recorded in the data sheet (Appendix B2) and illustrated in figure 4.4. The graph shows the relationship between coefficient of discharge and lift diameter ratio. The pattern also shows a similar pattern to the previous graph. It increases gradually and show a little increment after the fifth valve lift.

There is boundary layer in the intake port as explained in chapter 2 due to developing air flow. In this test, it can be said that Reynold number increases with the increase of valve lift or lift diameter ratio, L/D. Based on the moody diagram, friction coefficient reduces with the increase of Reynolds number and until a certain point, it remains constant. The flow in that constant region is a fully developed turbulent flow. The phenomena can be explained further using the Blasius equation (John B. Heywood, 1988) and by the boundary layer development in figure 4.3. Large increment at low end of the graph is due to developing air flow with developing boundary layer because of high coefficient of friction at small Reynold number. Small increment at top end of the graph is because the air flow is fully developed air flow with small boundary layer because of small coefficient of friction.

Air moving through any passages or restrictions will experience pressure drop from UNIVERSITI TEKNIKAL MALAYSIA MELAKA atmospheric pressure and the amount of air is subsequently reduced (Performance Trends Inc, 2012). When the valve lift is increased, amount of air increase because of restriction from small valve opening decrease as shown in the graph. At the same time flow rate of air passing the intake valve also increase with valve lift leading to the increase of discharge coefficient (N. A. Mohamad Shafie et al., 2017) When the valve lift increases, the bend of air flow exiting the valve as shown in figure 4.2 decreases, hence producing less flow loss.

In this steady state flow bench testing, flow separation was predicted to occur after the intake valve because of the typical inlet valve configuration that is sharp corner valve head. The larger the flow separation the larger the pressure in the cylinder adapter drop from atmospheric pressure (Y. Cengel and J. Cimbala, 2013). At very low valve lift, the air flow remains attached to the intake valve hence no flow separation and no pressure drop. When the valve lift increased, the air flow starts to separate from the intake valve because of increased flow rate (John B. Heywood, 1988). When flow separation area increased, pressure drop after the intake valve also increased. Because of this phenomena, Cd increases gradually from low valve lift to intermediate valve lift that is from 0 L/D to 0.2 L/D. At high valve lift the flow separation does not have a large increment. Hence, the pressure drop has a small increment resulting the Cd have the same trend.

A similar trend was obtained by Abdul Rahim et al (2008), Graham F. Pitcher (2011), M.F. Samuri (2015), C. Ramesh Kumar and G. Nagarajan (2012). A computational simulation was done by N.A. Mohamad Shafie et al (2017) also produce the same trend for the increment of Cd.

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Figure 4.2: Losses at intake port (SuperFlow Technologies Group, 2004).

Table 4.1:	Source of	flow	losses.
------------	-----------	------	---------

Figure	Source of flow losses	% of loss	
1	Wall Friction	4%	
2	Contraction at push-rod	2%	
3	Bend at valve guide	11%	
4	Expansion behind valve guide	4%	
5	Expansion, 25 degrees	12%	
6	Expansion, 30 degrees	19%	
7	Bend to exit valve	17%	
8	Expansion exiting valve	31%	
	What .		





Figure 4.3: The development of the velocity boundary layer in a pipe (Y. Cengel and J. Cimbala, 2013).



Paddle wheel swirl meter mounted under the head adapter was used to read the swirl speed in revolution per minute (rpm) while the flow is present. The swirl meter read the average swirl and display the readings on the screen. The paddle wheel produced some restriction on the air flow rate. The swirl meter reading for each valve lift was tabulated in the data sheet (Appendix B3) and illustrated in figure 4.5. The graph show that the swirl intensity increase with the valve lift but not in a uniform or linear trend. John B. Heywood (1988) agreed with the graph trend. The swirl speed increases with increasing valve lift (John B. Heywood, 1988). It can be seen that the intake port type of this engine is a direct port. Direct port is used to provide sufficient air volume and generate swirl (Ujwal D. Patil, 2013). Because of that, it can be said that this engine has swirl fluid motion. Swirl is used to produce

much more rapid mixing between the fuel and air mixture in a cylinder than the air fuel mixture that absence swirl (John B. Heywood, 1988).



Paddle wheel tumble meter was used but mounted differently from the swirl test because of the different experimental setup. The swirl meter read the average swirl and display the readings on the screen. The tumble meter reading at 0.2 L/D and 0.35 L/D valve lift at every cylinder head orientation that are from 0° to 360° was tabulated in the data sheet (Appendix B4 and B5) and illustrated in figure 4.6. The graph shows that the tumble speed is high at 0° at both 0.2 L/D and 0.35 L/D. This is because of the tumble axis is parallel to the paddle wheel rotational axis. At other angles of orientation, the tumble speed value is lower than the tumble speed at 0° because of the tumble axis is not parallel to the paddle wheel rotational axis. When tumble axis does not parallel to the paddle wheel axis, tumble speed recorded is low because the tumble motion does not spin the paddle wheel rapidly. When the tumble axis is perpendicular to the paddle wheel axis, there is no tumble reading since the tumble motion cannot spin the paddle wheel. The maximum tumble speed and the maximum swirl speed have a difference but it can be said that both values are high for a single intake valve engine. To validify the tumble speed for every cylinder head orientation, the test need to be repeated for several time. There is no previous study on tumble speed at every cylinder head orientation that can be referred to.



Figure 4.6: Tumble speed (rpm) versus Cylinder head orientation ( $\theta$ )



Figure 4.8: Tumble motion at 90° cylinder head orientation ( $\theta$ ).

#### 4.5 Cd Sample Calculation

4.5.1 Valve lift, L

$$L/D = 0.35$$

$$\frac{L}{D} = \frac{\text{Valve Lift}}{\text{Valve Diameter}}$$

$$0.35 = \frac{L}{30\text{mm}}$$

$$L = 10.5\text{mm}$$

#### 4.5.2 Effective valve area



# 4.5.4 coefficient of discharge, Cd

$$Cd = \frac{\text{test flow}}{\text{potential orifice flow (at 25"H2O)}}$$
$$= \frac{45.10 \ cfm/inch^2}{138 \ cfm/inch^2}$$
$$= 0.3$$

#### **CHAPTER 5**

#### **CONCLUSION AND RECOMMENDATION**

#### 5.1 Conclusion

From the steady flow test done, measured airflow was recorded (cfm) and Cd was then calculated and objective of determining the value of Cd was met. The graph show Cd increase gradually with the increase of lift diameter ratio, L/D due to developing boundary layer and flow separation effect.

Value of swirl speed was measured. The swirl test done had shown that the swirl increase with valve lift. The trend is more random. It can be said that swirl motion is present in a small displacement SOHC engine. The higher the valve lift the higher the swirl speed. The maximum swirl speed obtained was 1770rpm at 0.35L/D.

Test about in-cylinder tumble motion of the same engine was investigated because tumble is one of the in-cylinder fluid flow of an engine. The test was done to measure the tumble speed but with different experimental setup. The tumble speed is high at 0° of cylinder head orientation. This is because the tumble axis is parallel to the paddle wheel swirl meter. That's mean for future study on tumble motion. Test just need to be done on that specific angle of orientation. Maximum tumble speed obtained was 2250rpm that is at 0.35 L/D. From the results of tumble test, it can be said objective to measure tumble speed is accomplished.

#### **5.2 Recommendations**

There are several future studies that can be done. One of it is doing a simulation of swirl and tumble motion in the cylinder of the engine to see how the fluid motion in the cylinder more clearly. Coefficient of discharge analysis can also be done on the simulation of fluid flow and the data can be compared to the experimental data. Particle image velocimetry (PIV) can also be done. This test is to see how the actual fluid motion in the cylinder.

Study on the details of the intake port geometry such as intake size, intake valve angle and angle or offset of the intake valve itself can be done. Intake port is a generator of incylinder fluid flow. Swirl is very dependent on the intake port design. Modifications or tuning of intake port can also be done and the changes of fluid flow resulted from the modification can be tested. Modification of the intake port that can be done are port and polishing process on the intake valve, addition of swirl generator in the intake valve and change of intake valve to shrouded intake valve to promote swirl.

Future study on a 660cc engine with two intake valve can also be done. Volume flow rate of air, swirl and tumble motion can be done. The result is expected to be different from the engine with single intake valve. Test of in-cylinder fluid flow at each cylinder of the engine can also be done to find the exact difference across all the cylinders.

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# APPENDICES

# **APPENDIX A1**

Suggested Flow range based on valve diameter

Valve Diameter	Suggested Flow Range for 25" (63.5 cm) Test Pressure		
1.00" (25mm)	Range 3 – 100 cfm (47 lps)		
1.50" (38mm)	Range 4 – 150 cfm (71 lps)		
1.50" (38mm)	Range 5 – 200 cfm (94 lps)		
1.75" (45mm)	Range 6 – 300 cfm (142 lps)		
2.00" (51mm)	Range 7 – 400 cfm (189 lps)		
2.25" (57mm)	Range 8 – 500 cfm (236 lps)		
2.50" (63mm)	Range 8 – 500 cfm (236 lps)		
2.75" (70mm)	Range 9 – 700 cfm (330 lps)		



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# **APPENDIX A2**

Test Pressure	Peak Velocity	Flow/Unit Area*
(H20)	(ft./sec)	(cfm/sq. in)
1"	66.2	27.6
3"	114.7	47.8
5"	148.0	61.7
7"	175.1	72.9
10"	209.3	87.1
12" CLAYON	229.3	95.6
15"	256.4	106.9
20"	296.0	123.4
25" <sub>///1</sub>	331.0	138.0
مليسيا مروك	سيتي تد350.3 نيڪر	146.0 ويبوش
UNIVERSITI TE	KNIKAL MALAYSIA N	IELAKA 151.1
35"	391.6	163.3
40"	418.7	174.6
45"	444.1	185.1
48"	458.6	191.2
50"	468.1	195.2
60"	512.8	213.8
65"	533.7	222.5

Maximum potential orifice flow rate at every test pressure.

# **APPENDIX B1**

Test pressure (inch H2O)	25	25	25	25	25	25	25
Range	2	2	2	2	2	2	2
Valve Lift (L/D)	0.05	0.1	0.15	0.2	0.25	0.3	0.35
Corrected Flow (cfm)	13.7	24.3	34.3	42.1	45.1	46.3	46.9

Corrected flow (cfm) obtained from steady state flow bench test.

# **APPENDIX B2**

Results of coefficient of discharge, Cd.

		S2.					
Valve Lift (L/D)	0.05	0.1	0.15	0.2	0.25	0.3	0.35
Corrected Flow	13.7	24.3	34.3	42.1	45.1	46.3	46.9
(cfm)					IV		
Test flow	13.7	23.37	32.98	40.58	43.37	44.52	45.10
(cfm/sq.in)	1 1						
6 12		1	11	10 <sup>10</sup> 10 <sup>1</sup>			
Coefficient 2006	0.10	0.17	0.24	0.29	0.31	0.32	0.33
discharge, Cd	4. 4.				w 4.		
LINUX/	DEITIT	THE NUMBER OF STREET	AL BRAL	AVCIA	NACI ALZ	٨	
	The second se	The second se		and the second second		and the second s	

### **APPENDIX B3**

Swirl speed obtained from the paddle wheel swirl meter.

Valve Lift (L/D)	0.05	0.1	0.15	0.2	0.25	0.3	0.35
Corrected Flow (cfm)	11.0	21.5	32.2	40.6	43.2	44.5	45.7
Swirl speed (rpm)	6	206	800	834	925	1297	1770

# **APPENDIX B4**

Tumble speed obtained from the paddle wheel tumble meter at 0.2 L/D.

Angle (°)	0	20	40	60	80	100	120	140	160	180	200	220	240	260	280	300	320	340	360
Tumble(rpm)	1601	792	1743	757	212	1082	891	307	102	16	170	104	556	21	54	0	629	1153	1788
Fbflow(cfm)	38.9	39.0	38.9	38.9	38.9	38.9	38.7	38.6	38.3	38.6	38.5	38.8	38.6	38.6	38.9	39.1	39.0	39.1	38.9

# **APPENDIX B5**

Tumble speed obtained from the paddle wheel tumble meter at 0.35 L/D

Angle (°)	0	20	40	60	80	100	120	140	160	180	200	220	240	260	280	300	320	340	360
Tumble(rpm)	2250	2200	1877	1002	168	121	83	988	936	639	68	29	108	6	116	438	994	1066	1470
Fbflow(cfm)	44.6	44.4	44.2	44.5	43.9	43.9	43.5	43.7	43.6	43.9	44.4	44.1	43.8	44.3	44.3	44.4	44.5	44.5	44.4
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**UNIVERSITI TEKNIKAL MALAYSIA MELAKA** 

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E.

# **APPENDIX C1**

# Gant Chart for PSM 1

No		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Week																
	Activities																
1	Title Confirmation																
2	Objective &																
	problem statement																
3	Introduction																
4	Literature review																
5	Steady flow test																
	preparation																
6	Steady flow testing																
7	Result discussion																
8	Progress report																
9	Swirl test																
	preparation																
10	Swirl testing	-															
11	Result discussion	PIA	de.														
12	Draft report writing		\$														
13	Improvement		12														
14	PSM1 report		~														
15	PSM1 Presentation																
	Allen																
	-all			A	PE	NDD	X C2										
Gant	Chart for PSM 2	m	۵	4	-	: <		ů	in.	u.	~ in	اهد					

Gant (	Chart for PSM 2	m	ل م	$\leq$	2	. <	2		يبتج		يۇن	اوز					
No	Week Sectivities	1	2	(NI	κ <sup>4</sup> Α	5 M	6	AYS	8 <mark>8</mark>	9	10	<b>K</b> Å	12	13	14	15	16
1	Tumble test																
	preparation																
2	Tumble testing																
3	Result discussion																
4	Progress report																
5	Discussion																
6	Conclusion																
7	Draft for																
	presentation																
	slides																
8	Draft report																
9	PSM2																
	presentation																
10	PSM2 report																