

COMPUTATION AND STATISTICAL ANALYSIS OF INTAKE AIR PLENUM
PERFORMANCE FOR FORMULA STUDENT CAR BY MACHINE LEARNING



A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE
DEGREE OF BACHELOR OF ENGINEERING IN MECHANICAL ENGINEERING
FACULTY OF ENGINEERING
KING MONGKUT'S INSTITUTE OF TECHNOLOGY LADKRABANG
2020

COMPUTATION AND STATISTICAL ANALYSIS OF INTAKE AIR PLENUM
PERFORMANCE FOR FORMULA STUDENT CAR BY MACHINE LEARNING



A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE
DEGREE OF BACHELOR OF ENGINEERING IN MECHANICAL ENGINEERING
FACULTY OF ENGINEERING
KING MONGKUT'S INSTITUTE OF TECHNOLOGY LADKRABANG
2020

This material is reserved for educational use only, not allowed for commercial use.

Forbidden to modify the content, and cite the document when use



COPYRIGHT 2020

FACULTY OF ENGINEERING

KING MONGKUT'S INSTITUTE OF TECHNOLOGY LADKRABANG

This material is reserved for educational use only, not allowed for commercial use.

Forbidden to modify the content, and cite the document when use

Academic Year 2020

Department of Mechanical Engineering Program Mechanical Engineering

Faculty of Engineering King Mongkut's Institute of Technology Ladkrabang

Title: COMPUTATION AND STATISTICAL ANALYSIS OF INTAKE

AIR PLENUM PERFORMANCE FOR FORMULA STUDENT CAR BY MACHINE LEARNING

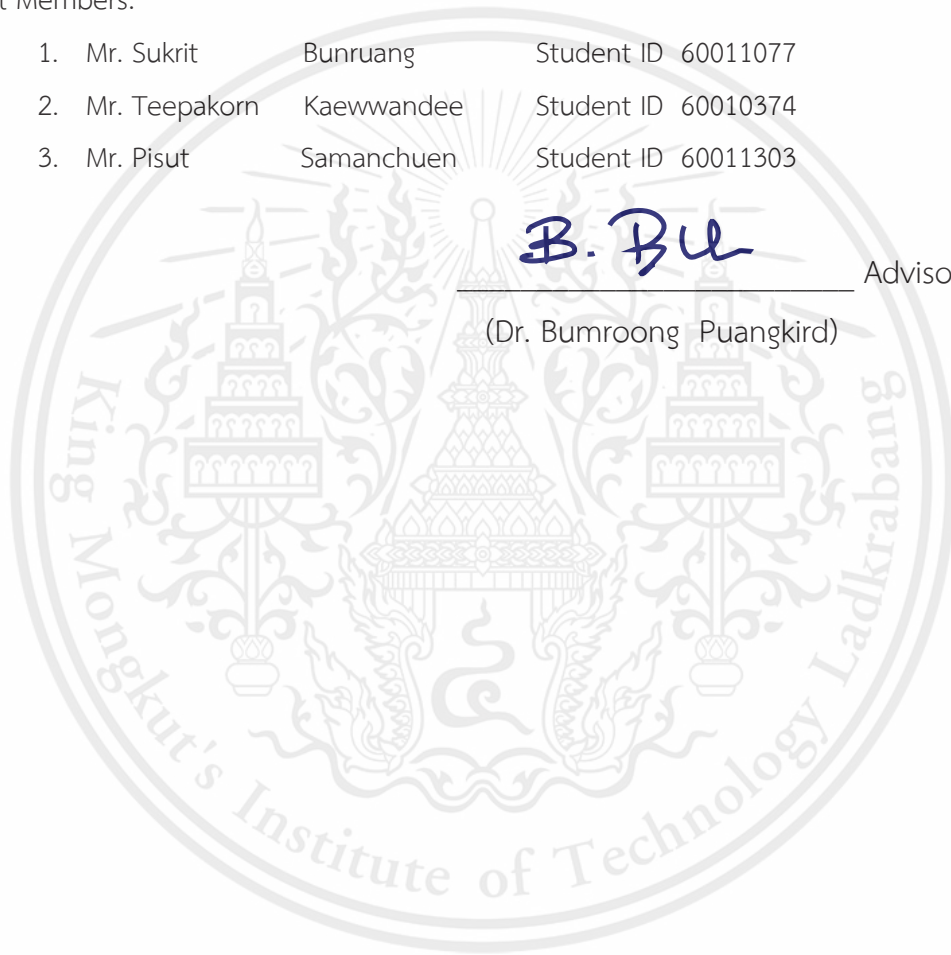
Student Members:

1. Mr. Sukrit Bunruang Student ID 60011077
2. Mr. Teepakorn Kaewwandee Student ID 60010374
3. Mr. Pisut Samanchuen Student ID 60011303

B. Pu

Advisor

(Dr. Bumroong Puangkird)



COMPUTATION AND STATISTICAL ANALYSIS OF INTAKE AIR PLENUM
PERFORMANCE FOR FORMULA STUDENT CAR BY MACHINE LEARNING

Mr. Sukrit Bunruang 60011077

Mr. Teepakorn Kaewwandee 60010374

Mr. Pisut Samanchuen 60011303

Dr. Bumroong Puangkird Advisor

Academic Year 2020

ABSTRACT

Study the parameter in a shape of intake plenum on a single cylinder to improve the design and performance of an air intake plenum for the Formula Student engine. For the principle of an intake plenum is to store air for the engine intake system to reserve the air for the next intake stroke, due to the restrictor of the FSAE Restriction. Intake plenum becomes one of the most significant parts of the system to improve the engine performance by its capacity, shape and material. The testing data is used to determine and analysis of the parameter of a shape of an intake plenum affecting the performance of the engine and summarize the most suitable to use in the Formula Student competition.

From the experiment and analysis, said that the shape of the plenum has significant effects to air behavior in the plenum that affect to power and response of the engine. In addition, the data from the simulation was consist to the shape of each plenum design, likewise the trend of significant factor of each plenum not only has significant differences in behavior but also the trend of transient pressure and velocity so we decide to analyze these bulk data by using statistical analysis and machine learning to get to know the criteria that affect to the performance of the engine.

Acknowledgement

First, most of values and success must be dedicated to our advisor, Dr. Bumroong Puangkird who has supported us throughout our thesis with his patience and knowledge. For many years of study, he has devoted his time to provide advice and brought us a perspective vision in solving problems.

Assistant Professor Chinda Charoenpornpanich and Associate Professor Preecha Karin for the knowledge of Internal Combustion Engine Principal and any of design criteria for this thesis. Mr. Watanyoo Pairoj for the machine shop advising and fabrication guidance. Mr. Jiramed Boonsakda for engine tuning theory and assisting in the tuning procedure and Assistance Professor Montree Thongkam for the Dynamometer Testing sponsorship.

We are grateful for the Department of Mechanical Engineering King Mongkut's Institute of Technology Ladkrabang who has provided the support and equipment we have needed to produce and complete our thesis.

In final words, we would like to give a special appreciation to our family for all kind of support, encouragement, and love, who has offered me on financial support and encouraged us to complete this work. who has passed away in the very hard moment when this thesis was being carried on.

Sukrit	Bunruang
Teepakorn	Kaewwande
Pisut	Samanchuen

CONTENT

	Page
ABSTACT.....	I
ACKNOWLEDMENT.....	II
CONTENT.....	III
LIST OF FIGURES.....	VII
LIST OF TABLES.....	X
NUMENCLATURE.....	XI
CHAPTER 1 INTRODUCTION.....	1
1.1 Background.....	1
1.2 Objective.....	2
1.3 Scope of work.....	2
1.4 Expected Benefit.....	2
CHAPTER 2 THEORIES AND LITERATURE REVIEW.....	3
2.1 Introduction.....	3
2.2 Principle of 4-Stroke Engine.....	3
2.2.1 Intake Stroke.....	3
2.2.2 Compression Stroke.....	3
2.2.3 Power Stroke.....	3
2.2.4 Exhaust Stroke.....	4
2.3 Air-Fuel Ratio.....	5
2.4 Intake System.....	6
2.4.1 Electronics Throttle Body.....	7
2.4.2 Restrictor.....	8
2.4.3 Plenum.....	9
2.4.4 Bellmouth.....	10
2.4.5 Intake Runner.....	11
2.4.6 Fuel Injector.....	12
2.5 Air Velocity to the Effect of a Volumetric Efficiency.....	12

CONTENT

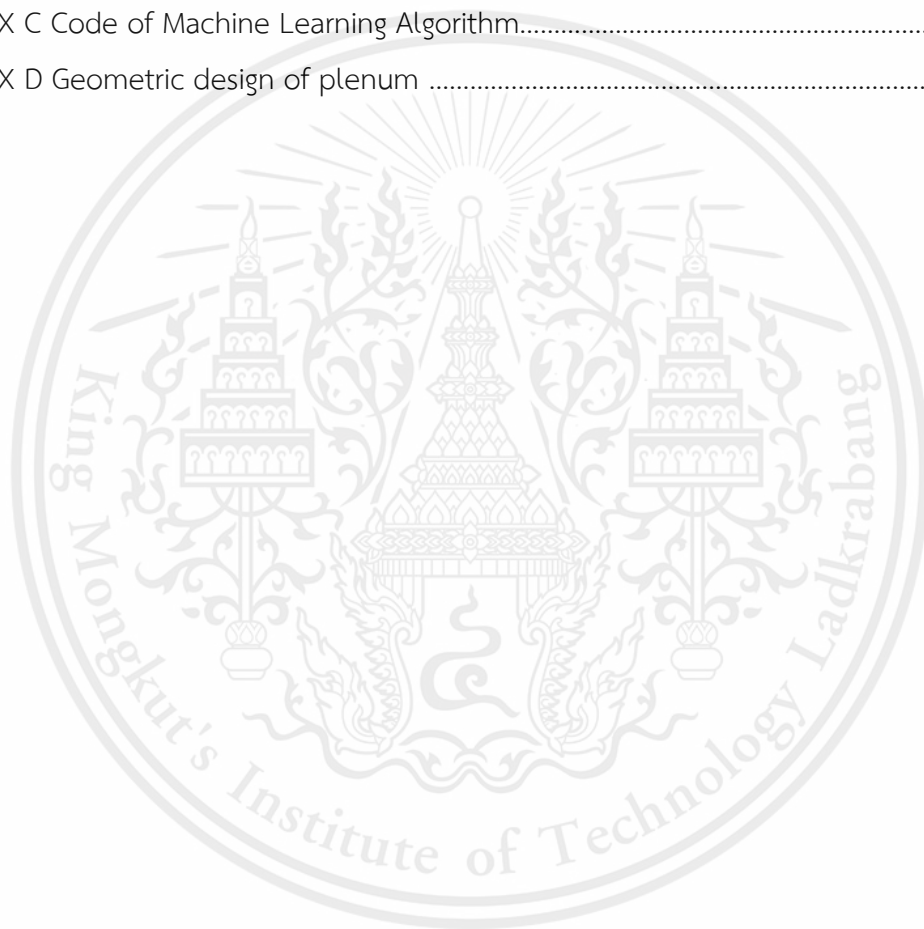
	Page
2.6 Machine Learning.....	13
2.6.1 Linear Regression Algorithm.....	14
2.6.2 :Polynomial Regression Algorithm.....	15
2.6.3 Kalman filter Algorithm.....	16
2.6.4 Decision Tree Algorithm.....	17
2.6.4.2 Gini index.....	17
2.7 Computer Program was used for Machine Learning.....	19
2.7.1 VS code.....	19
2.8 CAD (Computer Aid Designed).....	19
2.8.1 Catia.....	19
2.9 CAM (Computer Aid Manufacturing).....	20
2.10 CFD (Computational Fluid Dynamics).....	20
2.10.1 Meshing.....	21
2.10.2 Numerical Method for CFD.....	22
2.10.3 Finite-Volume method.....	22
2.10.4 Transient flow.....	24
CHAPTER 3 DESIGN.....	24
3.1 Introduction.....	24
3.2 Plenum Design.....	24
3.2.1 Plenum 1 Design.....	25
3.2.2 Plenum 2 Design.....	25
3.2.3 Plenum 3 Design.....	25
3.3 Plenum Simulation.....	26
CHAPTER 4 Equipment and Experiment Procedure	27
4.1 Introduction.....	27
4.2 Experimental Description.....	27
4.3 Experimental Setup.....	28
4.3.1 Intake system.....	28
4.3.2 KTM Duke 690 CC years 2010.....	29
4.3.3 Exhaust System.....	30

CONTENT

	Page
4.3.4 Engine Control Unit.....	30
4.3.5 Formula Student Car.....	31
4.3.6 Gasoline E10 Fuel (Gasohol 95).....	31
4.4 Measurement and data logging instrument.....	31
4.5 Instrumental Calibration.....	34
4.5.1 Oxygen Sensor.....	34
4.5.2 Air flow rate sensor.....	34
CHAPTER 5 Experimental results.....	35
5.1 Velocity, times and pressure of the piston relative to piston position.....	35
5.2 Result of airflow in plenum affected by shape.....	36
5.2.1 Streamline in plenums.....	36
5.2.2 Pressure and Velocity of an air particle in the plenum chamber simulated on ANSYS CFX in Transient method.....	39
5.3 Engine power relative to pressure of intake air from plenum	41
5.3.1 Mode pressure.....	41
5.3.2 Relative of mode pressure and output power.....	42
5.3.3 Polynomial regression of pressure and output power.....	42
5.4 Engine power respect to design variable of Air Plenum design.....	43
5.4.1 Result from Machine Learning model.....	43
5.4.2 Result from Algorithm selected design.....	43
5.5 Comparing the results.....	44
5.5.1 Timesteps pressure and velocity.....	44
5.5.2 Pressure and velocity at 90 degrees(before intake port closed) and 360 degrees (before intake port opened).....	45
5.5.3 Statistical value of each plenum.....	47
5.5.4 Bar graph of statistical value of each plenum.....	48
5.6 Engine output power measured by dynamometer	52

CONTENT

	Page
CHAPTER 6 Conclusion and analysis Experimental results.....	53
6.1 Conclusion	53
6.2 Experimental Suggestion	54
REFERENCES.....	55
APPENDIX A Results of simulation.....	58
APPENDIX B Code of Machine Learning Algorithm.....	75
APPENDIX C Code of Machine Learning Algorithm.....	80
APPENDIX D Geometric design of plenum	87



LIST OF FIGURES

	Page
Figure 1.1 Formula student.....	1
Figure 2.1 The process of 4-stroke engine.....	4
Figure 2.2 The effect of an air-fuel ratio and a lambda on engine power.....	6
Figure 2.3 Intake system	7
Figure 2.4 Electronics throttle body	7
Figure 2.5 Restrictor design throat venturi nozzle.....	8
Figure 2.6 The shape of a restrictor was used for the theory.....	9
Figure 2.7 Plenum.....	10
Figure 2.8 The loss due to inefficient entry to the system.....	10
Figure 2.9 Bellmouth was sketched and scale the bellmouth.....	11
Figure 2.10 Intake Runner.....	11
Figure 2.11 Fuel Injector.....	12
Figure 2.12 The effect of air velocity on volumetric efficiency.....	12
Figure 2.13 Machine learning process.....	13
Figure 2.14 Linear Regression Algorithm plots the energy predicted.....	14
Figure 2.15 Polynomial Regression Algorithm draw the line through the data points.....	15
Figure 2.16 The trend line generated by the bulk data.....	16
Figure 2.17 Example of Kalman filter for tracking a moving object in 1-D	16
Figure 2.18 Decision Tree Algorithm.....	18
Figure 2.19 VS code.....	19
Figure 2.20 Catia.....	19
Figure 2.21 3D printer.....	20
Figure 2.22 Diffusion of air intake and exhaust in lung.....	20
Figure 2.23 Ansys Computational Fluid Dynamics and Finite Element Analysis comparison..	21
Figure 2.24 Mesh quantities improve a precision of a simulation result.....	21
Figure 2.25 Transient response for plenum volume	23
Figure 3.1 Geometric design of plenum 1.....	25
Figure 3.2 Geometric design of plenum 2.....	25

LIST OF FIGURES

	Page
Figure 3.3 Geometric design of plenum 3.....	25
Figure 3.4 Streamline of an air flow from ANSYS Simulation.....	26
Figure 3.5 Pressure Contour of a plenum designed from CAD software by ANSYS.....	26
Figure 3.6 Raw data exported from the ANSYS simulation result for inputting into Machine Learning Algorithm.....	26
Figure 4.1 Table of maximum power for each selected design case	27
Figure 4.2 Assembly of the engine setup for intake system testing.....	28
Figure 4.3 Assembly of air intake system	28
Figure 4.4 KTM Duke Original condition from the manufacturer	29
Figure 4.5 Assembly of Exhaust system	30
Figure 4.6 Engine Control Unit	30
Figure 4.7 Formula Student car use in the experiment	31
Figure 4.8 Manifold Absolute Pressure Sensor from Toyota 4AGE-FE Engine	32
Figure 4.9 Air flow rate sensor from Toyota 1UZ-FE VTi Engine	32
Figure 4.10 Wideband Oxygen sensor	32
Figure 4.11 Innovate LM2 Oxygen volumetric transducer	33
Figure 4.12 Rolling Dynamometer	33
Figure 4.13 Calibration procedure of air flow rate sensor	34
Figure 4.14 Calibrated data of air flow rate sensor with the regression equation	34
Figure 5.1 Graph of relative of velocity and crank angle at 7500 RPM	35
Figure 5.2 Graph of relative of pressure and times at 7500 RPM	35
Figure 5.3 Streamline at 90 degrees of crank angle of plenum 1.....	36
Figure 5.4 Streamline at 360 degrees of crank angle of plenum 1.....	36
Figure 5.5 Streamline at 90 degrees of crank angle of plenum 2.....	37
Figure 5.6 Streamline at 360 degrees of crank angle of plenum 2.....	37
Figure 5.7 Streamline at 90 degrees of crank angle of plenum 3.....	38
Figure 5.8 Streamline at 360 degrees of crank angle of plenum 3.....	38
Figure 5.9 36 timesteps mean pressure of plenum 1	39
Figure 5.10 36 timesteps mean pressure of plenum 2	39

LIST OF FIGURES

	Page
Figure 5.11 36 timesteps mean pressure of plenum 3	40
Figure 5.12 36 timesteps mean velocity of plenum 1.....	40
Figure 5.13 36 timesteps mean velocity of plenum 2.....	40
Figure 5.14 36 timesteps mean velocity of plenum 3	41
Figure 5.15 Histogram of mode pressure in plenum.....	42
Figure 5.16 Scatter plot of Relative of mode pressure and output power.....	42
Figure 5.17 Scatter plot of Relative of mode pressure and output power.....	42
Figure 5.18 Intercept of the equation and Coefficient of the relation equation determined by polynomial feature (3rd order polynomial).....	43
Figure 5.19 Result from Algorithm selected design.....	43
Figure 5.20 36 timesteps pressure comparing in each plenum.....	44
Figure 5.21 36 timesteps velocity comparing in each plenum.....	44
Figure 5.22 Pressure comparing in each plenum before intake port close.....	45
Figure 5.23 Pressure comparing in each plenum before intake port open.....	45
Figure 5.24 Velocity comparing in each plenum before intake port close.....	46
Figure 5.25 Velocity comparing in each plenum before intake port open.....	46
Figure 5.26 Mean pressure comparing in each plenum before intake port close.....	48
Figure 5.27 Mean pressure comparing in each plenum before intake port open.....	48
Figure 5.28 Standard deviation of pressure comparing in each plenum before intake port close.....	49
Figure 5.29 Standard deviation of pressure comparing in each plenum before intake port open.....	49
Figure 5.30 Mean velocity comparing in each plenum before intake port close.....	50
Figure 5.31 Mean velocity comparing in each plenum before intake port open.....	50
Figure 5.32 Mode velocity comparing in each plenum before intake port close.....	51
Figure 5.33 Mean velocity comparing in each plenum before intake port open.....	51
Figure 5.34 Dynamometer testing results of engine output power and torque on designed plenum 2.....	52

LIST OF TABLES

	Page
Table 2.6.6 advantage and disadvantage of decision tree.....	17
Table 3.1 specification of formular student.....	22
Table 5.5.1 Mean, Mode, Standard Deviation of pressure in each plenum.....	37
Table 5.5.2 Mean, Mode, Standard Deviation of velocity in each plenum.....	37



NUMENCLATURE

AF	: Air-fuel ratio
A	: Intake Cross section area
m	: Mass
L	: Intake length
R	: Intake radius
λ	: Relative air fuel ratio
ρ	: Density
v	: Speed of sound
m_{air}	: Mass of air
m_{fuel}	: Mass of fuel
AF_{actual}	: Actual ratio of fuel-air
AF_{stoich}	: Stoichiometric ratio of fuel-air
P_o	: Atmospheric pressure
x	: Position with respect to crank angle
v	: Velocity with respect to time
a	: Acceleration with respect to crank angle
ω	: Velocity with respect to crank angle

CHAPTER 1

INTRODUCTION

1.1 Background

The air plenum is one of the components of internal combustion engine (ICE). To improve engine performance of engine depends on many factors, plenum is one of fundamental component to increase engine performance. One of the factors that used to maintain amount of air for the engine is the design of plenum that reserve the air before mixing with fuel in combustion chamber.

Formula SAE set a rule for formula student racing car that limit inlet airflow in plenum by restrictor to limit the diameter of inlet not exceed of 20 mm that affect to the air pressure and velocity in the plenum that cause of lacking of air in the plenum or pressure drop.

To design plenum for the competition is find appropriate design factor that restricted by the 20mm diameter restrictor to reduce pressure drop and lacking of air, then develop the design of plenum by using Computational and Statistical Analysis of Fluid Dynamics and Machine Learning Theory to know the trend of airflow in the plenum , the most applicable factor of the plenum maximize power of the engine and improve the engine respond.



Figure 1.1 formula student

1.2 Objective

To study, design and develop an intake air plenum for Formula Student engine and to escalate the design of the plenum by using Data Analysis and Machine Learning, the result should determine the most appropriate factor for the engine to get better efficiency.

1.3 Scope of Work

1. Study the single cylinder KTM duke 690 cc. engine to know the effect the engine that cause by plenum runner length, volume and shape.
2. Design plenum from the data that studied from the engine in various shape to collecting data of airflow.
3. Design machine learning model to analyze the airflow data to get the most suitable parameters for intake system and design plenum from the most suitable parameters.

1.4 Expected Benefits

1. Understanding the airflow in plenum to develop plenum and improve the engine performance.
2. Develop a mathematic model and machine learning algorithm for a formula student racing car and applicable with other part of the car.
3. To increase a chance to get a score in competition by develop air intake plenum for better response and power of the engine.

CHAPTER 2

THEORIES AND LITERATURE REVIEW

2.1 Introduction

Formula Student is a racing car with a opened wheel which designed by student under the rules and restriction of SAE International for safety and fairness of the competition. In powertrain system[1] has a restriction of an air intake which limit the air flow with a restrictor of a 20 millimeter-diameter and engine which state that the displacement volume shall not be exceed 710 cubic centimeters. This Thesis are consist of 2 section of the theory which is a Theory of Internal Combustion Engine and Theory of The Computer-Computation analysis.

Section 1: Theory of Internal Combustion Engine

2.2 Principle of 4-Stroke Engine

A 4-stroke engine[2] is fairly standard for all engines. The engine is a internal combustion. It is from chemical reaction inside the combustion chamber with fuel injector feed gasoline fuel and sparking plug ignited that there are controlled by an electronics device. This consist of mainly 4 strokes.

2.2.1 Intake stroke

The piston cylinder is when intake valve opens. The piston moves toward from Top dead center to Bottom dead center. This causes increasing volume and decreasing pressure in the combustion chamber. The resulting pressure differential from atmospheric pressure and the pressure on the inside. This is causes air to be moved into the cylinder. During fuel injectors add fuel air mixing.

2.2.2 Compression stroke

The compression cycle is when the intake and exhaust valves are closed. The piston continues to move upward. This causes the air-fuel mixture to be compressed. The compression makes pressure increasing and easier ignition.

2.2.3 Power stroke

The power stroke is when the intake and exhaust valves are still closed. The air-fuel mixture is ignited by the spark plug. The resulting energy of the combustion forcefully pushes the piston downward. This motion is converted to a rotary motion through the crankshaft

This material is reserved for educational use only, not allowed for commercial use.

Forbidden to modify the content, and cite the document when use

2.2.4 Exhaust stroke

The exhaust stroke is when the exhaust valves open and the piston move upward. This cause the exhaust gases of combustion out of the cylinder. when the end of the exhaust stroke. The piston is Top dead center and intake valve starts again.

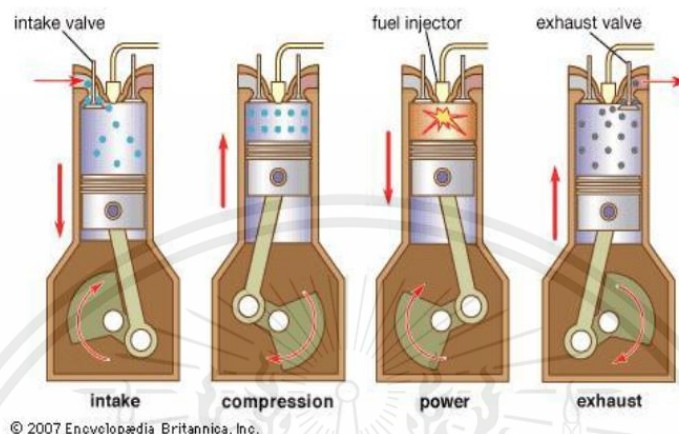


Figure 2.1 The Process of 4-Stroke Engine [3]

Position

Position with vary to crank angle

$$x = r \cdot \cos A + \sqrt{l^2 - r^2 \cdot \sin^2 A} \quad \text{----- (2.2.1.)}$$

Position with vary to time is simply:

x

Velocity

Velocity with vary to crank angle

$$x' = -r \cdot \sin A - \frac{r^2 \sin A \cdot \cos A}{\sqrt{l^2 - r^2 \sin^2 A}} \quad \text{----- (2.2.2.)}$$

Velocity with vary to time

$$v = \frac{dx}{dt} = x' \cdot \omega \quad \text{----- (2.2.3.)}$$

Acceleration

Acceleration with vary to crank angle

$$x'' = -r \cdot \cos A - \frac{r^2(\cos^2 A - \sin^2 A)}{\sqrt{l^2 - r^2 \sin^2 A}} - \frac{r^4 \sin^2 A \cdot \cos^2 A}{(\sqrt{l^2 - r^2 \sin^2 A})^3} \quad \text{---- (2.2.4)}$$

Acceleration with vary to time

$$a = \frac{d^2x}{dt^2} = x'' \cdot \omega^2 \quad \text{---- (2.2.5)}$$

2.3 Air Fuel Ratio

In this research, Formula student is four-stroke cycle of gasoline and one-cylinder 450 cc with SI engine. As the air passes through the intake system. This causes a mixture of fuel and air (Air Fuel Ratio) to be released into the cylinder. So, we can choose an Air Fuel Ratio that have the most power. It is determined by relative amounts of air mass and fuel mass as show in equations.

Equation of Air-fuel ratio (AF) is:

$$AF = \frac{m_{air}}{m_{fuel}} \quad \text{----(2.3.1)}$$

Equation of Equivalence ratio (lambda) is:

$$\lambda = \frac{AF_{actual}}{AF_{stoich}} \quad \text{----(2.3.2)}$$

The figure 2.2 shows the effect of an air-fuel ratio and a lambda on engine power and fuel consumption. An air-fuel ratio at 12.6:1 and a lambda at 0.86 have largest number of engine power. The best fuel economic and bottom out of fuel consumption are an air-fuel ratio at 15.4:1 and a lambda at 1.05. The graph show that there are exactly enough atoms of oxygen to burn 100% of the fuel. This point is an air-fuel ratio at 14.7:1 and a lambda at 1. If you have more air with same amount of fuel you have a lean mixture and less air than stoichiometric is a rich mixture.

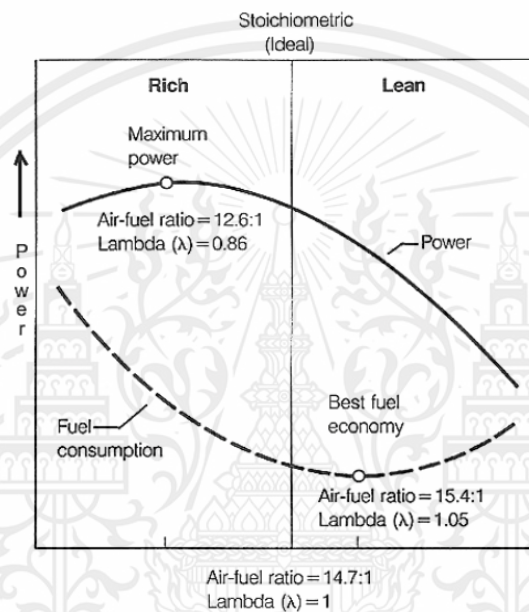


Figure 2.2 The effect of an air-fuel ratio and a lambda on engine power [4]

2.4 Intake System

For Intake System, the fuel is infused into the air to achieve the perfect air-fuel ratio. The air and fuel are drawn into the cylinder. The intake System is one of important thing for Formula Student car. We can use the perfect air-fuel ratio to boost engine power. The intake system is consisting of these following components:

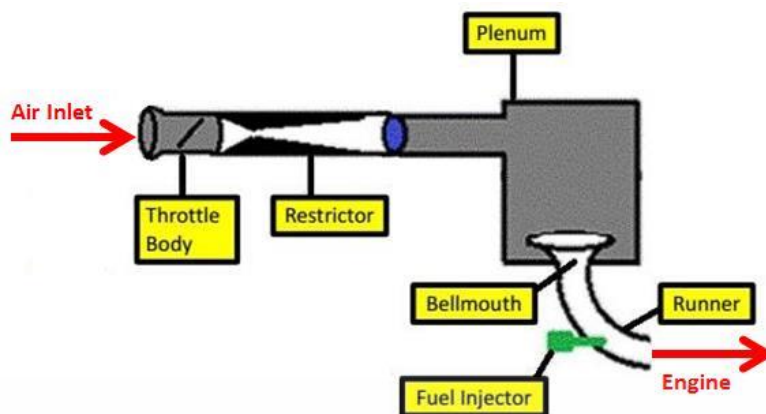


Figure 2.3 Intake System

2.4.1 Electronics Throttle Body(ETB)

The ETB [5] controls the volume of air flowing into the engine and acceleration. The electronic throttle body (ETB) has three main components: (1) a module at the accelerator pedal (2) a throttle valve (3) a powertrain or engine control module



Figure 2.4 Electronics Throttle Body [6]

1 module at the accelerator

It has two or more independent sensors include mass airflow sensor, engine speed sensor, vehicle speed sensor, and accelerator position sensor.

2 throttle valve

Valve opens and closes according to a signal from the engine control unit. that's controlled by an electric motor.

3 engine control module

The ECM that is connected to this network. then uses all this data to open the throttle valve to the desired angle, controlling fuel delivery and acceleration.

2.4.2 Restrictor

The restrictor [7] throat diameter limits the ultimate amount of air flow into the system, but the designers attempt to minimize any additional flow losses. Restrictor is a volume between Throttle and Plenum. The Restrictor will have throat diameter of 20 mm as per rules of the competition. With the basic information for throttle body diameter for an engine with 720 cc of displacement. the diameter of throttle body is taken to be 40mm; the same is widely used in competition.

The shape of a restrictor uses the theory of flow measurement handbook [8] It was decided to design Throat venturi nozzle. A venturi nozzle would decrease a lot of pressure loss downstream of the restrictor, and the resultant effect would create the efficiency of the line of airflow. The Restrictor design is following these Figure 2.5:

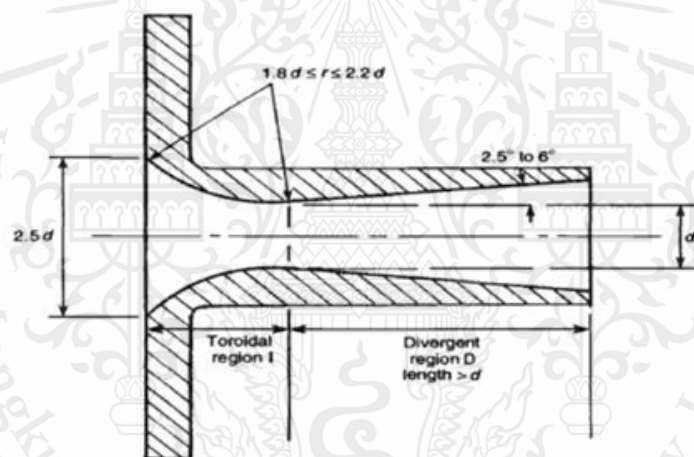


Figure 2.5 Restrictor design Throat venturi nozzle [8]

The following has two main region components:

1 the radius of concavity at inlet. The diameter of bottleneck is d , and the radius of concavity at inlet is r in condition of $1.8d < r < 2.2d$

2 the angle of bottleneck at outlet. in condition of Throat venturi nozzle. the angle at outlet is 2.5-6 degree.

The formula has used a restrictor on the intake air flow since last year. The restrictor uses the theory of flow measurement handbook. The Restrictor will have radius of concavity of 25 mm, and the angle of bottleneck at outlet is 6 degree.

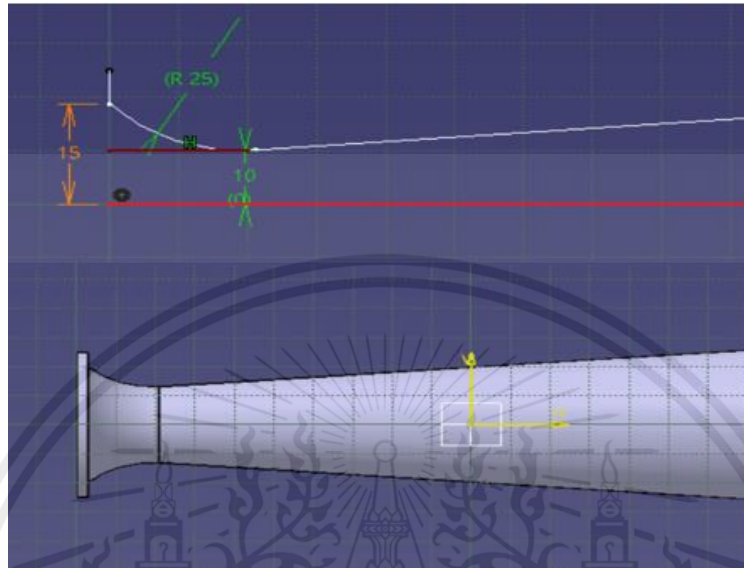


Figure 2.6 The shape of a restrictor uses the theory[7]

2.4.3 Plenum

Plenum is a Chamber volume between restrictor and runners. It provides a reserve to the individual intake runners and distributes air equally in all the runners. This helps all cylinders generate equal power which is a crucial factor for the safety of engine. Formula Student The air plenum is one of the component To improve engine performance of engine depends on many factors.

Plenum has two main factors that is shape and volume. it uses the theory of Intake Manifold Design & Testing [9]. From the previous research outcome that the volume of plenum is from 1.5-2 times of volumetric displacement. Using this as a fix constrain to design all the plenum with this volume From the scope of study are focusing on the significant changing of engine output power due to the shape and air fuel mixture, in this experiment, 4-stroke , single cylinder engine. the design of plenum by using Computational and Statistical Analysis of Fluid Dynamics and Machine Learning Theory to know the trend of airflow in the plenum



Figure 2.7 Plenum [9]

2.4.4 Bellmouth

Bellmouth is a duct of variable cross section area. It is used to allow air to enter into runner from inlet, usually The flowing fluid strikes the wall, it make flow area increase and velocity decrease it cause turbulence which increases the resistance to flow. So, Bellmouth is used to allow high velocity air to enter from the inlet without flow separation called as velocity stack

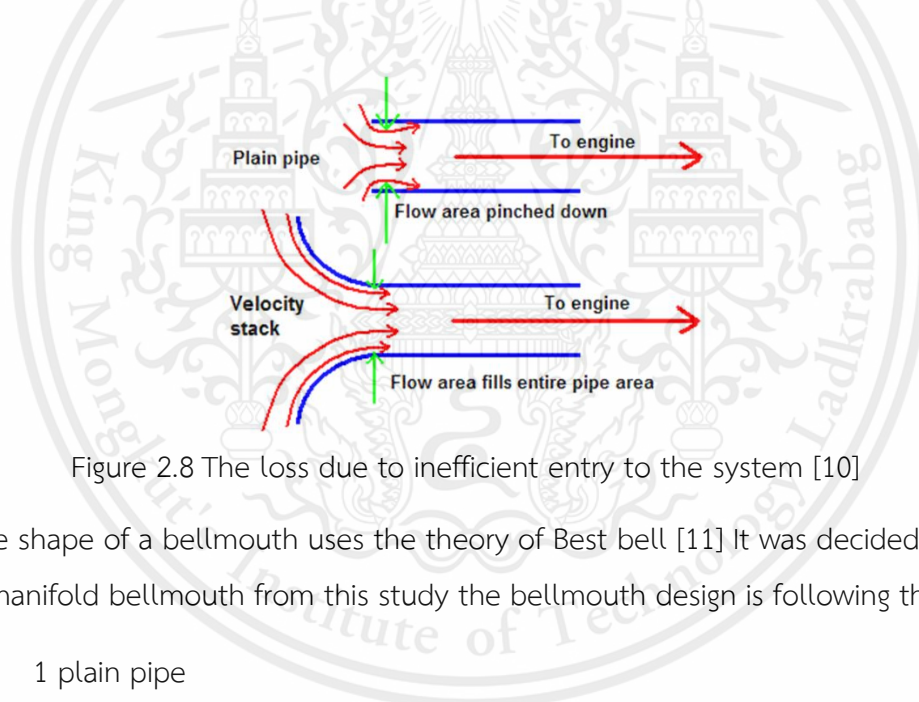


Figure 2.8 The loss due to inefficient entry to the system [10]

The shape of a bellmouth uses the theory of Best bell [11] It was decided to design of intake manifold bellmouth from this study the bellmouth design is following these

1 plain pipe

A plain pipe. is simple pipe without bell wrap-round radius.

2 simple radius

A simple radius is semi-ball wrap-round radius installed at the end of the pipe.

3 elliptical profile

The elliptical profile is cylindrical shapes. It is inconstant diameter.

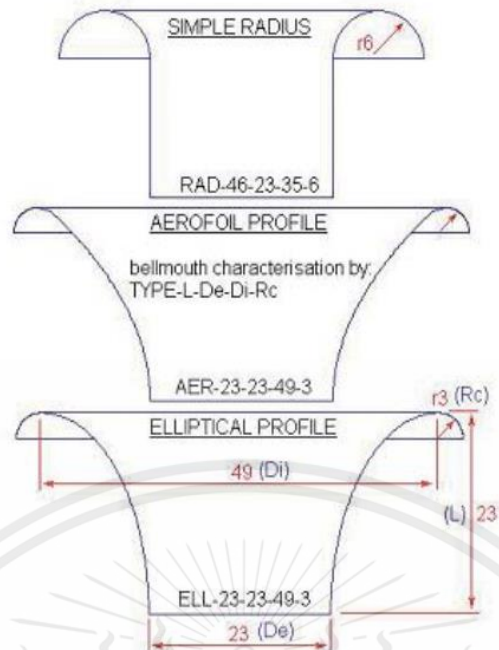


Figure 2.9 is sketched, to scale, the bellmouths[11]

2.4.5 Intake Runner

Runner is used to deliver incoming air to the cylinders. runner length is defined as the distance between the plenum surface with the cylinder head in most SI engines. fuel is added to the air in the runner by fuel injectors. or with a carburetor This causes a mixture of fuel and air (Air Fuel Ratio) to be released into the cylinder.

Runner is used the theory of Helmholtz Resonance that air can be compressed. and, the effects of the flow was measured by obtaining the resonance frequency.



Figure 2.10 Intake Runner [12]

2.4.6 Fuel Injector

Form this thesis fuel injectors spray gasoline into the intake system, On spark ignition engines, The fuel injector method is following these 1)Port injection is where injectors are located at the intake valve 2)Carburetor is when injectors spray into throttle body at the intake system. 3)Direct injection is when injectors spray directly into the cylinder. For formular student, method of mixture preparation is Direct fuel injection.



Figure 2.11 Fuel Injector[13]

2.5 Air velocity to the respect of a volumetric efficiency

Form this thesis, Volumetric efficiency is effect on torque produced. It is parameters used to describe the air velocity in the intake system. So, we can choose the volumetric efficiency that have the most power. Volumetric efficiency is relative amounts of the actual air mass and ideal air mass that shown in equations.

Volumetric efficiency is:

$$\eta_v = \frac{m_{air,actual}}{m_{air,ideal}} \quad \text{---- (2.5.1)}$$

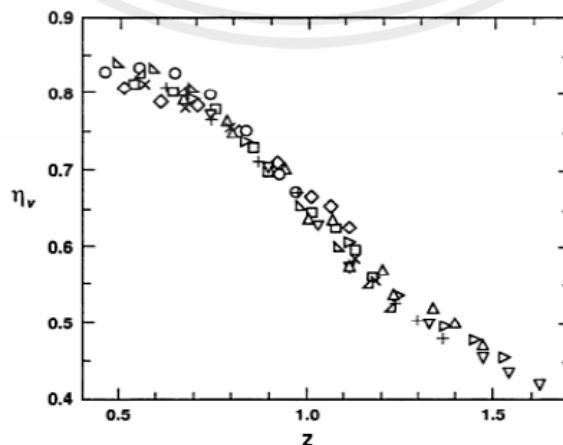


Figure 2.12 The effect of air velocity on volumetric efficiency[14]

This material is reserved for educational use only, not allowed for commercial use.

Forbidden to modify the content, and cite the document when use

The graph shows the effect of air velocity on volumetric efficiency. Air velocity at 0.5 time the speed of sound has the largest number of volumetric efficiencies. The number of volumetric efficiencies decreases by air velocity since 0.5 time the speed of sound. So, we can say. Intake System is used volumetric efficiency increases by nearly 0.5-time speed of sound. Overall, volumetric efficiency increased from 0.8 to 0.86.

Section 2: Theory of Computer-Computation Analysis

2.6 Machine Learning

Machine learning [15] is used to make decisions or predictions. For Formula Student. We use the Machine Learning to select the best design with least pressure drop to running the dynamometer test on a formula student car.

The figure 2.14 show the process of machine learning (1) we provide the machine learning methods and input data from to predict (2) we feed the new data to train model (3) If not we continue improve the algorithm or provide the new methods .

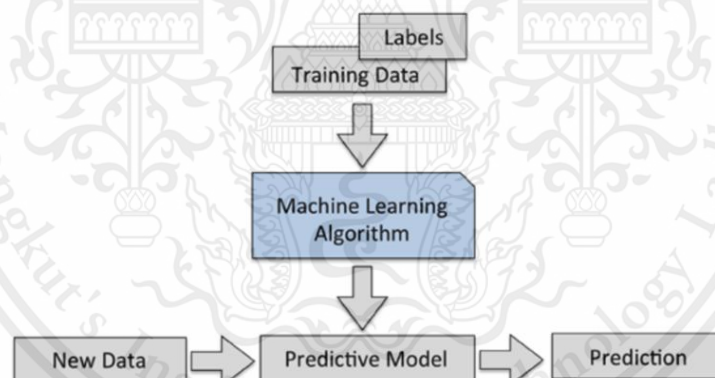


Figure 2.13 Machine Learning process [15]

In this study, We have a massive of data from CFD (Computational Fluid Dynamics) such as air pressure and streamline in each position of plenum in form of dataset then use an algorithm to find the trend of flowing fluid in the plenum by machine learning methods. Machine learning method is following this

2.6.1 Linear Regression Algorithm

Linear regression[18] was simple mathematical equation. We predict or explain a equation of the line. for example. we predict the energy consumption of building. The output can be energy consumption of other properties building.

Linear Regression equation is

$$y = b_0 - b_1x_1 \quad \text{----(2.6.1)}$$

For the example: The chart the effect of energy observed on energy predicted. Energy observed increased by age and square feet of building. This cause increasing energy consumption. Linear regression be used to draw a line that represents the energy predicted.

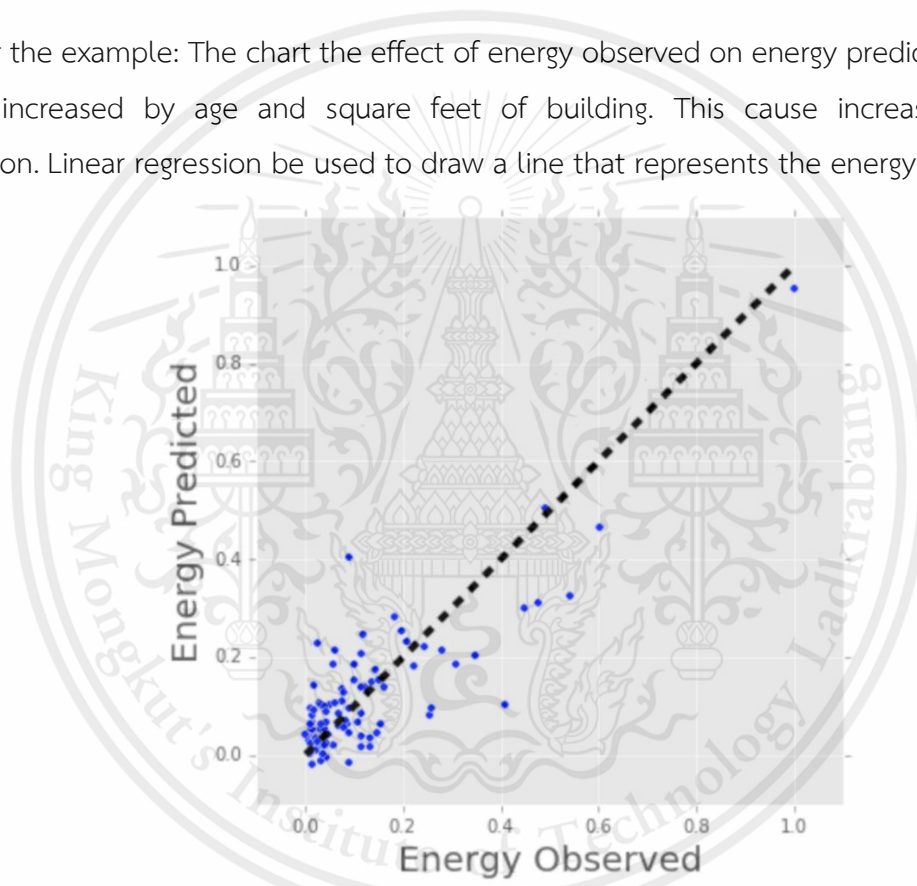


Figure 2.14 Linear Regression Algorithm plots the energy predicted [16]

2.6.2 Polynomial Regression Algorithm

Objective of this algorithm is to predict a chance of interest data that are not a linear regression. polynomial regression like a linear regression. It is relationship between the variables x and y.

Polynomial Regression equation is

$$y = b_0 + b_1x_1 + b_2x_1^2 + \dots + b_nx_1^n \quad \text{----(2.6.2)}$$

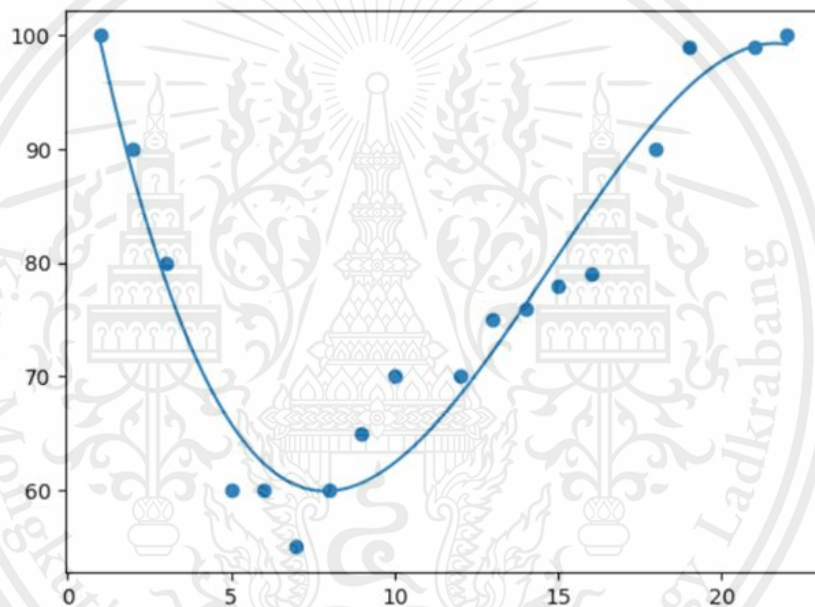


Figure 2.15 Polynomial Regression Algorithm draw the line through the data points[17]

In this study, we use this algorithm to analyze data from CFD (Computational Fluid Dynamics) to determine the trend of the flowing fluid in the intake system.

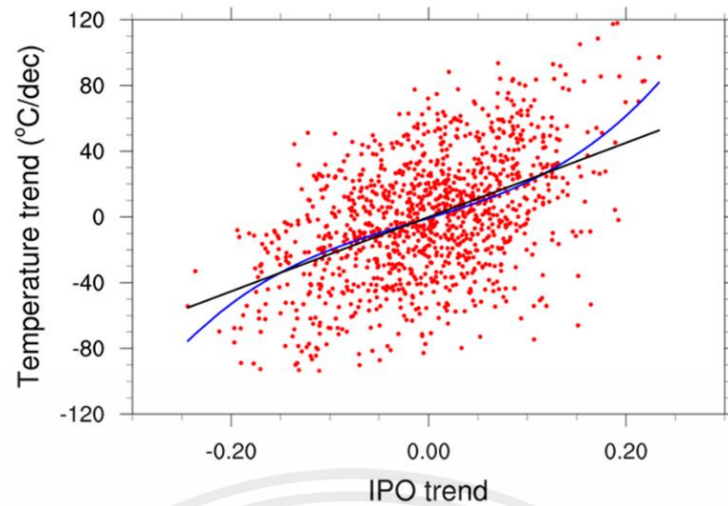


Figure 2.16 The trend line generated by the bulk data [18]

2.6.3 Kalman filter Algorithm

Kalman filter algorithm is used for tracking a single moving object for given observations or measurements. Kalman Filter are not needed to provide training data and it has ability to handle noisy and the states of a system Such as radar and sonar tracking and state estimation in robotics, autonomous navigation systems, economics prediction, etc.

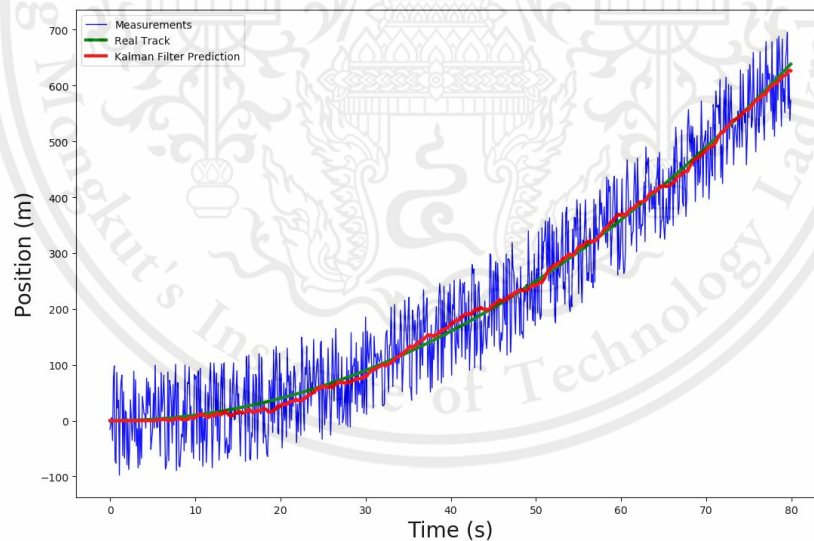


Figure 2.17 Example of Kalman filter for tracking a moving object in 1-D [19]

2.6.4 Decision Tree Algorithm

Decision tree [20] is the algorithm used in the decision for categorizing or selecting the data from the input criteria of the design. For the Decision tree algorithm, the following are the common use components and descriptions of the components in the algorithm:

1 Root node and Decision nodes

Root node is where the decision tree starts and represents the whole dataset. And

Decision nodes are used to make a decision, whereas leaf nodes are the output

2 Splitting and Parent node

Splitting is used to divide a node into sub-nodes according to conditions. And Parent node is the root node, whereas other nodes are child nodes.

3 Branch tree and sub tree

Branch tree and sub tree are a tree that divide from a tree which is a specific value or condition to categorize.

In this study, we use this algorithm to make any decision from massive data and transfer function to get the solution to design the plenum to be better efficiency and performance

2.6.4.2 Gini index

Gini index [20] is a coefficient of the distribution of data. It is used to make a decision in Decision Tree Algorithm by selecting an attribute type of data. Attribute type that makes the Gini index be the least. It will be the best value.

Gini index equation is

$$Gini(t_i) = 1 - \sum_{i=1}^N [P(t_i)]^2 \quad \text{-----(2.6.4.2)}$$

Advantage	Disadvantage
Simple to understand which act like a human making a decision in real life.	Complex and massive of tree layer
Useful for solving and decide any problem that related	Possible to have overfitting that can be resolved by using Random Forest algorithm.
Can help to found out the chance of possible result of the problem	More class lables more complexity for computational
Less requirement data for making an algorithms if compared with other	

Table 2.6.6 advantage and disadvantage of decision tree

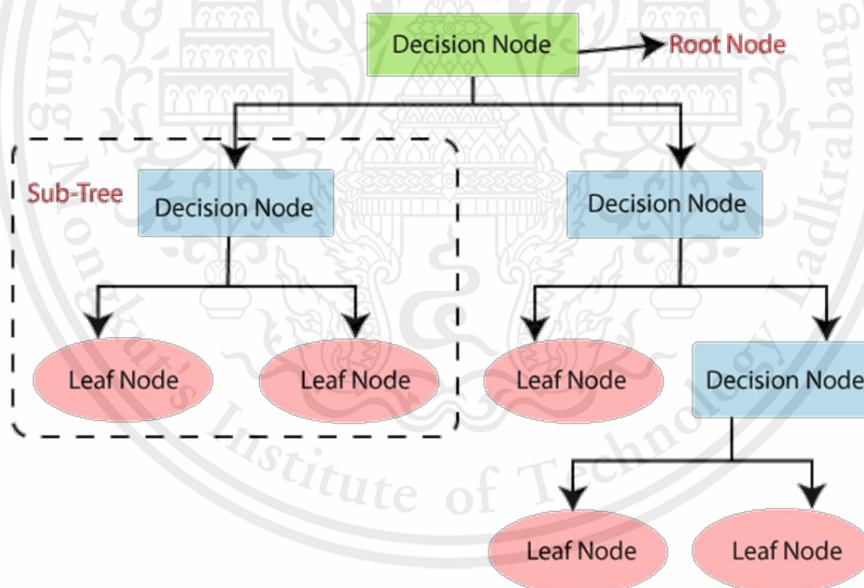


Figure 2.18 Decision Tree Algorithm [20]

2.7 Computer Program was used for Machine Learning

2.7.1 VS code

Visual Studio Code is a streamlined code editor. We used VS code because they operations well and task running well. From this study we use Visual Studio Code to write programming languages, including Java, JavaScript, C++ and python for Machine Learning program.

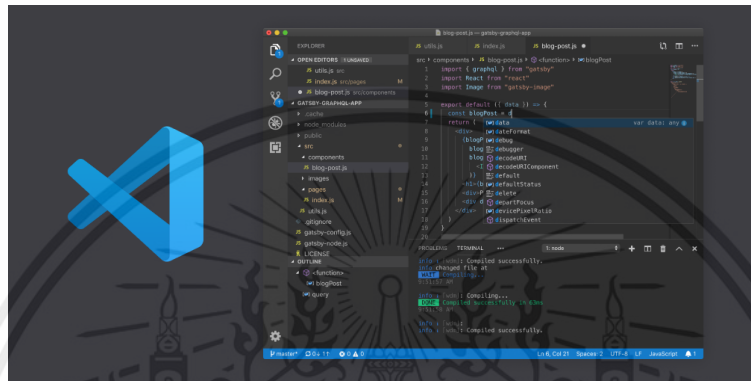


Figure 2.19 VS code [21]

2.8 CAD (Computer Aid Designed)

Computer Aid Designed is designing technology to make either a 2D or 3D drawing, from this study we use CAD to modify and improve design quality. Computer program was used follow these:

2.8.1 Catia

Catia is design software used for physical modeling. it facilitates to create 3D designs from Catia . from this study, we use Catia to develop and design the products. We create Intake System component. Including Restrictor and Plenum and Bellmouth for the competition.

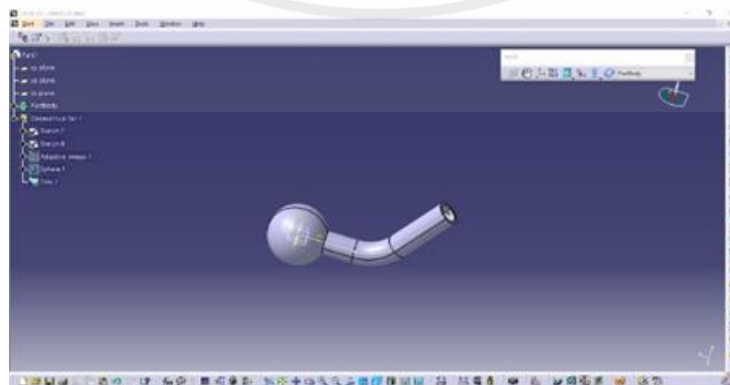


Figure 2.20 Catia

This material is reserved for educational use only, not allowed for commercial use.

Forbidden to modify the content, and cite the document when use

2.9 CAM (Computer Aid Manufacturing)

In this thesis we make physical properties with a CAM system. CAM is computer focuses on the design of a product or part. and we use 3D printer to fabricate prototype for making a plenum part.

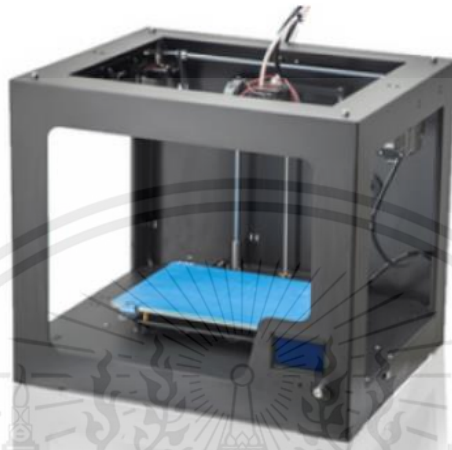


Figure 2.21 3D printer [22]

2.10 CFD (Computational Fluid Dynamics)

An analysis method about fluid flowing effect, heat transfer, particle diffusion or chemical reaction by using computer to find solution and simulate effect of fluid that happen in each condition by solving Navier-Stokes equation.

In this study, we use CFD for predict transition and turbulence flow in intake system for Formula Student Car to get to know about factor that effect to streamline and air pressure in the plenum to improve the design of plenum for better efficiency and performance.

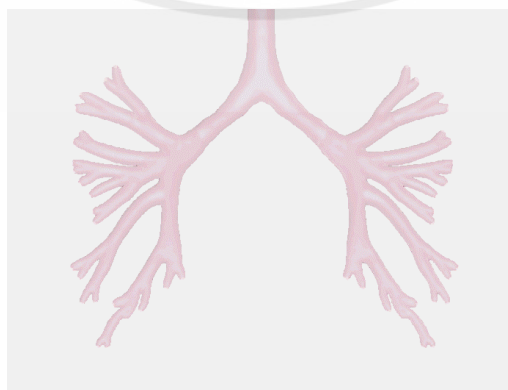

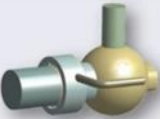


Figure 2.22 Diffusion of air intake and exhaust in lung [23]

This material is reserved for educational use only, not allowed for commercial use.

Forbidden to modify the content, and cite the document when use

Cell / Element count comparisons		ANSYS			
	Nodes Before	Nodes After	Cells Before	Cells After	
FEA meshing example					
	856,123	695,863	505,019	399,144	
		23% reduction		27% reduction	
CFD meshing example					
	562,123	390,271	2,035,975	1,469,804	
		23% reduction		39% reduction	

© 2010 ANSYS, Inc. All rights reserved. 28 ANSYS, Inc. Proprietary

Figure 2.23 Ansys Computational Fluid Dynamics and Finite Element Analysis comparison[24]

From figure 2.22 above showing the CFD (Computational Fluid Dynamics) have better reduction rate that have an advantage over FEA (Finite Element Analysis) in computing speed by the less node and cell the less time it takes.

2.10.1 Meshing

Meshing [25] is used to determine the path and direction of a fluids in a CFD simulation using Design Modeler in ANSYS Workbench to generate mesh for our fluids domain in the simulation process

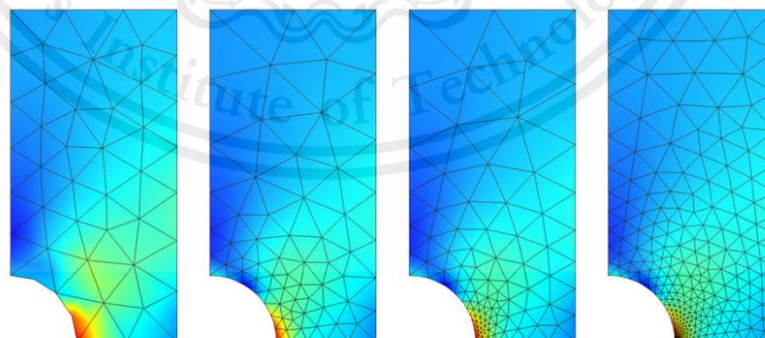


Figure 2.24 Mesh quantities improve a precision of a simulation result [25]

2.10.2 Numerical Method for CFD

In CFD modelling most of the problem not taking place on a cubic box, Finite-Element are required in this simulation in fact that 3D and 2D mesh are flexible in term of geometry and mesh element; any type of mesh can be applying to a geometry. For instance, Local Conservation such as mass conservation is not necessary for being a property of the finite-element method, but finite-element method is not much use for a CFD. The numerical method for CFD is generally use this following

2.10.3 Finite-Volume method

principle of finite-volume method [25] is a local conservation such as a mass conservation by employing the Gauss' law by the partial derivatives expressing a conservation principle, such as $\text{div } u$, can be rewritten at each cell as an algebraic contribution. The governing equation, expressed in the partial differential equations, is reformulated, at each computational cell, into a set of linear algebraic equations. Flowrate Measurement we use Bernoulli equation is

$$p_1 + \frac{1}{2} \rho V_1^2 + \gamma z_1 = p_2 + \frac{1}{2} \rho V_2^2 + \gamma z_2 \quad \text{---- (2.10.3.)}$$

2.10.4 Transient flow

From a ANSYS it is useful to separate possible flows into the steady and transient flow. Transient flow depends on the properties of fluids that change over time such as velocity, pressure, density

$$\frac{\partial \rho}{\partial t} \neq 0, \frac{\partial P}{\partial t} \neq 0, \frac{\partial v}{\partial t} \neq 0 \quad \text{---- (2.10.4.)}$$

This thesis we focus fluid pressure relative to boundary transient volume. This graph show effect of pressure and transient response for plenum volume at 4 strokes. engine.

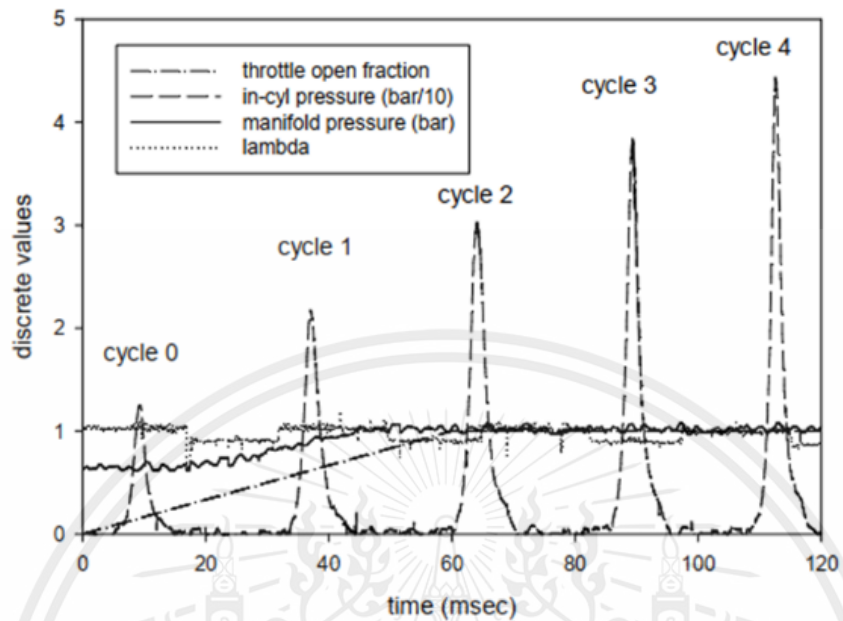


Figure 2.25 transient response for plenum volume [25]

CHAPTER 3

DESIGN

3.1 Introduction

From the scope of study are focusing on the significant changing of engine output power due to the shape and air fuel mixture, in this experiment, 4-stroke , single cylinder engine, port injection will be used.

Manufacturer	KTM
Displacement	690 cc
Type	4-stroke, Single Cylinder
Cooling	Water-based coolant
Valve Train	DOHC, 4-Valve Single
Bore/Stroke	102.0x80.0 mm.
Compression Ratio	11.8:1
Fuel System	Fuel Injection, Port Injection
Lubricant	Semi-Dry sump
Transmission	6-speed sequential

Table 3.1 specification of formular student

3.2 Plenum Design

From the previous research outcome that the optimum power output of engine are from 6.65 times of volumetric displacement due to the FSAE Regulation of an envelop close surface. Using this as a fix constrain to design all the plenum with this volume and simulation using ANSYS. The keys of plenum design is to following these criteria:

- design to a lowest pressure drop in an intake system
- pressure of the air inside the plenum chamber should be the same with atmospheric pressure in purpose of getting the most air density of an air
- mass flow rate should meet the theoretical air amount of the combustion equation

From the above criteria, we have designed a 3 different shape with the same volume to be simulate by ANSYS Fluent CFX.

This material is reserved for educational use only, not allowed for commercial use.

Forbidden to modify the content, and cite the document when use

3.2.1 Plenum 1 Design

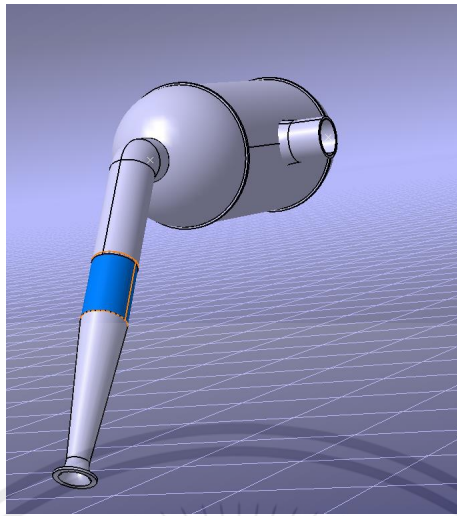


Figure 3.1 Geometric design of plenum 1

3.2.2 Plenum 2 Design

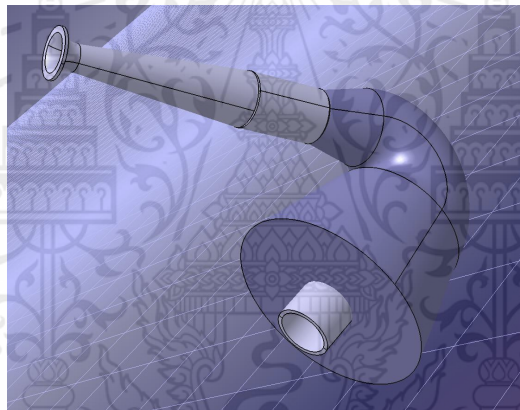


Figure 3.2 Geometric design of plenum 2

3.2.3 Plenum 3 Design



Figure 3.3 Geometric design of plenum 3

This material is reserved for educational use only, not allowed for commercial use.

Forbidden to modify the content, and cite the document when use

Chapter 4

Equipment and Experiment Procedure

4.1 Introduction

This thesis consist of the control value of fuel type ignition timing, lambda (relative air fuel ratio), plenum size which is about 13.5 times to engine displacement and Independence variable is a plenum shape, runner length which is use to studying the engine behavior to response to the air inlet to optimize the engine power in the Formula Student car.

4.2 Experimental Description

This experiment will be testing the engine power with a dynamometer with a 5 different shape of plenum design which is has been selected from a Machine Learning procedure that will produce the most horsepower by simulation and 4 of intake runner length. Then using the data logger to log the dynamometer graph into the spreadsheet and analyze using the machine learning algorithm to select the maximum power in each case into the table following in the figure 4.1

Testing object		Plenum Design				
		Design 1	Design 2	Design 3	Design 4	Design 5
Tuning run	Run 1					
	Run2					
	Run3					
	Run4					

Figure 4.1 Table of maximum power for each selected design case

4.3 Experimental Setup

This experiment will use the following setup to run the testing procedure



Figure 4.2 Assembly of the engine setup for intake system testing

4.3.1 Intake system

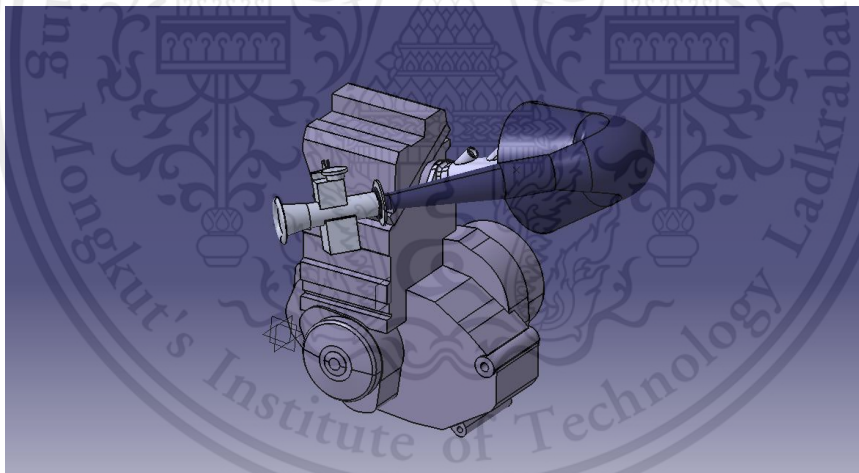


Figure 4.3 Assembly of air intake system

This material is reserved for educational use only, not allowed for commercial use.

Forbidden to modify the content, and cite the document when use

In this setup we are setting up the engine to be a port-fuel injection by the Figure 4.2. For the air intake system are consist of these following part

- 1 Intake Bellmouth
- 2 Throttle Body with Throttle position sensor
- 3 FSAE Air Restrictor
- 4 Intake Plenum
- 5 Intake runner
- 6 Injector mount

4.3.2 KTM Duke 690 CC years 2010

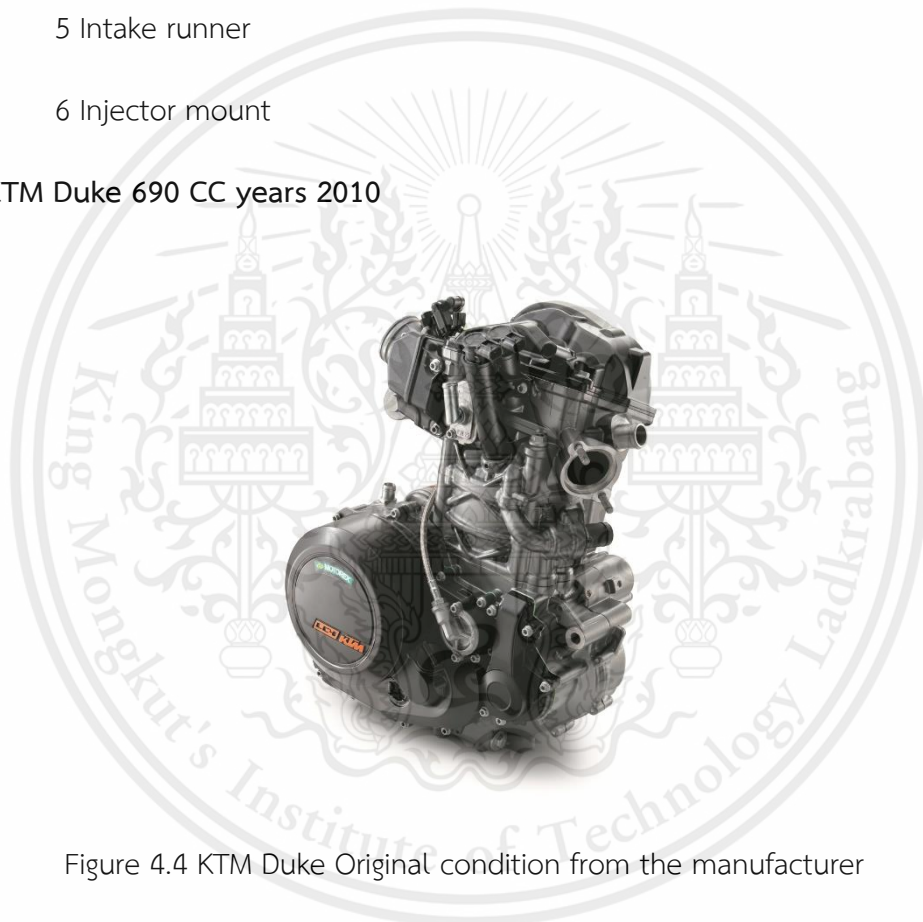


Figure 4.4 KTM Duke Original condition from the manufacturer

A motorcycle engine which can be used in Formula Student Competition which modified in a performance purpose with non-OEM Engine Control Unit

4.3.3 Exhaust System

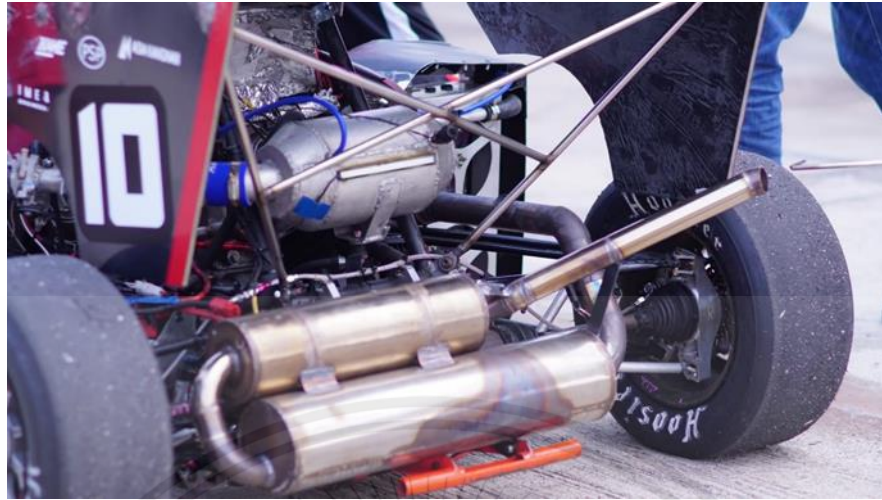


Figure 4.5 Assembly of Exhaust system

In exhaust system are using the CAD and CAE in designing the pipe length and using the machine learning procedure to optimize the design parameter along with the exhaust muffler to ensure the maximum efficiency of an exhaust outlet.

4.3.4 Engine Control Unit



Figure 4.6 Engine Control Unit

Using Link Xtreme G4+ engine control unit from Link Management to control the fuel injection and engine ignition system

4.3.5 Formula Student Car



Figure 4.7 Formula Student car use in the experiment

4.3.6 Gasoline E10 Fuel (Gasohol 95)

4.4 Measurement and data logging instrument

- 1 Manifold absolute pressure sensor (MAP)
- 2 Air flow rate sensor
- 3 Oxygen Sensor
- 4 Innovate LM2 (Oxygen transducer to CAN)
- 5 Rolling Dynamometer



Figure 4.8 Manifold Absolute Pressure Sensor from Toyota 4AGE-FE Engine

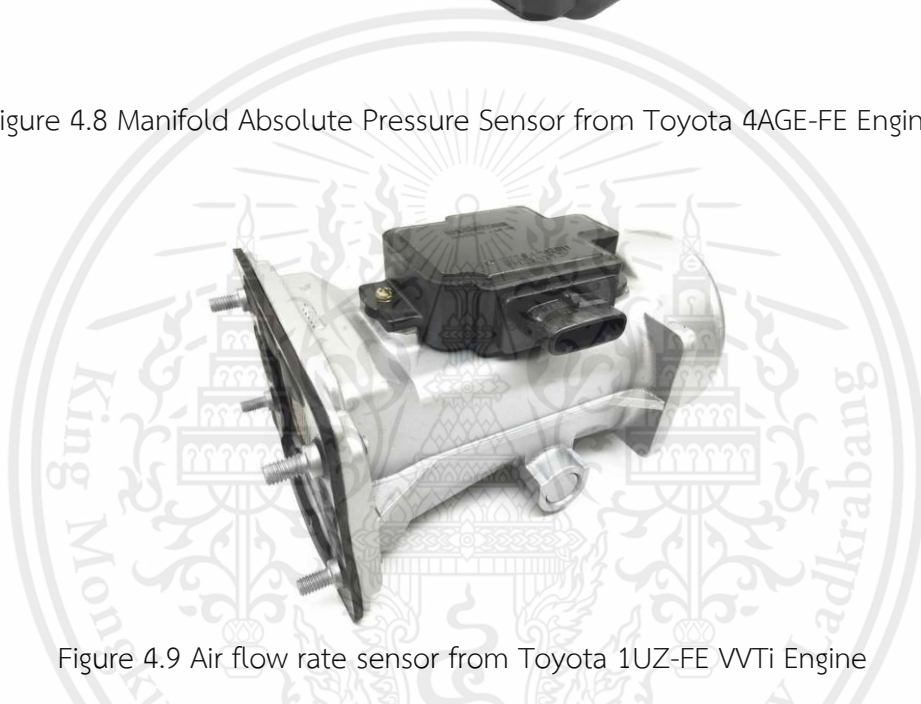


Figure 4.9 Air flow rate sensor from Toyota 1UZ-FE VVTi Engine



Figure 4.10 Wideband Oxygen sensor



Figure 4.11 Innovate LM2 Oxygen volumetric transducer



Figure 4.12 Rolling Dynamometer

4.5 Instrumental Calibration

For measurement tools such as Manifold absolute pressure and mass air flow rate need to be calibrated with the standardized measuring instrument to program a data logger

4.5.1 Oxygen Sensor

Using the calibrated sensor and data provided from the supplier

4.5.2 Air flow rate sensor

Using the controllable fan duct to simulate the air flow rate and decode the signal from the sensor. In figure 4.13 show the calibration procedure for air flow rate sensor



Figure 4.13 Calibration procedure of air flow rate sensor

After the calibration procedure, trends of a raw voltage of the sensor compared to the air flow rate are shown in the figure 4.14

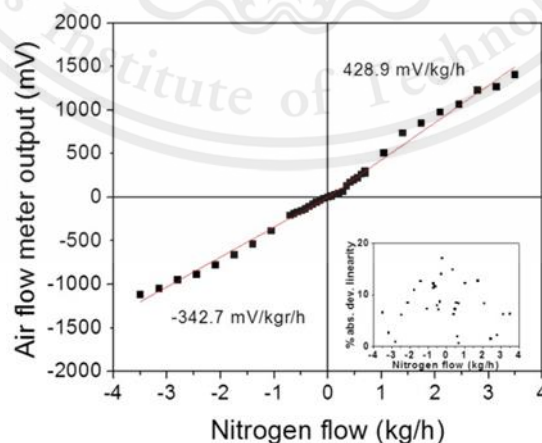


Figure 4.14 Calibrated data of air flow rate sensor with the regression equation

Chapter5

Experimental results

5.1 Velocity, times and pressure of the piston relative to piston position

From experimental found the relative of piston position and velocity of piston in 1 cycle in figure 5.1

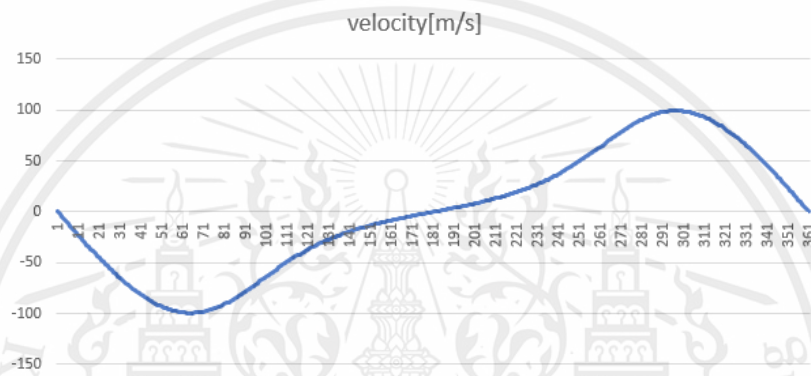


Figure 5.1 Graph of relative of velocity and crank angle at 7500 RPM

From experimental found the relative of piston velocity and pressure of air in combustion chamber due to time in 1 cycle in figure 5.2

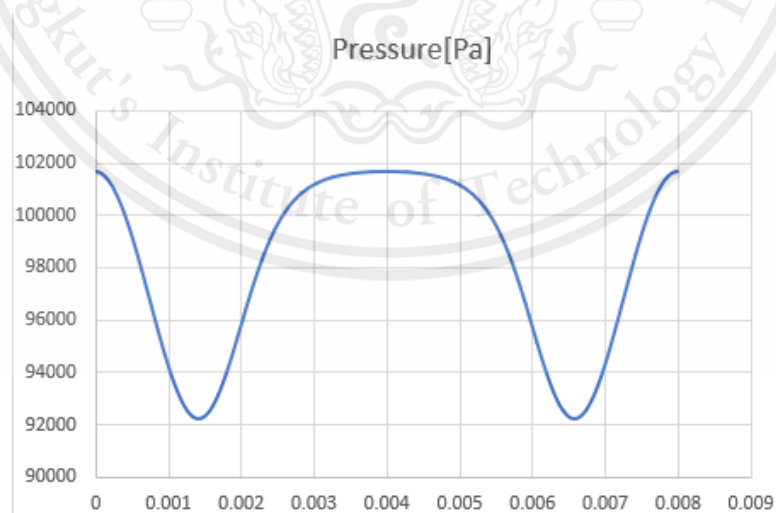


Figure 5.2 Graph of relative of pressure and times at 7500 RPM

5.2 Result of airflow in plenum affected by shape

Simulation of airflow in plenum using ANSYS CFX to get time step data by set relative pressure and pressure in combustion chamber in each 360 degrees of crank angle.

5.2.1 Streamline in plenums

Velocity streamline at 90 degrees (Before port closed) and 360 degrees (Before port opened) of crank angle have a difference of density path of air flow in each plenum.

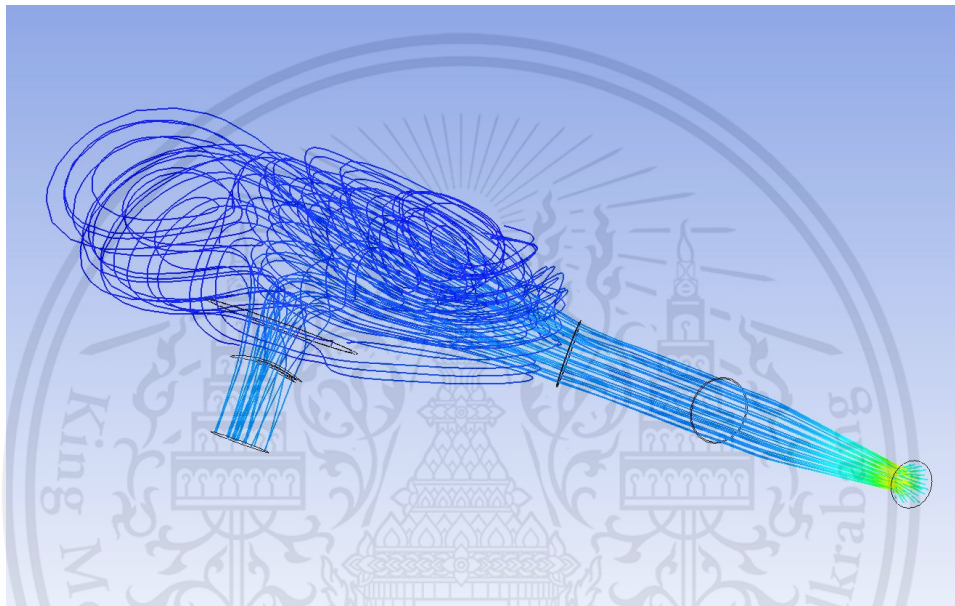


Figure 5.3 Streamline at 90 degrees of crank angle of plenum 1

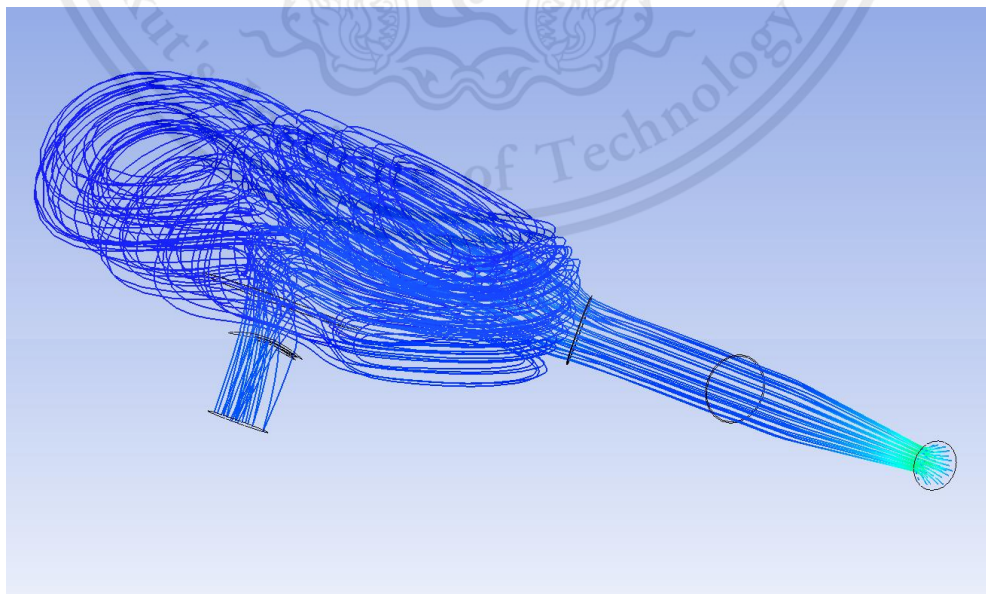


Figure 5.4 Streamline at 360 degrees of crank angle of plenum 1

This material is reserved for educational use only, not allowed for commercial use.

Forbidden to modify the content, and cite the document when use

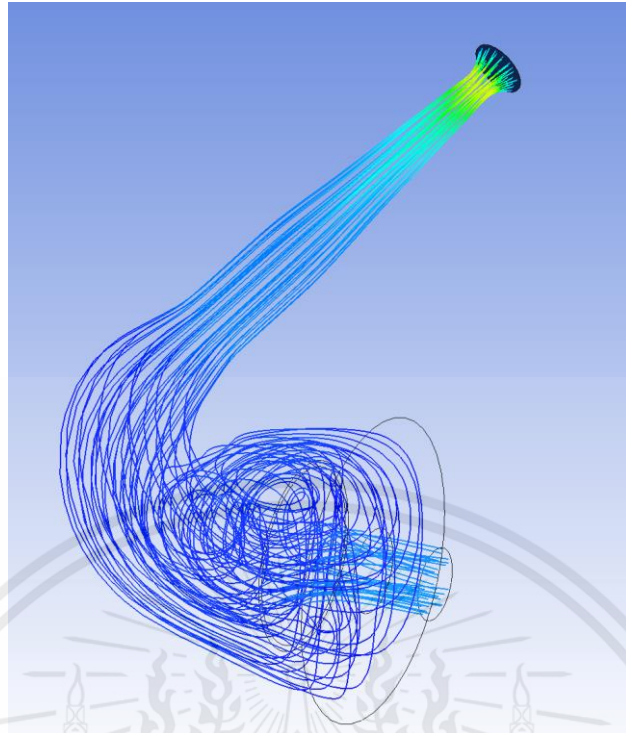


Figure 5.5 Streamline at 90 degrees of crank angle of plenum 2



Figure 5.6 Streamline at 360 degrees of crank angle of plenum 2

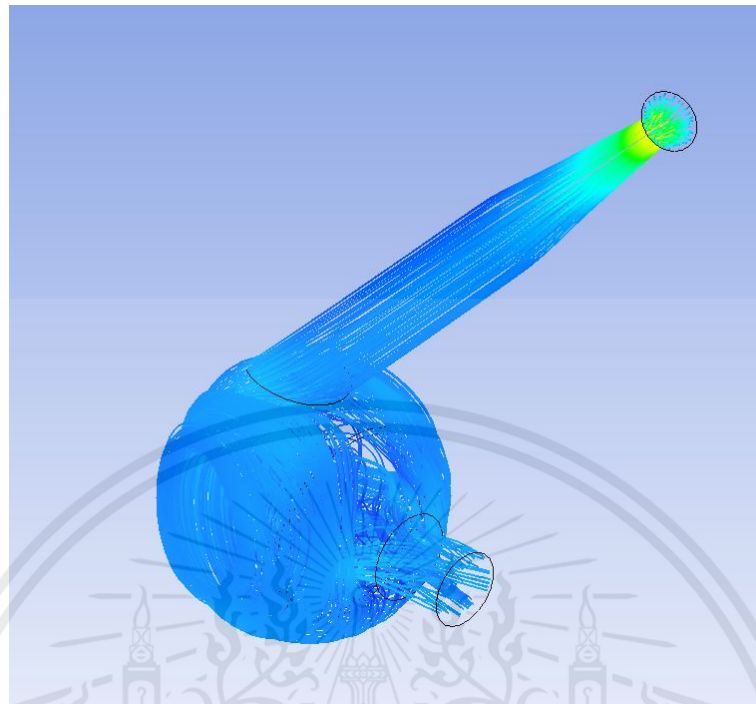


Figure 5.7 Streamline at 90 degrees of crank angle of plenum 3

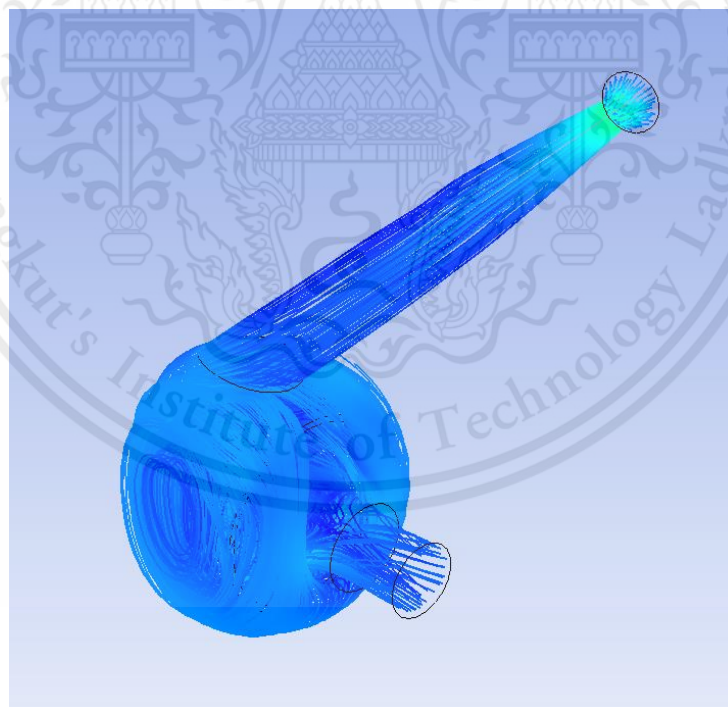


Figure 5.8 Streamline at 360 degrees of crank angle of plenum 3

5.2.2 Pressure and Velocity of an air particle in the plenum chamber simulated on ANSYS CFX in Transient method.

Figure 5.9-5.14 shown the statistical value of each variable of an air particle inside the plenum chamber to be used in the machine learning process.

1 Pressure.

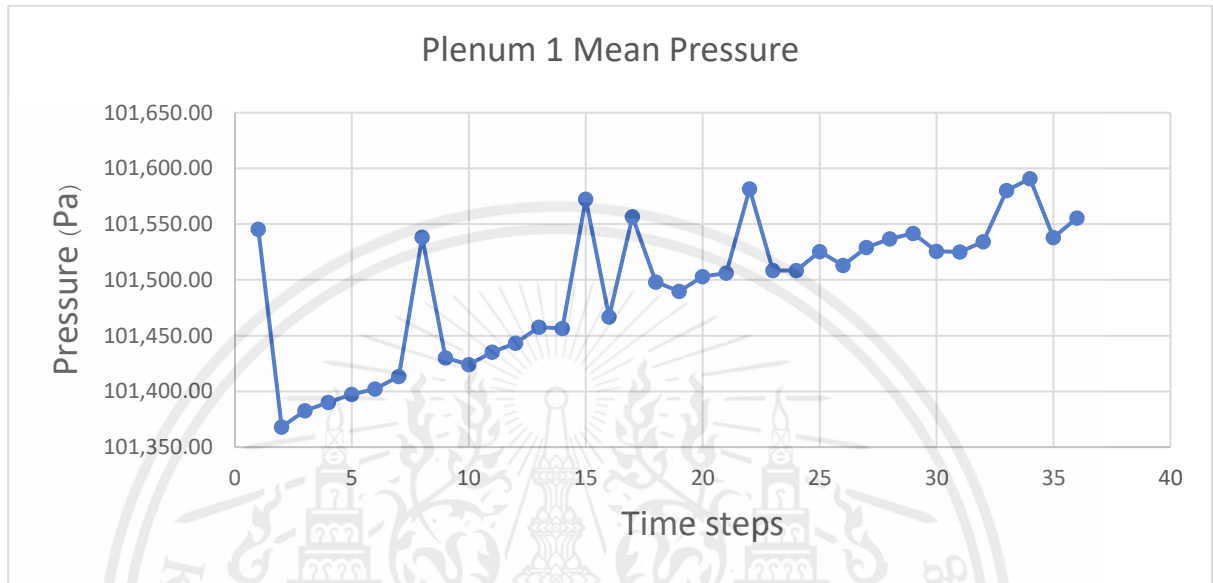


Figure 5.9 36 timesteps mean pressure of plenum 1

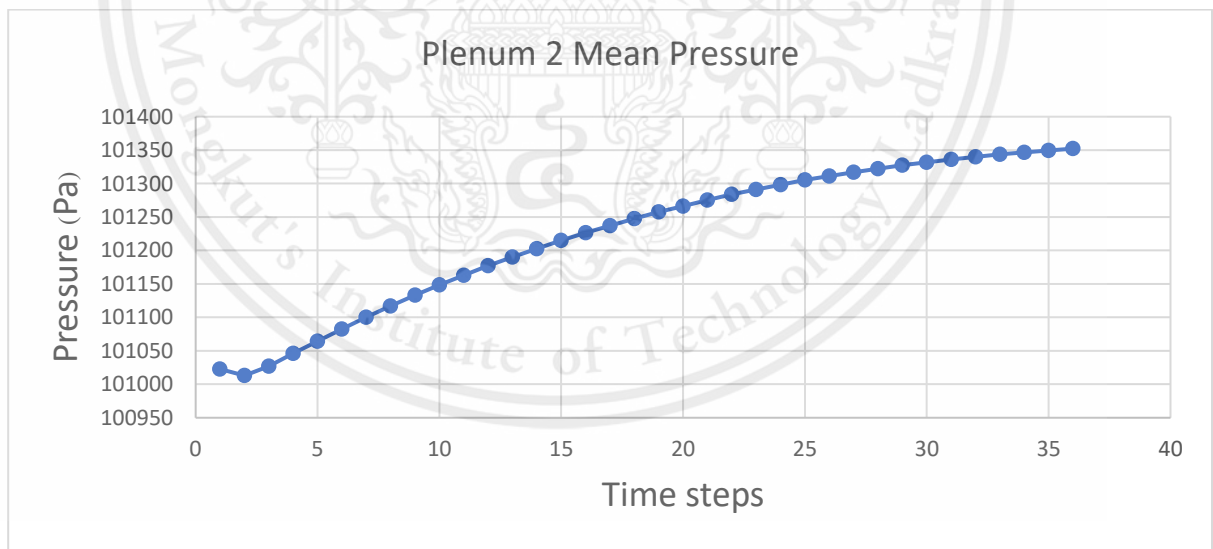


Figure 5.10 36 timesteps mean pressure of plenum 2

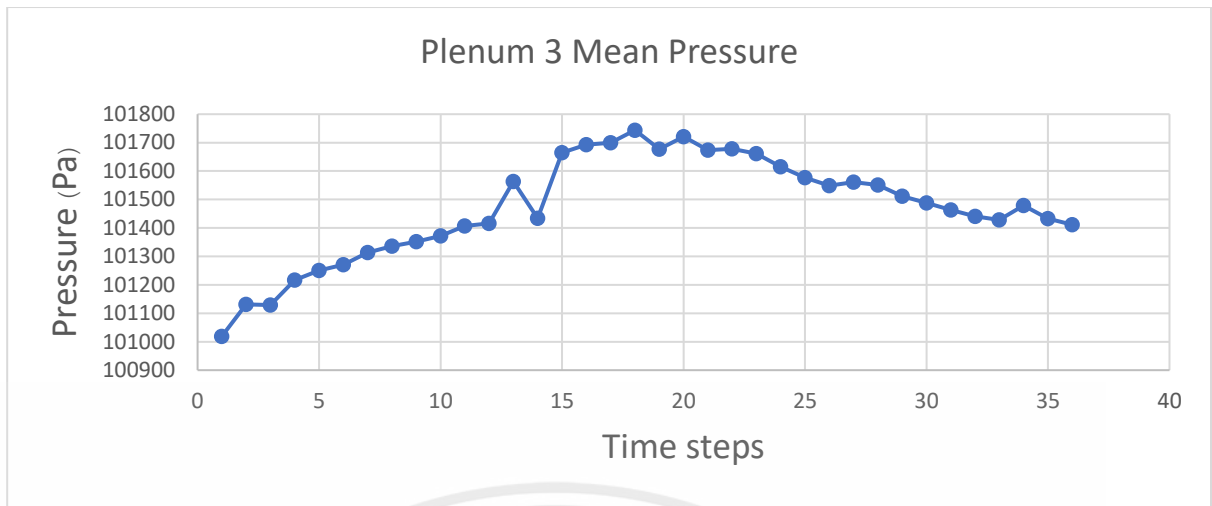


Figure 5.11 36 timesteps mean pressure of plenum 3

2 Velocity

Graph of timesteps mean of each plenum that show the trend of velocity from 0-360 degrees of crank angle to get the relation and difference of each plenum designs.

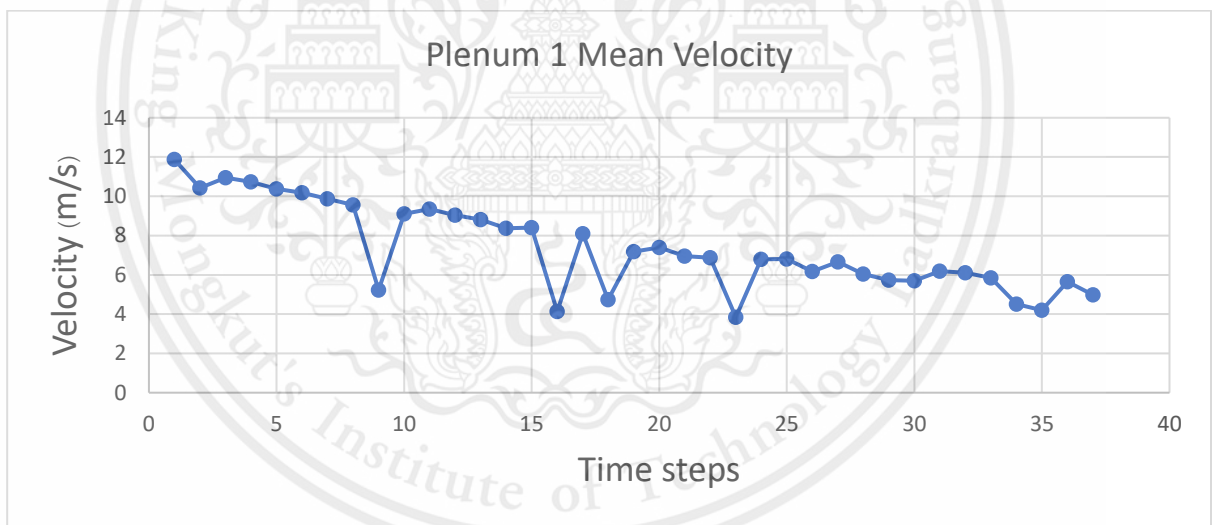


Figure 5.12 36 timesteps mean velocity of plenum 1

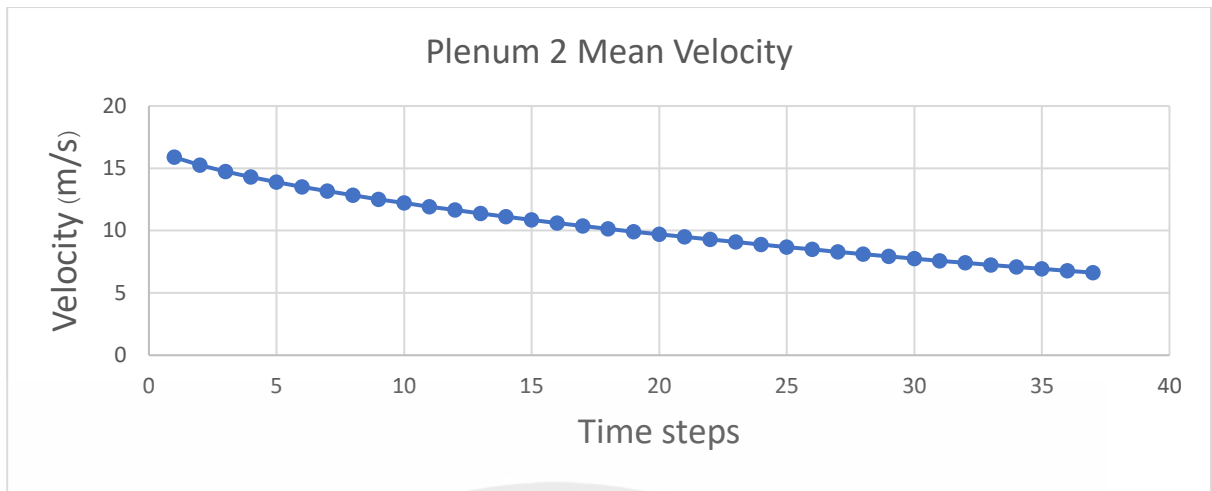


Figure 5.13 36 timesteps mean velocity of plenum 2

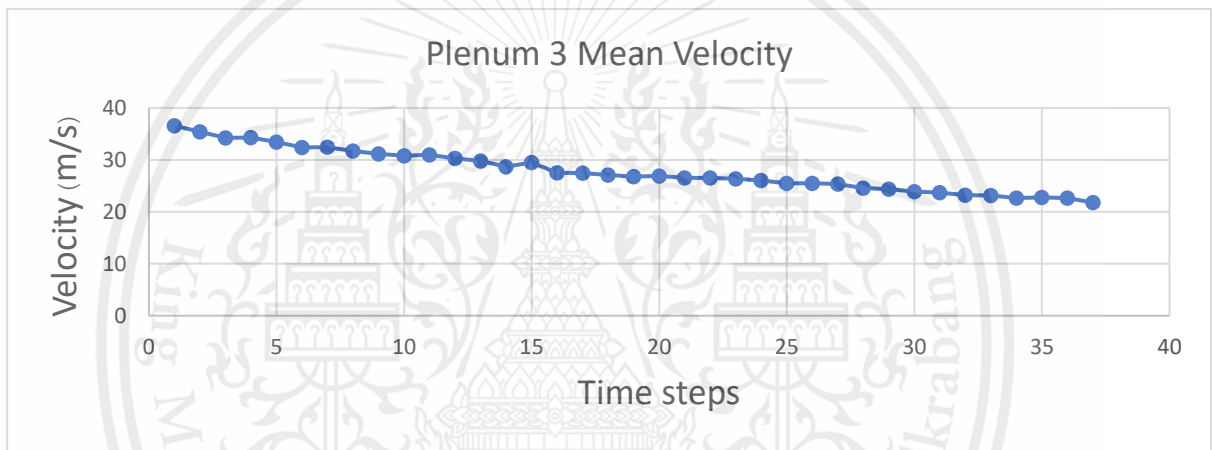


Figure 5.14 36 timesteps mean velocity of plenum 3

5.3 Engine power relative to pressure of intake air from plenum

After gathering data from the ANSYS CFX result in the form of .csv files, Using the VS Code editor to run the Machine Learning algorithm to analyze the result from the simulation into the prediction model and classification.

5.3.1 Mode pressure

Figure 5.15 shown the result of the mode pressure of the air particle inside the plenum chamber in every timestep.

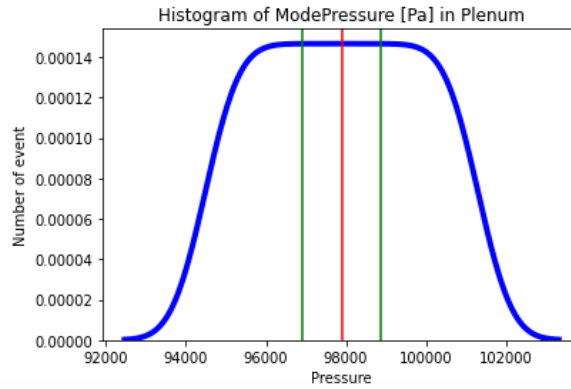


Figure 5.15 Histogram of mode pressure in plenum.

5.3.2 Relative of mode pressure and output power

Figure 5.16 shown the result of the mode pressure related to the output power by splitting data to use as a training data.

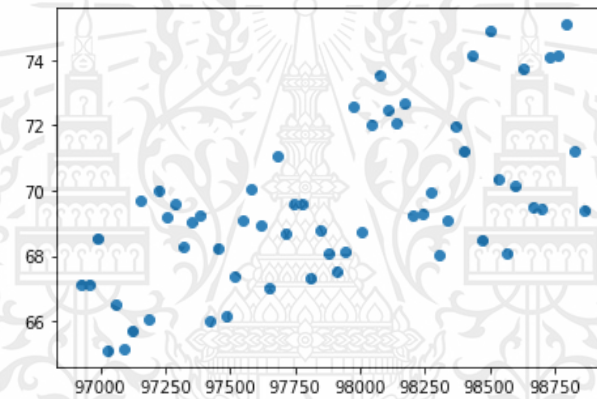


Figure 5.16 Scatter plot of Relative of mode pressure and output power.

5.3.3 Polynomial regression of pressure and output power

Figure 5.17 shown the result of the Machine Learning generated model to use in output power prediction in the black line by polynomial regression.

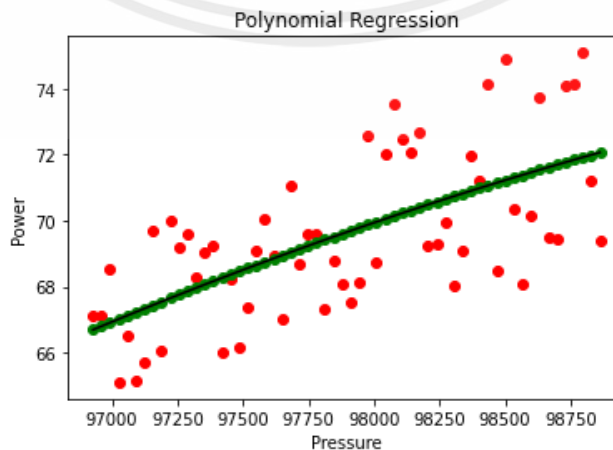


Figure 5.17 Polynomial regression line of pressure and output power.

This material is reserved for educational use only, not allowed for commercial use.

Forbidden to modify the content, and cite the document when use

5.4 Engine power respect to design variable of Air Plenum design

5.4.1 Result from Machine Learning model

In the same manner of data preparation from the section 5.3, Inspecting the using polynomial multivariable feature to formulate more accuracy model of power outputs. From the figure 5.18, shown that the coefficient of determination of the multiple variable models are 0.852 which considered as acceptable to use.

```
[157] > ML
PolyOutFit.fit(XtrP,OutputPoly)
r_sq = PolyOutFit.score(XtrP, OutputPoly)
print('coefficient of determination:', r_sq)
coefficient of determination: 0.8520888778955038

[158] > ML
PolyOutFit.intercept_
110895.17921596917

[159] > ML
PolyOutFit.coef_
array([-6.72397408e-01, -3.77809631e+00, 3.37183609e-01, 1.30025976e-02,
-3.78692896e-04, 3.69224696e-05, 4.98454350e-06, 5.01778001e-02,
-3.02464287e-01, -6.32298669e-06, -4.84771888e-02, 3.00486931e-01,
5.62670889e-03, -1.01590959e-02, 2.69500425e-03, -1.20281863e-10,
-2.68385927e-11, -9.25248606e-08, 2.08127797e-06, 3.51425627e-12,
-3.73709657e-07, -1.05875246e-06, 5.92345796e-03, 8.26173182e-05,
-2.74777380e-03, 2.10345035e-11, 4.49805078e-07, -1.00376092e-06,
-6.15707712e-03, 4.52572014e-05, -2.53882567e-03, -5.57882707e-02,
6.25803998e-02, 2.36106312e-02, -2.00150779e-02])
```

Figure 5.18 Intercept of the equation and Coefficient of the relation equation determined by polynomial feature (3rd order polynomial).

5.4.2 Result from Algorithm selected design

By using all the statistical variable exported from the ANSYS CFX simulation, classification model can be formulate as shown in figure 5.19

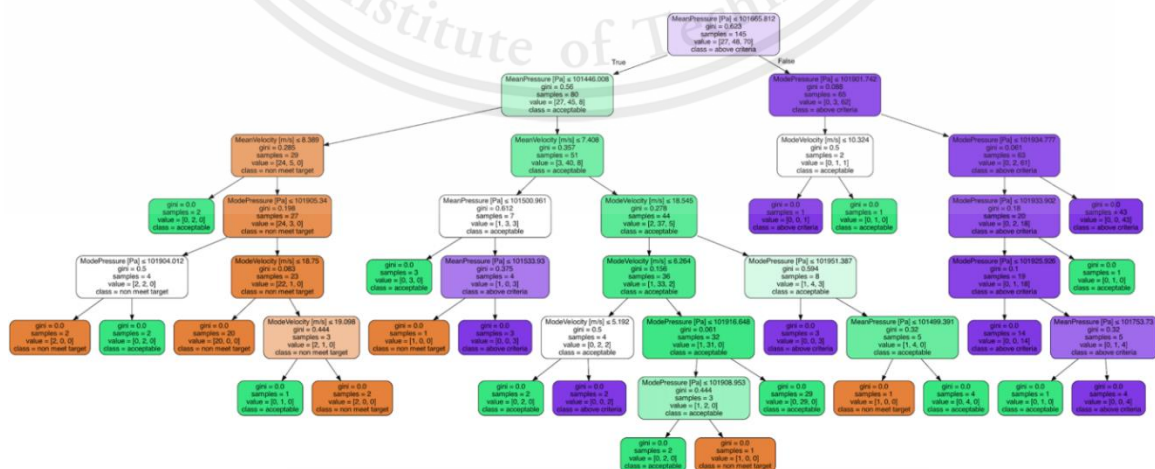


Figure 5.19 Result from decision tree

5.5 Comparing the results

5.5.1 Timesteps pressure and velocity

Comparing pressure and velocity we visualized to see how different of each plenums in term of pressure and velocity.

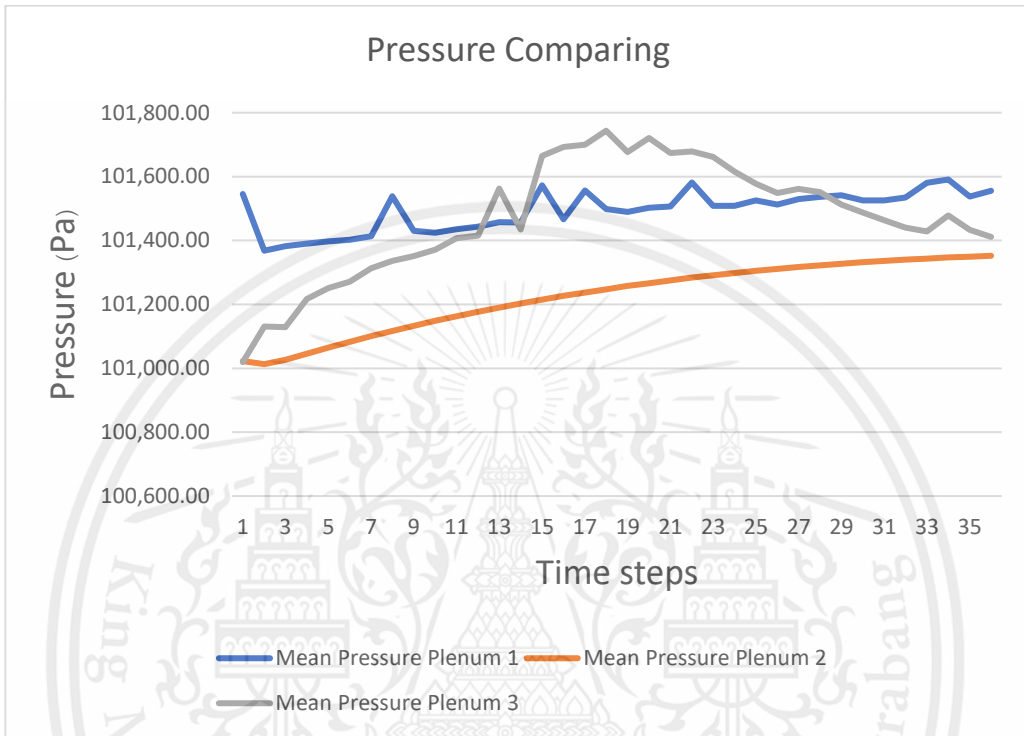


Figure 5.20 36 timesteps pressure comparing in each plenum

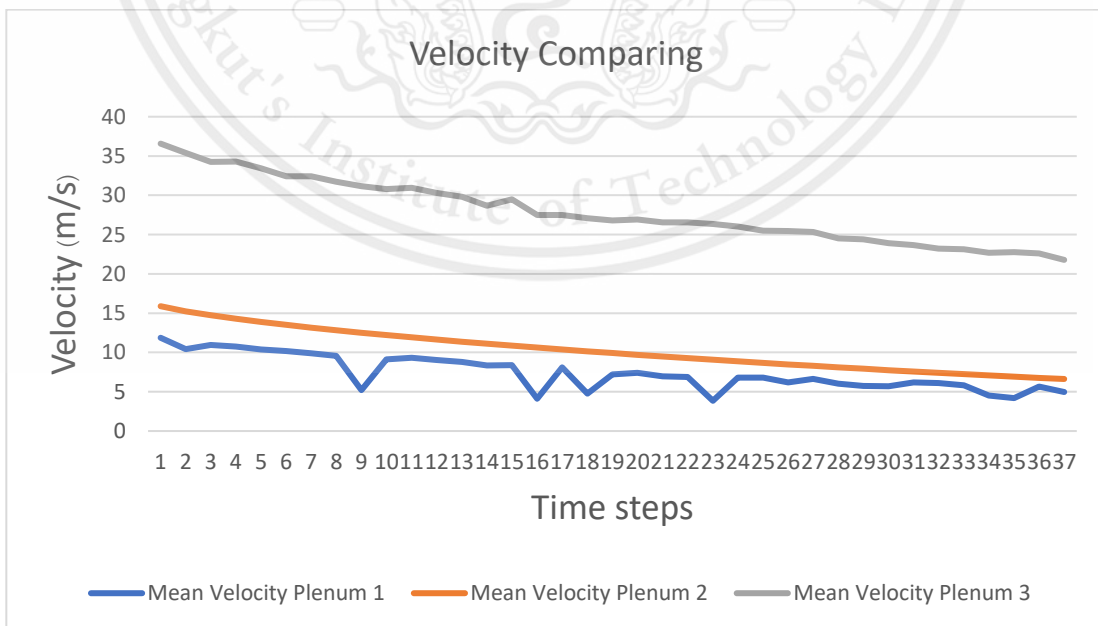


Figure 5.21 36 timesteps velocity comparing in each plenum

5.5.2 Pressure and velocity at 90 degrees(before intake port closed) and 360 degrees (before intake port opened)

To compare the difference of each plenum at interested points of crank angle (Blue is Plenum1) , (Orange is Plenum2) and (Green is Plenum3).

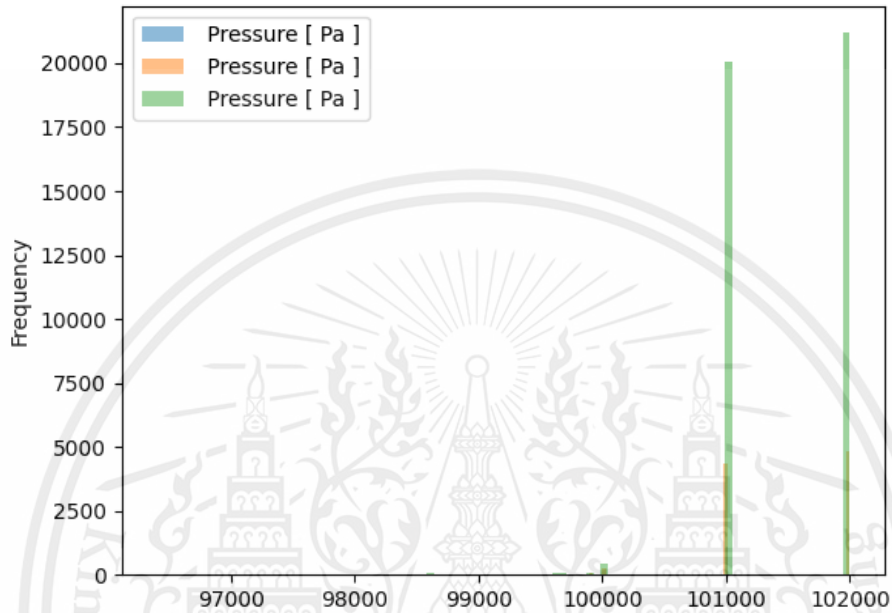


Figure 5.22 Pressure comparing in each plenum before intake port close.

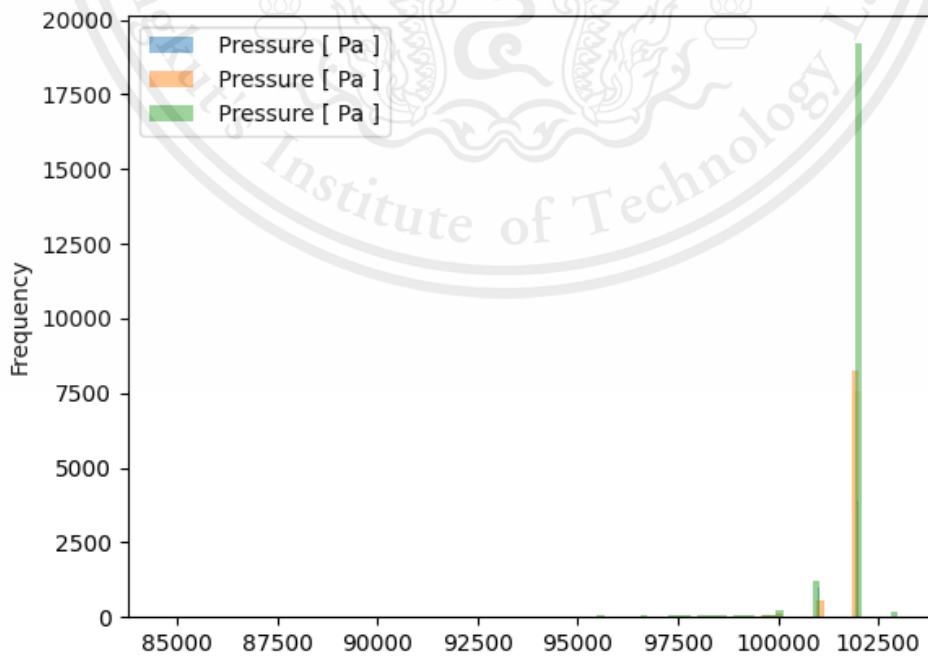


Figure 5.23 Pressure comparing in each plenum before intake port open.

This material is reserved for educational use only, not allowed for commercial use.

Forbidden to modify the content, and cite the document when use

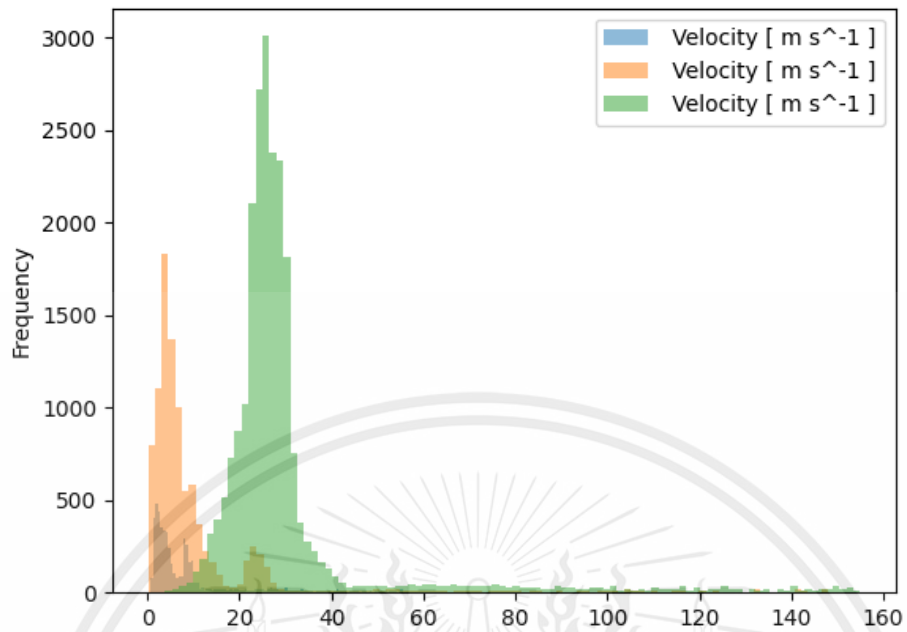


Figure 5.24 Velocity comparing in each plenum before intake port close.

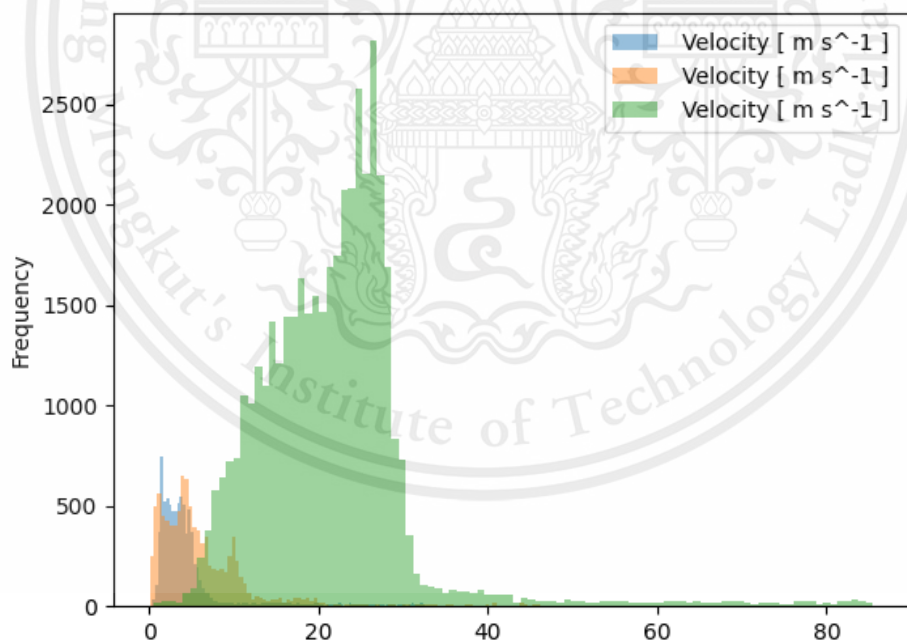


Figure 5.25 Velocity comparing in each plenum before intake port open.

5.5.3 Statistical value of each plenum

For some of graphs cannot show which plenum as well as it can be. This statistical value can find how different of each by mean, mode and Standard deviation but mode pressure was seem to be not the great significant factor for this part of analysis.

Pressure [Pa]			
Plenum 1	Mean	Mode	Standard deviation
90 deg	101655.88	102000	604.6065783
360 deg	101864.91	102000	341.8432581
Plenum 2	Mean	Mode	Standard deviation
90 deg	101374.74	102000	2187.407605
360 deg	101419.71	102000	660.758917
Plenum 3	Mean	Mode	Standard deviation
90 deg	101393.27	102000	2145.409715
360 deg	101434.82	102000	684.7336239

Table 5.5.1 Mean, Mode, Standard Deviation of pressure in each plenum.

Velocity [m/s]			
Plenum 1	Mean	Mode	Standard deviation
90 deg	9.51	8.93	11.47236776
360 deg	4.98	1.53	5.379972627
Plenum 2	Mean	Mode	Standard deviation
90 deg	12.52	10.5	21.44698352
360 deg	6.63	10.1	6.707428691
Plenum 3	Mean	Mode	Standard deviation
90 deg	30.99	26.2	21.09951561
360 deg	21.78	26.4	9.575846288

Figure 5.5.2 Mean, Mode, Standard Deviation of velocity in each plenum.

5.5.4 Bar graph of statistical value of each plenum

From mode pressure was not different then we visualized mean and standard deviation of pressure and mean, mode and standard deviation velocity to find difference in each plenum.

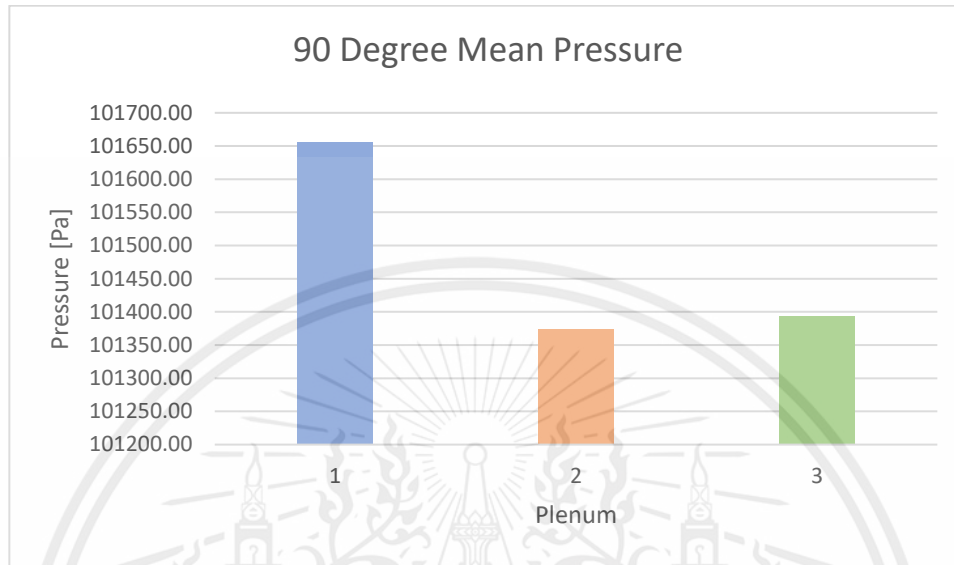


Figure 5.26 Mean pressure comparing in each plenum before intake port close.

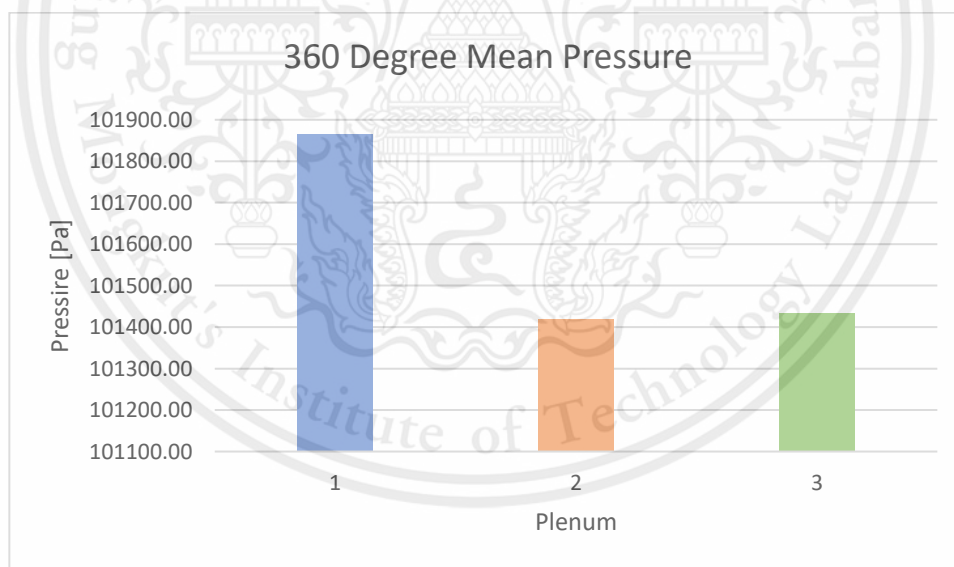


Figure 5.27 Mean pressure comparing in each plenum before intake port open.

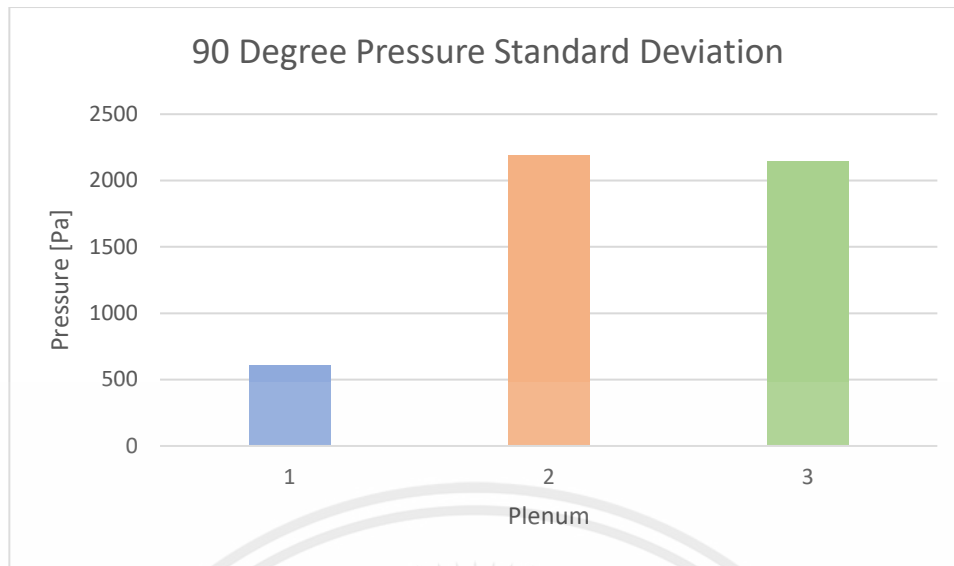


Figure 5.28 Standard deviation of pressure comparing in each plenum before intake port close.

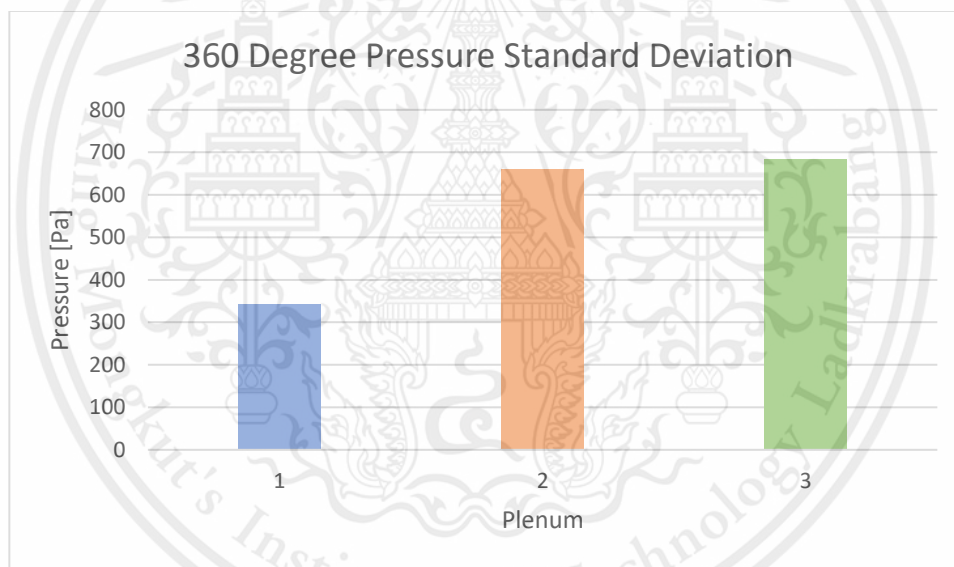


Figure 5.29 Standard deviation of pressure comparing in each plenum before intake port open.

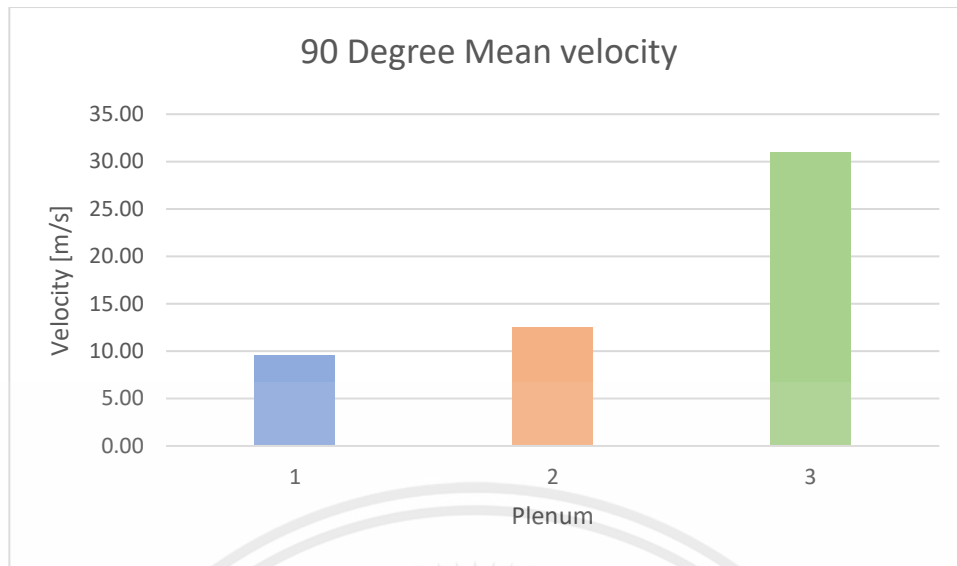


Figure 5.30 Mean velocity comparing in each plenum before intake port close.

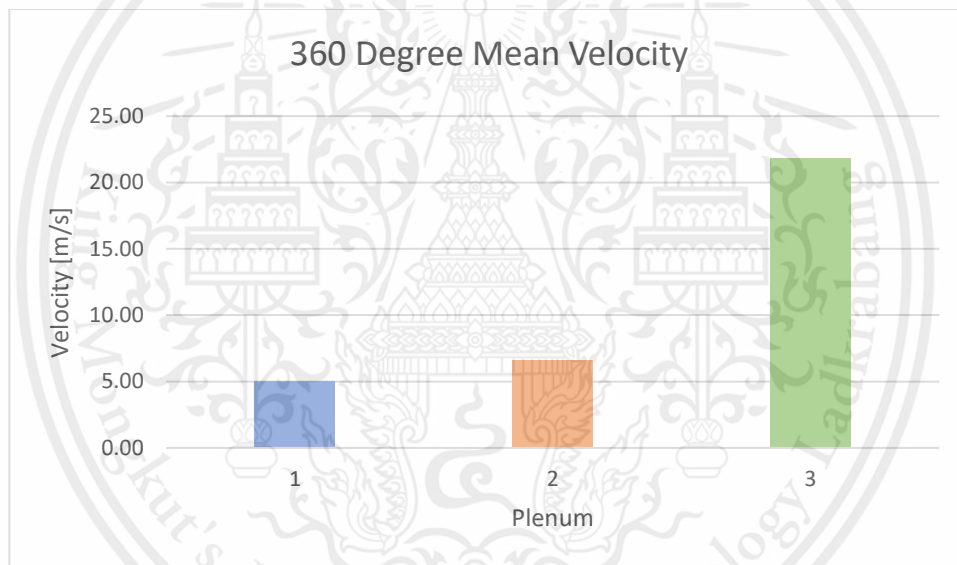


Figure 5.31 Mean velocity comparing in each plenum before intake port open.

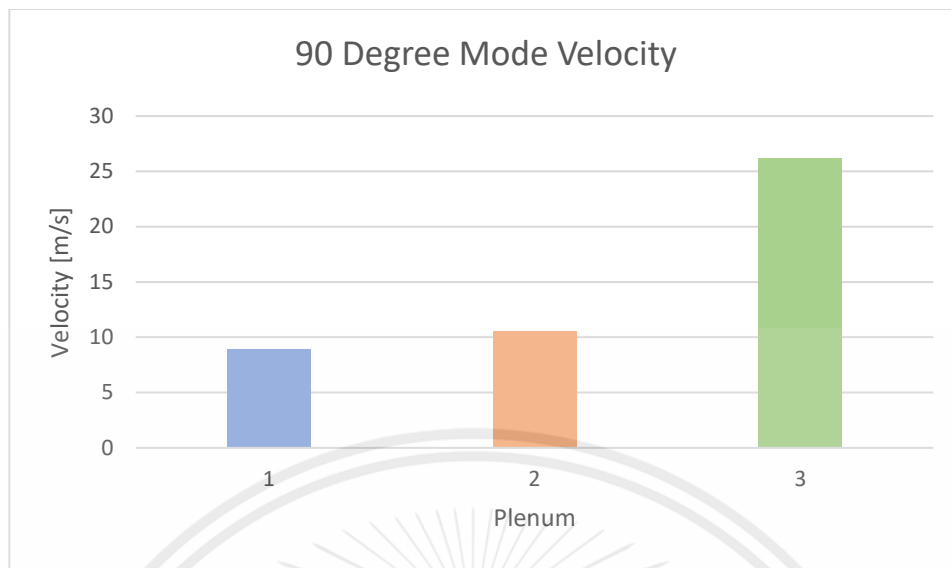


Figure 5.32 Mode velocity comparing in each plenum before intake port close.

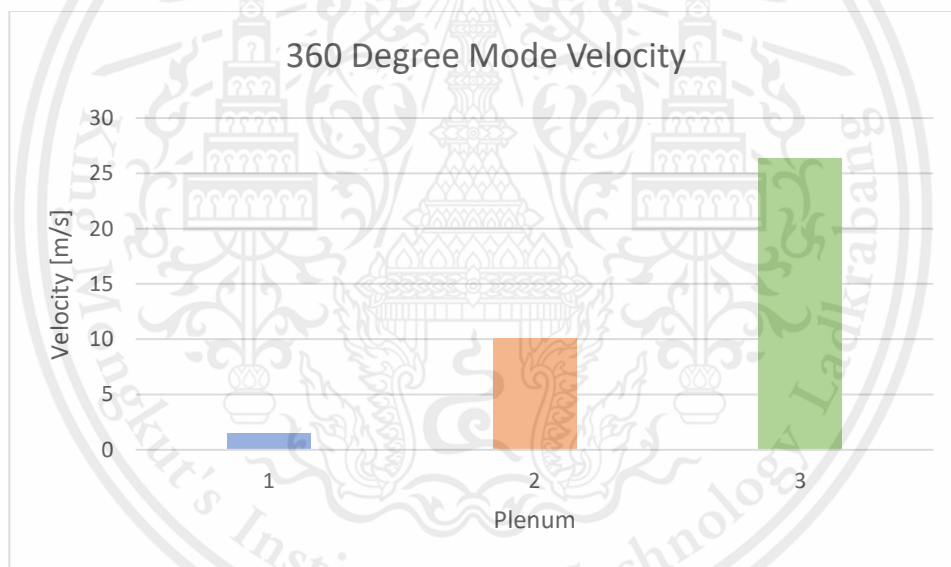


Figure 5.33 Mean velocity comparing in each plenum before intake port open.

5.6 Engine output power measured by dynamometer

The testing result of the plenum design 2 are shown in figure 5.34 given the maximum torque of 7.675 kgm and the output power of 71.519 HP.

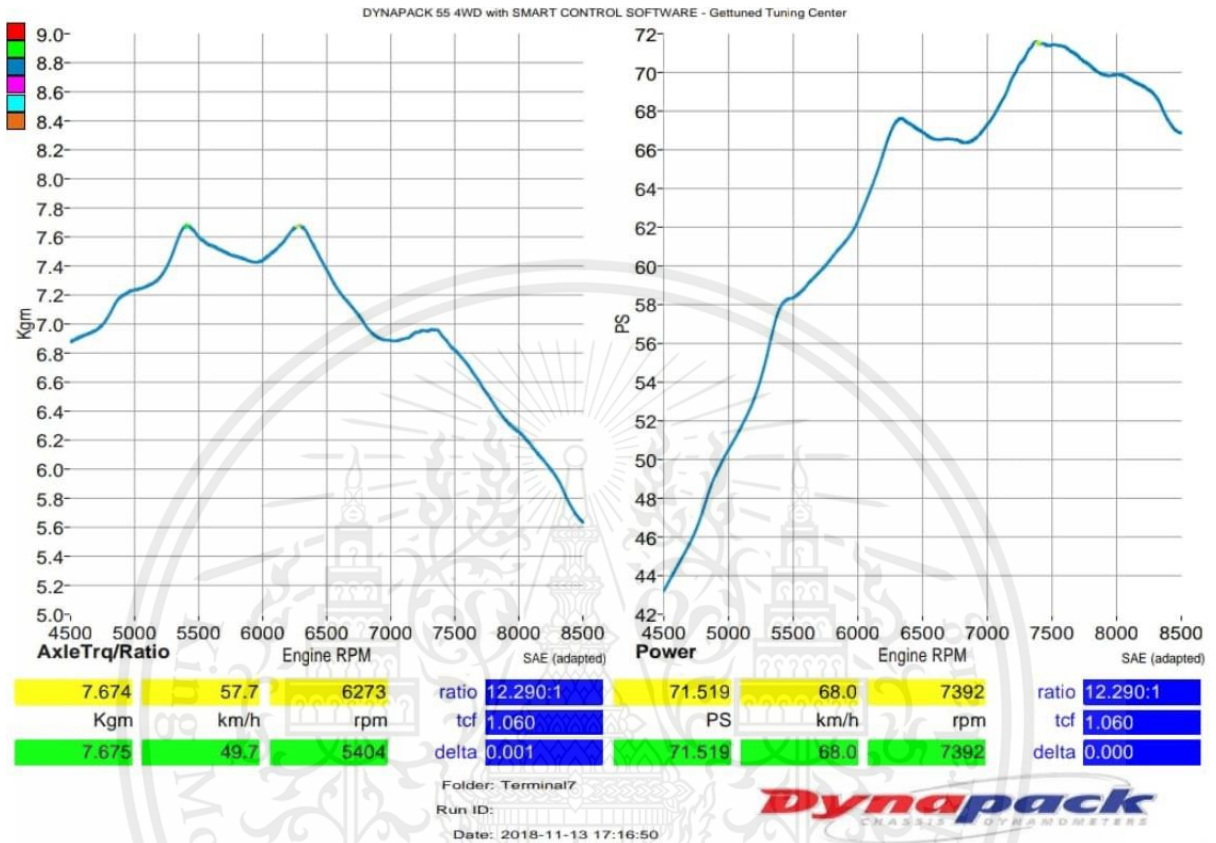


Figure 5.34 Dynamometer testing results of engine output power and torque on designed plenum 2

Chapter 6

Conclusion and Analysis of experimental result

6.1 Conclusion

Due to COVID-19 Pandemic, Part for using in Drivetrain cannot be machined the testing result is gathered from testing jig and Some error in the experiment might be due to the exhaust system design and other which is out of project scope, due to COVID-19 Pandemic and lockdown policies of Thai Government resulting in cancellation in TSAE Auto Challenge 2021, dynamometer testing, section of furthermore design optimization cannot be performed. For this reason, Dynamometer testing on all plenum design cannot be possible. The model result cannot be confirmed by only one design.

From the Pressure/Velocity-Power Model shown in Chapter 5, proof that this equation can be use as evaluation tools of the design of the intake system in a competition. This experimental result has shown that the shape of plenum not only affects the power output of the combustion engine but also takes effect on the engine response as shown in Chapter 5 in Linear Regression-Learning relationship equation then engine response has been increased by approximately 20.5% compared to the former design along with the result of Decision Tree, to optimize the output power of the engine. Designing criteria should be the pressure that to maximize the pressure of air particles inside the plenum chamber while the velocity should not exceed 10.324 m/s. In respect of the transient behavior, shown that Plenum design 1 perform the lowest mode velocity of an air particle with the output power of 70.2 Horsepower and Plenum design 2 perform the best output power from the Machine Learning model of 70.89 Horsepower and Plenum design 3 output the lowest power among all the design of 65.74 Horsepower but tends to have the best response among all the design, Moreover, Comparing the model to the dynamometer testing result upcoming that the model has the error from the actual dynamometer of 0.866 percent.

Testing engine has been modified for the purpose of performance, so it takes most of the time in maintenance due to the failure of part inside an engine. In addition, testing rig

require a firm foundation and fresh air, therefore the experimental must perform outside the building to prevent confined working space accident.

6.2 Experimental Suggestion

For further use in industrial, the machine learning program should have a GUI (Graphic User Interface) to make the design process more convenient in visualizing the criteria and result of the process. Maximizing the result, this study should conduct along with exhaust system Design.



REFERENCES

- [1] Rules of formular student [online]:
<http://www.fsaonline.com/attend/student-events/>
 (accessed 14 July 2020,)
- [2] Willard W. Pulkrabek. (2003).Engineering Fundamentals of the Internal Combustion Engine. Prentice Hall.
- [3] Figure 2.1 The Process of 4-Stroke Engine[online]:
<http://www.britannica.com/EBchecked/topic/290504/internal-combustionengine> (accessed 15 July 2020,)
- [4] Figure 2.2 The effect of an air-fuel ratio and a lambda on engine power [online]: http://en.wikipedia.org/wiki/Air%E2%80%93fuel_ratio
 (accessed 16 July 2020,)
- [5] Electronics Throttle Body [online]:
http://mte.kmutt.ac.th/elearning/Electronic_Fuel_Injection_System/unit31.html (accessed 17 July 2020,)
- [6] Figure 2.4 Electronics Throttle Body [online]:
<https://www.amazon.com/Throttle-Assembly-2009-2011-Nissan-16119ED00C/dp/B01MY91GHS>
 (accessed 18 July 2020,)
- [7] Hermann Hiereth Peter Prenninger. (2003).Charging the Internal Combustion Engine,Powertrain. SpringerWienNewYork
- [8] Roger C.Baker. (2000).Flow Measurement Handbook. New York: Cambridge University Press.
- [9] Martin Musial. Intake manifold design and testing. Modified Magazine
- [10] Figure 2.9 The loss due to inefficient entry to the system [online]:
http://en.wikipedia.org/wiki/Velocity_stack (accessed 19 July 2020,)
- [11] Gordon P.Blair, W.Melvin Cahoon. (2006).Best Bell. Race Engine Technology Magazine.
- [12] Figure 2.11 Intake Runner [online]:
<http://www.chrysler300club.com/uniq/allaboutrams/ramtheory>
 (accessed 20 July 2020,)

REFERENCES

- [13] Hermann Hiereth Peter Prenninger. (2003).Charging the Internal Combustion Engine,Powertrain. SpringerWienNewYork.
- [14] John L. Lumley . (1999).Engines: An Introduction . Cambridge University Press
- [15] Machin learning [online]
<https://www.analyticssteps.com/blogs/introduction-machine-learning-supervised-and-unsupervised-learning> (accessed 21 July 2020,)
- [16] linear regression [online]
<https://towardsdatascience.com/10-machine-learning-methods-that-every-data-scientist-should-know-3cc96e0eeee9>
 (accessed 22 July 2020,)
- [17] Polynomial Regression Algorithm [online]
<https://sites.google.com/site/mystatistics01/chapter7/logistic-regression> (accessed 23 July 2020,)
- [18] karma filter [online]:
<https://sites.google.com/site/mystatistics01/regression-correlation-analysis/simple-linear-regression-analysis> (accessed 24 July 2020,)
- [19] Figure 2.18 The trend line generated by the bulk data [online]:
<https://images.app.goo.gl/OKzgRt6uJNeCHifV8>
 (accessed 25 July 2020,)
- [20] Decision tree [online]:
<https://www.javatpoint.com/machine-learning-decision-tree-classification-algorithm>(accessed 26 July 2020,)
- [21] Figure 2.20 VS code [online]:
<https://code.visualstudio.com/> (accessed 27 July 2020,)
- [22] Figure 2.23 3D printer [online]:
<https://th.rs-online.com/web/p/3d-printers/1734711/>
 (accessed 28 July 2020,)
- [23] Figure 2.24 Diffusion of air intake and exhaust in lung [online]:
<http://eng.sut.ac.th/me/2014/document/CFD.php>
 (accessed 29 July 2020,)

REFERENCES

[24] Figure 2.25 Ansys Computational Fluid Dynamics and Finite Element Analysis comparison [online]:

<https://www.youtube.com/watch?v=RELLrEJ9chg>

(accessed 30 July 2020,)

[25] Bengt Anderson(2000) Computational Fluid Dynamics for Engineers Handbook. New York: Cambridge University Press.





This material is reserved for educational use only, not allowed for commercial use.

Forbidden to modify the content, and cite the document when use

5.2.2.1 Pressure

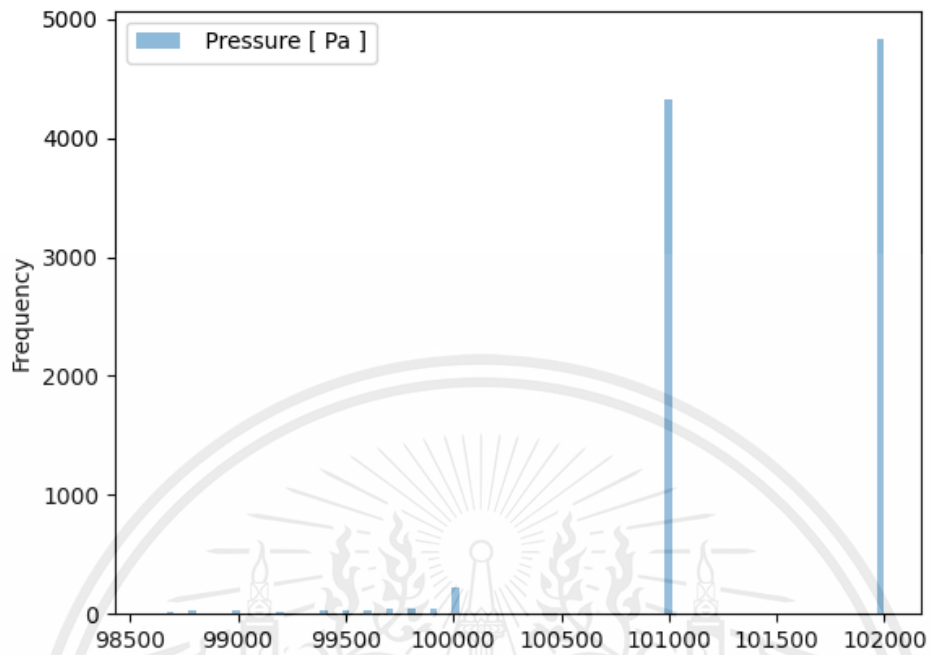


Figure 5.9 Graph of air pressure in plenum 1 at 90 degrees of crank angle.

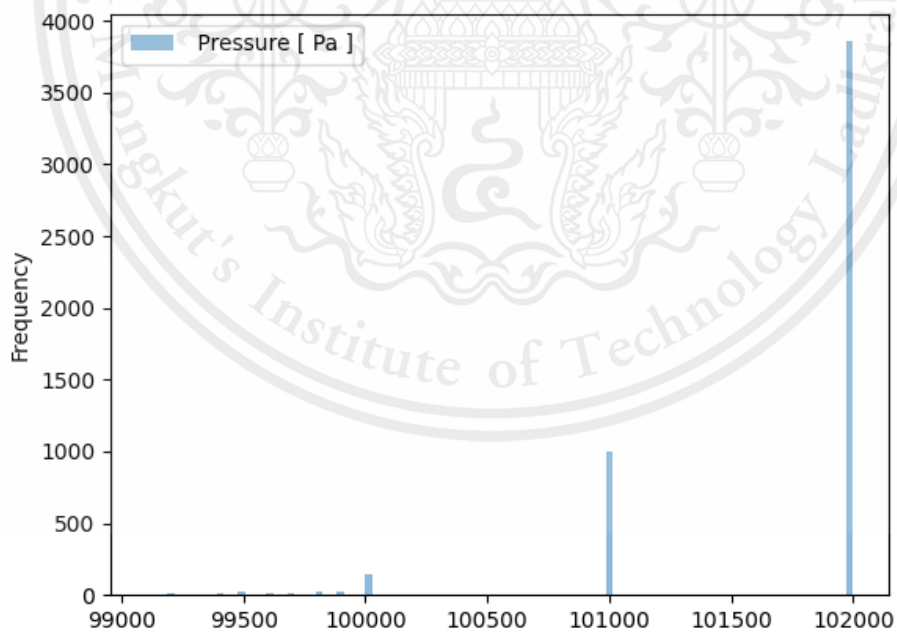


Figure 5.10 Graph of air pressure in plenum 2 at 90 degrees of crank angle.

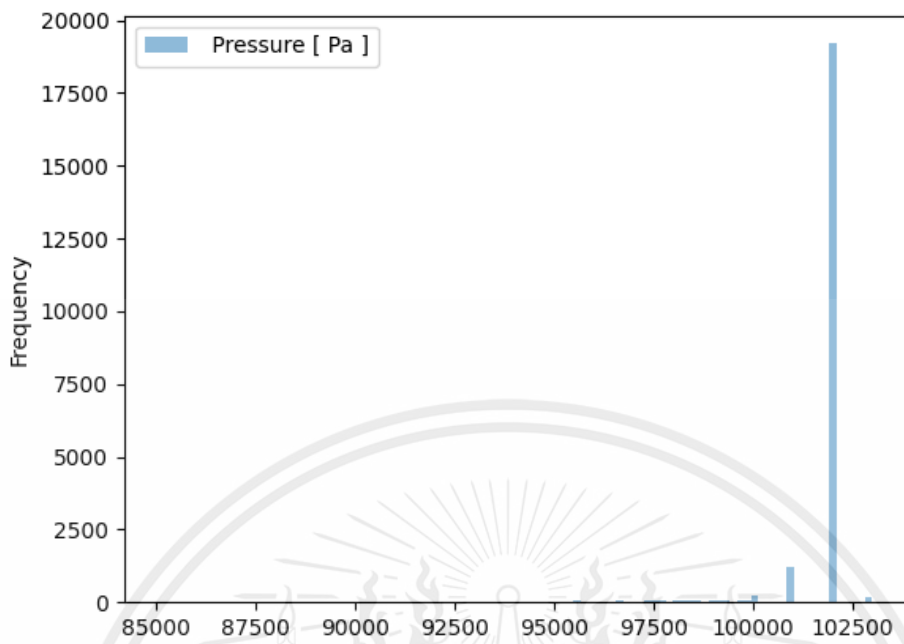


Figure 5.11 Graph of air pressure in plenum 3 at 90 degrees of crank angle.

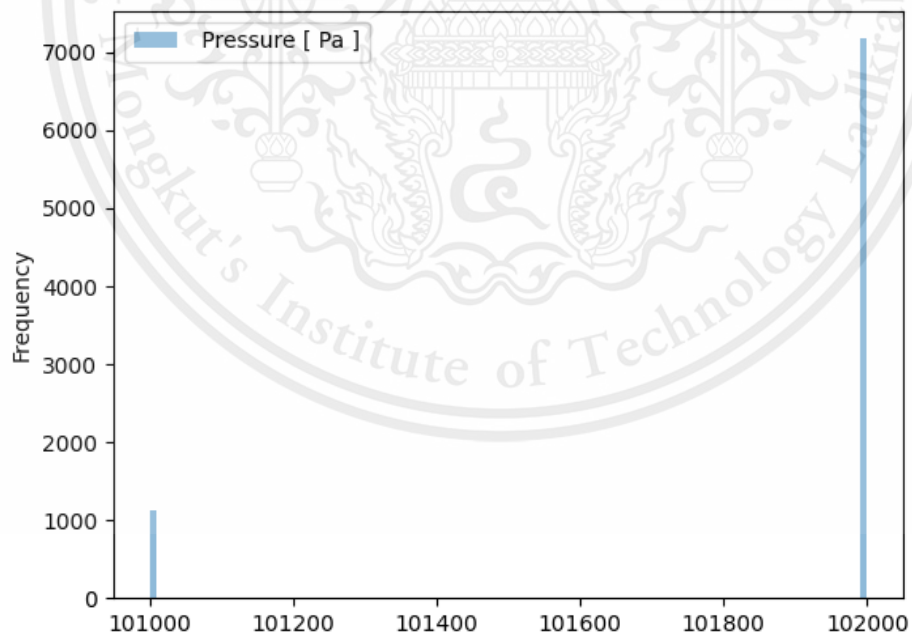


Figure 5.12 Graph of air pressure in each plenum 1 at 360 degrees of crank angle.

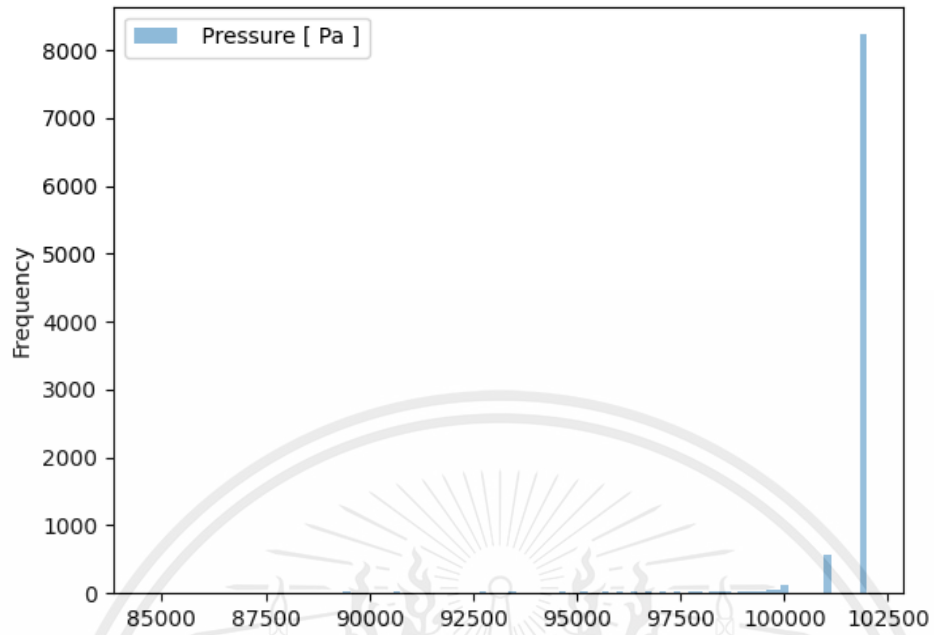


Figure 5.13 Graph of air pressure in each plenum 2 at 360 degrees of crank angle.

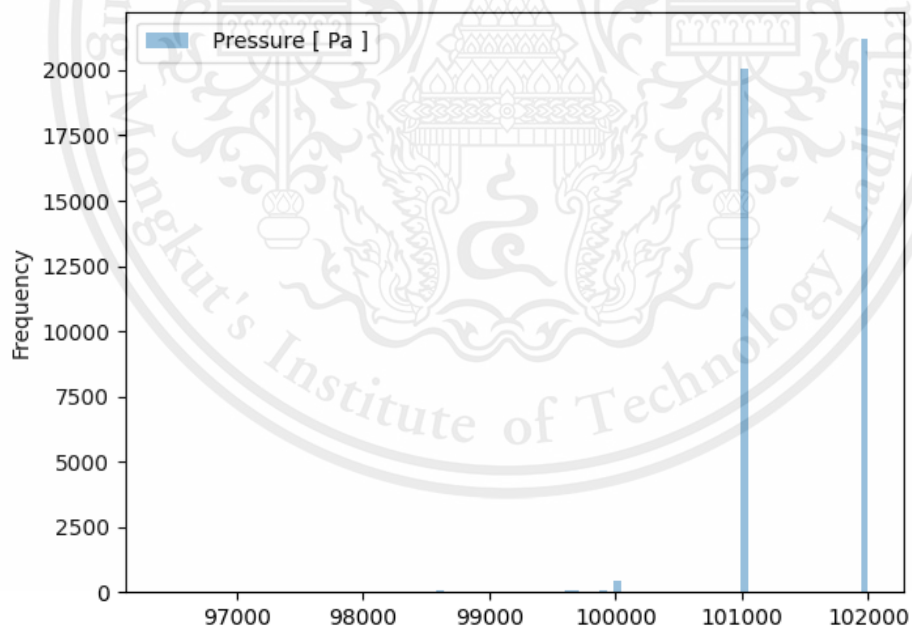


Figure 5.14 Graph of air pressure in each plenum 3 at 360 degrees of crank angle.

5.2.2.2 Velocity

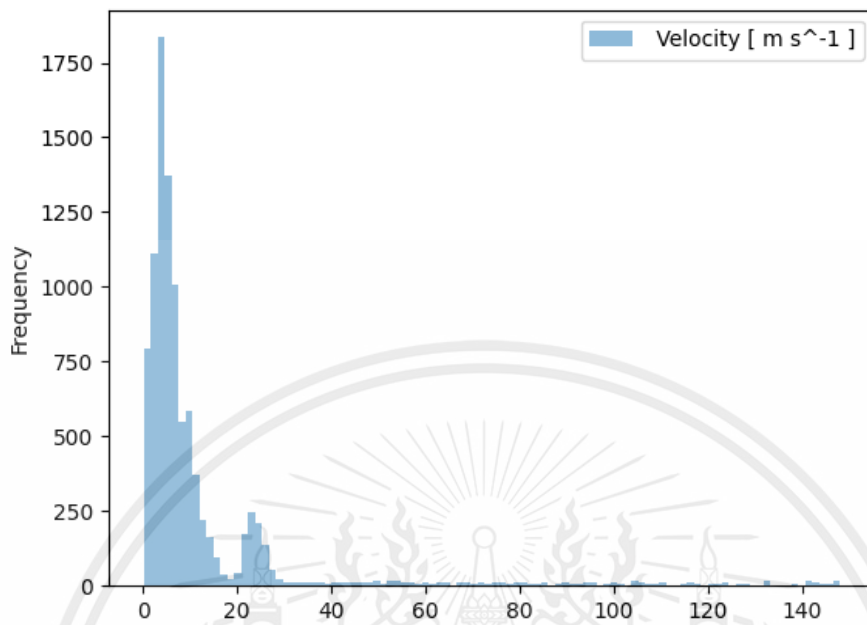


Figure 5.15 Graph of air velocity in plenum 1 at 90 degrees of crank angle.

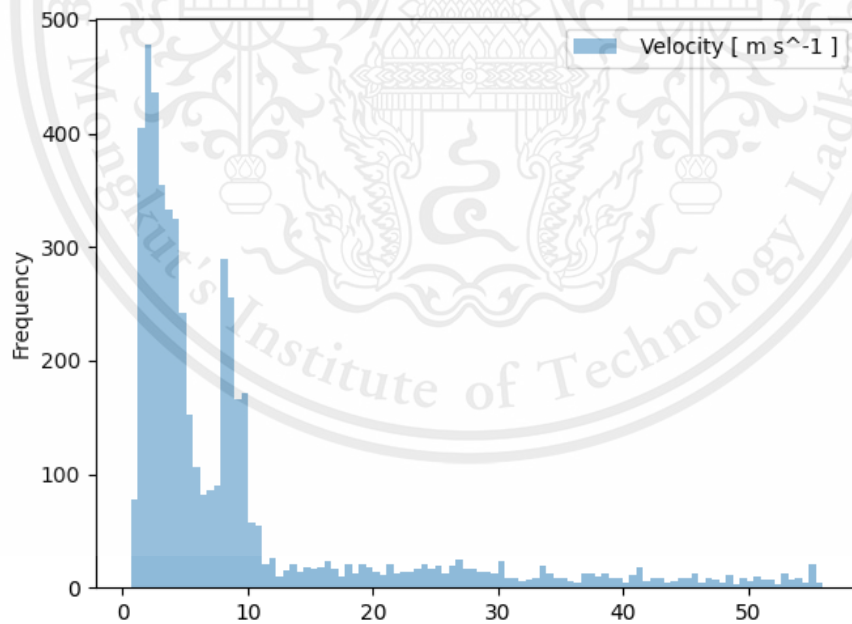


Figure 5.16 Graph of air velocity in plenum 2 at 90 degrees of crank angle.

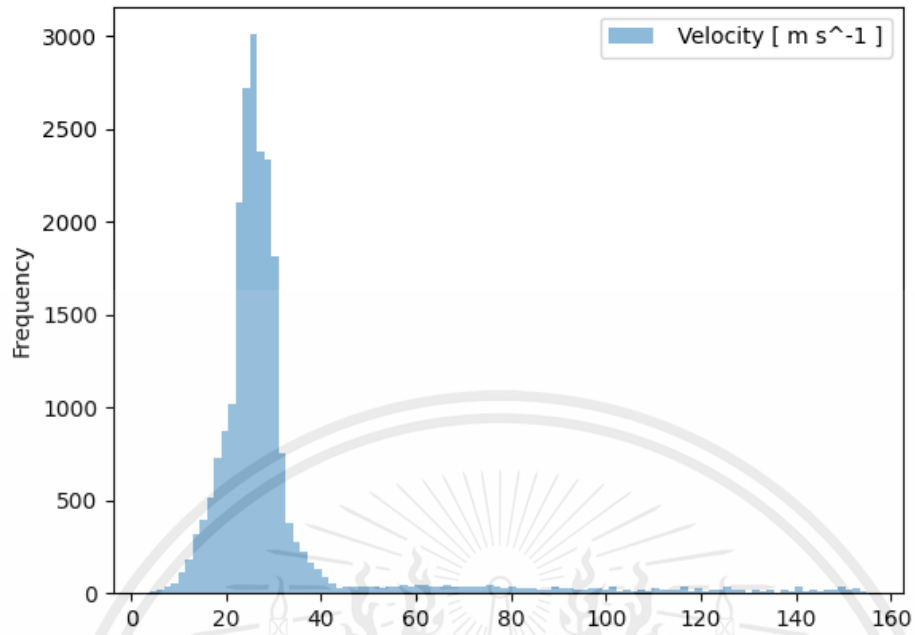


Figure 5.17 Graph of air velocity in plenum 3 at 90 degrees of crank angle.

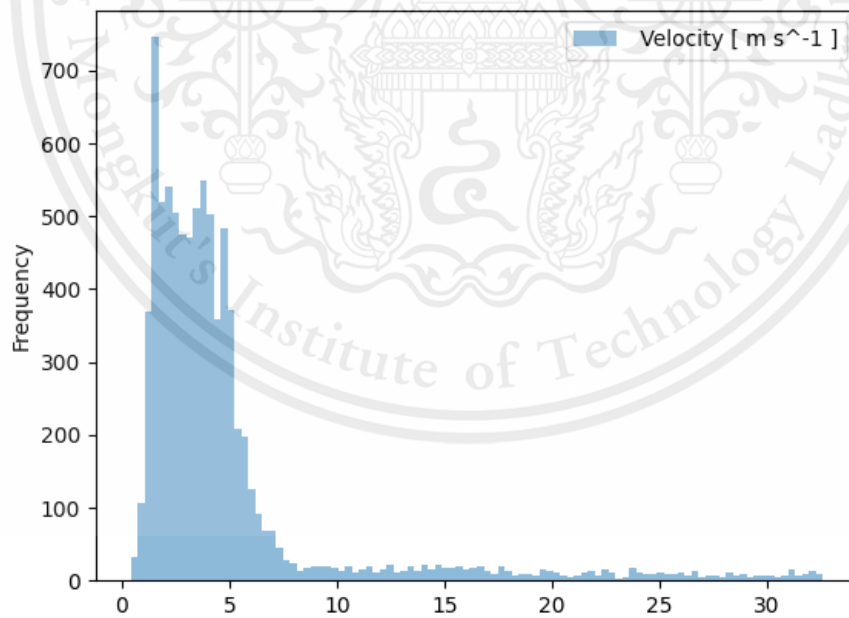


Figure 5.18 Graph of air velocity in plenum 1 at 360 degrees of crank angle.

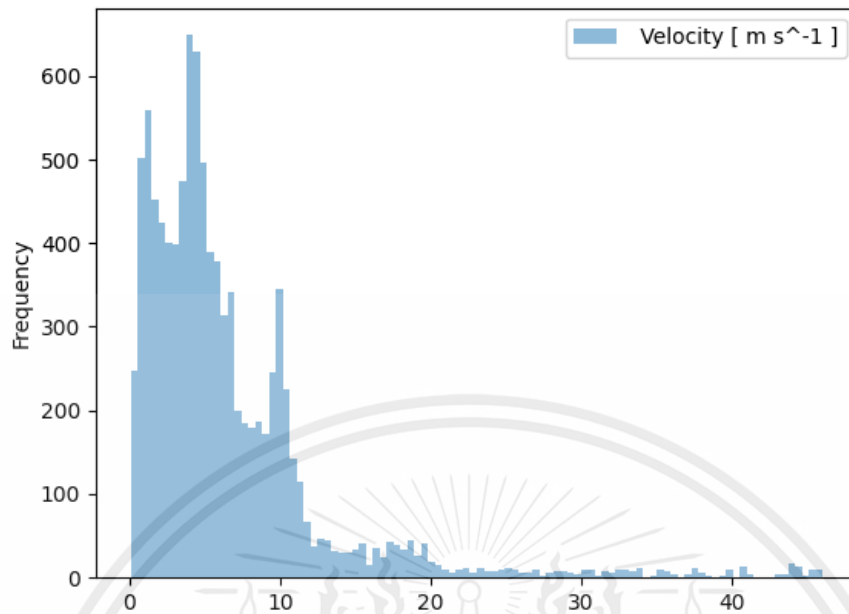


Figure 5.19 Graph of air velocity in plenum 2 at 360 degrees of crank angle.

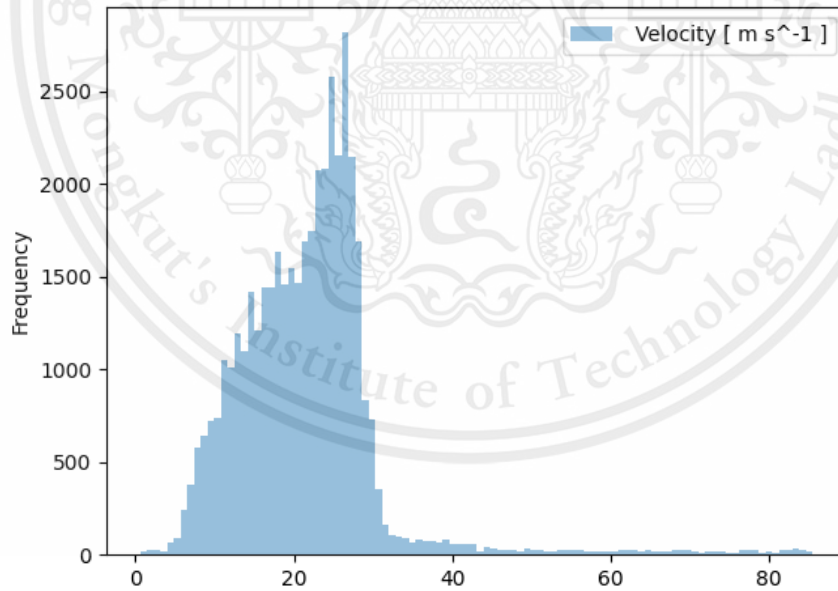


Figure 5.20 Graph of air velocity in plenum 3 at 360 degrees of crank angle.

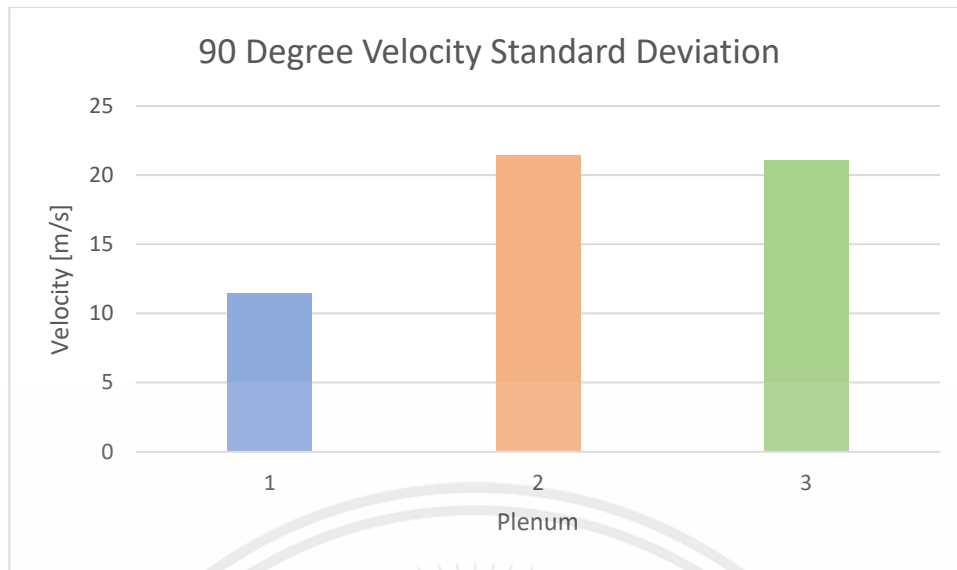


Figure 5.38 Standard deviation of velocity comparing in each plenum before intake port close.

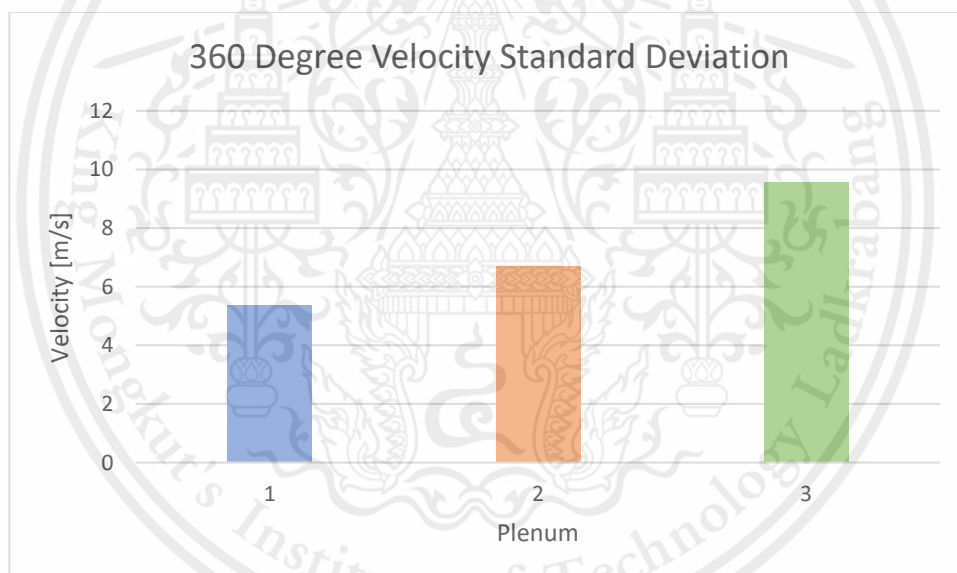


Figure 5.39 Standard deviation of velocity comparing in each plenum before intake port open.

```
[184] > ▶ MI
import pandas as pd
import numpy as np
import matplotlib.pyplot as plt
import seaborn as sns
import matplotlib.pyplot as plt #for plotting purpose
from sklearn.linear_model import LinearRegression
from sklearn.metrics import mean_squared_error, r2_score
from sklearn.preprocessing import PolynomialFeatures
#PolynomialFeatures
%matplotlib inline
stdFactor = 1
import operator
polyDeg = 3
DesignCandidate = 3

[185] > ▶ MI
RawData = pd.read_excel('KTM690PlenumDesign1.xls', sheet_name = 'Summary')
EssData = RawData.drop(columns=['Test ID', 'RandomFactor', 'Volume [m^3]', 'Output [HP]'])
```

Import module and database of experimental result

	MeanPressure [Pa]	ModePressure [Pa]	MeanVelocity [m/s]	ModeVelocity [m/s]	TestOutput[HP]
0	101303.14	101906.079313	13.721918	8.011314	59.412154
1	101306.28	101942.143583	16.066704	14.365030	62.302882
2	101309.42	101999.320889	11.737653	6.142769	59.657377
3	101312.56	101900.449794	9.010439	8.018041	63.483134
4	101315.70	101995.812458	16.375017	11.534510	64.023862
...
203	101940.56	101916.392790	13.558160	17.995358	79.425585
204	101943.70	101963.498241	5.174049	14.733352	75.266854
205	101946.84	101935.145452	15.192595	18.275551	77.289694
206	101949.98	101934.290575	16.154177	9.224877	76.490874
207	101953.12	101967.395668	6.827640	12.095430	79.564448

Data Trimmed for raw analyze in Machine Learning Algorithm

Case 1 : Single Variable Regression model

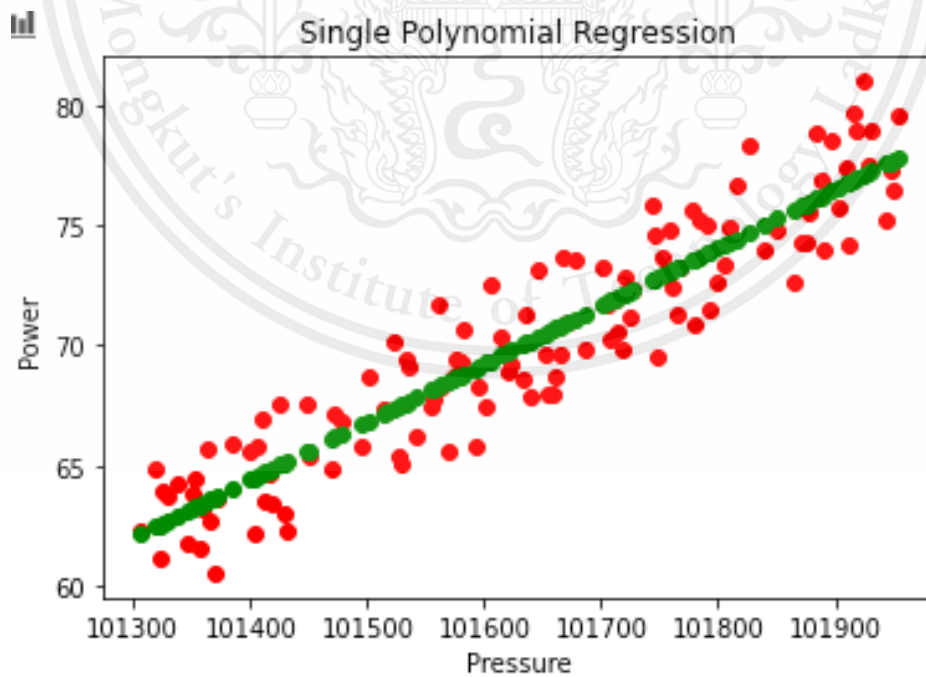
```

y_pred = lin_reg.predict(X)
#df = pd.DataFrame({'Real Values':Y, 'Predicted Values':y_pred})
y_pred

array([[62.14466104],
       [62.44851614],
       [62.52447991],
       [62.60044369],
       [62.67640746],
       [62.90429879],
       [63.13218011],
       [63.20815389],
       [63.28411767],
       [63.36008144],
       [63.43604522],
       [63.51200899],
       [63.58797277],
       [63.66393654],
       [63.73990032],
       [64.04375542],
       [64.42357429],
       [64.49953807],
       [64.57550184],
       [64.65146562],
       [64.72742939],
       [64.80339317],
       [64.87935695],
       [65.0312845 ],
       [65.10724827],
       [65.18321205],
       [65.56303092],
       [65.6389947 ],
       [66.09477351],
       [66.17074112],
       [66.32268688],
       [66.70248755],
       [66.8544151 ],
       [67.1582702 ],
       [67.23423398],
       [67.38616153],
       [67.4621253 ],
       [67.53808908],
       [67.61405285],
       [67.69001663],
       [67.84194418],
       [68.14579928],
       [68.22176306],
       [68.29772683],
       [68.37369061],
       [68.52561816],
       [68.60158193],
       [68.67754571],
       [68.75350948],

```

Predicted Target Vector from linear regression Machine Learning



Predicted Target vector compared to Training data

This material is reserved for educational use only, not allowed for commercial use.

Forbidden to modify the content, and cite the document when use

```
[197] ▶ ▶ M4
      rmse = np.sqrt(mean_squared_error(Y,y_pred))
      r2 = r2_score(Y,y_pred)
      print(rmse)
      print(r2)

1.8051731574602639
0.8636007700486807
```

R-Square value of the single variable model compare to the actual value of the experiment

Case 2 : Multiple Variable Polynomial Linear Regression

```
polyFit = PolynomialFeatures(polyDeg)
XtrP = polyFit.fit_transform(XpolyFit)
print(XtrP)

[[1.00000000e+00 1.01303140e+05 1.01906079e+05 ... 1.50845855e+03
 8.80688510e+02 5.14175381e+02]
 [1.00000000e+00 1.01306280e+05 1.01942144e+05 ... 3.70817411e+03
 3.31543000e+03 2.96428263e+03]
 [1.00000000e+00 1.01309420e+05 1.01999321e+05 ... 8.46304569e+02
 4.42903991e+02 2.31788829e+02]
 ...
 [1.00000000e+00 1.01946840e+05 1.01935145e+05 ... 4.21827007e+03
 5.07426230e+03 6.10395672e+03]
 [1.00000000e+00 1.01949980e+05 1.01934291e+05 ... 2.40730028e+03
 1.37469401e+03 7.85021978e+02]
 [1.00000000e+00 1.01953120e+05 1.01967396e+05 ... 5.63848643e+02
 9.98879841e+02 1.76955456e+03]]
```

Input vector of Multiple Variable Polynomial Linear Regression

```
array([59.41215376, 62.30288191, 59.65737728, 63.48313407, 64.02386165,
64.92313132, 61.19486108, 63.98318245, 63.71990766, 62.9718967,
64.00179744, 64.27500183, 62.38967031, 65.81034038, 61.74220408,
63.82501429, 64.50857772, 61.540475, 63.25468605, 65.66550227,
62.7170692, 60.53253044, 63.64164502, 66.00513595, 64.36165555,
66.38534612, 65.95560699, 66.45658336, 64.9146121, 63.83152931,
64.62288318, 65.60072378, 62.23149702, 65.78780855, 66.98598091,
63.53353985, 64.66574709, 63.47293385, 65.34086257, 67.60951688,
63.03489736, 62.24167633, 65.07566951, 63.45149752, 64.97602354,
64.71044598, 67.56204578, 65.43765596, 65.04466469, 68.30740941,
67.32828586, 67.4237863, 62.73374489, 64.92108996, 67.1371255,
68.55626067, 66.84544319, 67.19765735, 64.03394318, 68.70856997,
68.33322698, 65.76054688, 68.82042715, 68.67200582, 67.15307522,
63.70674874, 68.83789261, 67.371149, 67.2989626, 65.84853358,
70.20537354, 65.33899181, 65.07284073, 69.45987935, 69.14765907,
67.348567, 66.24072234, 66.55948658, 64.8585234, 68.73628203,
67.46844262, 67.80791604, 71.73654054, 68.24968942, 69.82948513,
65.56609201, 68.71382281, 69.38455599, 69.34031326, 70.65073552,
68.10360409, 67.00610795, 65.76483013, 68.33926321, 66.08371385,
67.44694715, 72.5226709, 66.90617532, 69.80705072, 70.34559712,
71.1031302, 68.94815998, 69.26413106, 69.22040494, 70.85954206,
68.6202474, 71.30479802, 67.87767452, 66.97614952, 73.17313477,
68.34043997, 69.60655051, 67.93648626, 68.02724374, 68.70281962,
69.61936579, 73.64561555, 70.95802271, 70.95391475, 73.52155415,
71.79188866, 70.6050409, 69.8167418, 69.11846924, 69.80690117,
71.29932674, 68.17096805, 73.2476493, 71.74001296, 70.23020626,
71.90196597, 70.54621574, 69.88846739, 72.8734072, 71.21795577,
72.35446294, 71.20221501, 75.50699953, 71.73886584, 71.15570479,
75.89559987, 74.60044267, 69.54299921, 73.67913973, 70.97485682,
74.76285218, 72.45554765, 71.33800562, 73.31174615, 76.80595164,
74.80941246, 75.6850196, 70.88386506, 75.17906017, 74.45472114,
75.0112906, 71.46868097, 76.31770011, 72.68110955, 76.30047416,
73.37429147, 74.92669945, 77.02041582, 76.70376433, 75.48535397,
75.85418438, 76.27830085, 78.38462089, 74.92680091, 72.10539017,
76.62401952, 74.0108633, 77.59947209, 76.67905479, 74.85150369,
79.28281072, 78.93740527, 77.39734898, 75.26660462, 72.63609173,
74.59750351, 74.2728769, 74.25009512, 75.54900385, 75.89592678,
78.89460924, 76.93153788, 73.95405736, 73.25172185, 78.51905011,
79.31966656, 75.76814627, 79.05812226, 77.40398453, 74.18527347,
79.71774505, 78.94091299, 78.45721731, 81.0015612, 77.51665561,
78.9933512, 78.71467915, 78.16612197, 79.42558459, 75.26685393,
77.28969391, 76.49087405, 79.56444794])
```

Target Vector of Multiple Variable Polynomial Linear Regression

```
PolyOutFit.fit(XtrP,OutputPoly)
r_sq = PolyOutFit.score(XtrP, OutputPoly)
print('coefficient of determination:', r_sq)
coefficient of determination: 0.7877376969890066
```

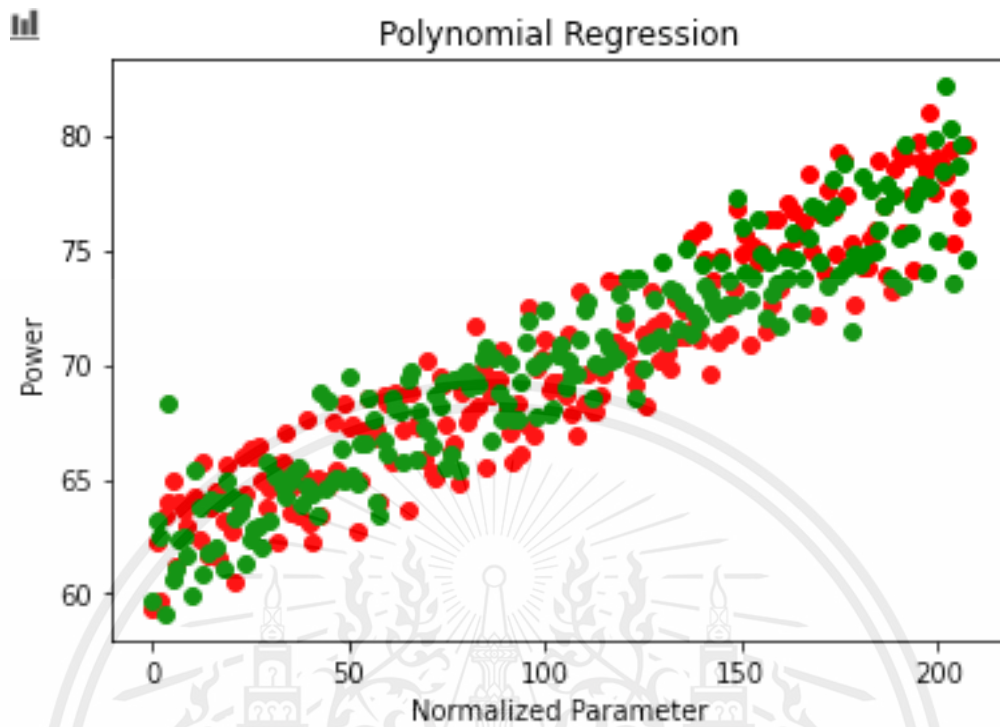
R-Squared Value of Multiple Variable Polynomial Linear Regression

```
▶ M4
PolyOutFit.intercept_
-112520.12936152153

▶ M4
PolyOutFit.coef_
array([-3.00320137e+01, -3.63251641e+00,  7.34213933e-02, -3.39099475e-02,
       -1.00111660e-04,  1.75883016e-02, -3.47895985e-02, -3.43691284e-01,
        5.66286555e-01,  1.73050167e-02,  3.47635887e-01, -5.82753081e-01,
       -3.77871404e+01,  2.31148538e+01,  6.26359849e+01, -2.91169918e-08,
       -8.63958479e-08,  7.09273236e-06,  3.00631420e-07,  2.56691410e-07,
       -1.07668690e-05, -6.14535967e-06, -2.55934617e-05,  1.23296473e-05,
       -4.97706365e-05, -1.41747220e-07,  3.63542420e-06,  6.00625043e-06,
        3.96131112e-04, -2.38028750e-04, -5.64924627e-04,  1.79516900e-03,
       -4.46526382e-03,  3.06667899e-04,  5.27893917e-05])
```

Intercept and coefficient of Multivariable Polynomial Model

Case 3 : Multiple Variable Linear Regression



Multivariable Linear Model compared to training data

```

> print(regr.coef_)
> print(regr.intercept_)
[ 0.02485091 -0.00105006 -0.03688168 -0.02579202]
-2347.6618186862547

```

Intercept and Coefficient of Linear Model

```

> r_sq = regr.score(XpolyFit, OutputPoly)
> print(r_sq)
0.8675157225953235

```

R-Squared Value of Linear Model

This material is reserved for educational use only, not allowed for commercial use.

Forbidden to modify the content, and cite the document when use


```

OutputPoly = EssData[['TestOutput[HP]']]
#-----Data manual catergorizing-----#
OutputPoly.loc[OutputPoly['TestOutput[HP]'] < 65, 'TestOutput[HP]'] = 0
OutputPoly.loc[OutputPoly['TestOutput[HP]'] >= 70, 'TestOutput[HP]'] = 2
OutputPoly.loc[OutputPoly['TestOutput[HP]'] >65, 'TestOutput[HP]'] = 1
OutputPoly = OutputPoly.iloc[:, -1].values
#OutputPoly = OutputPoly[:, np.newaxis]
y = OutputPoly.astype('int')
y

```

Classified Criteria

```

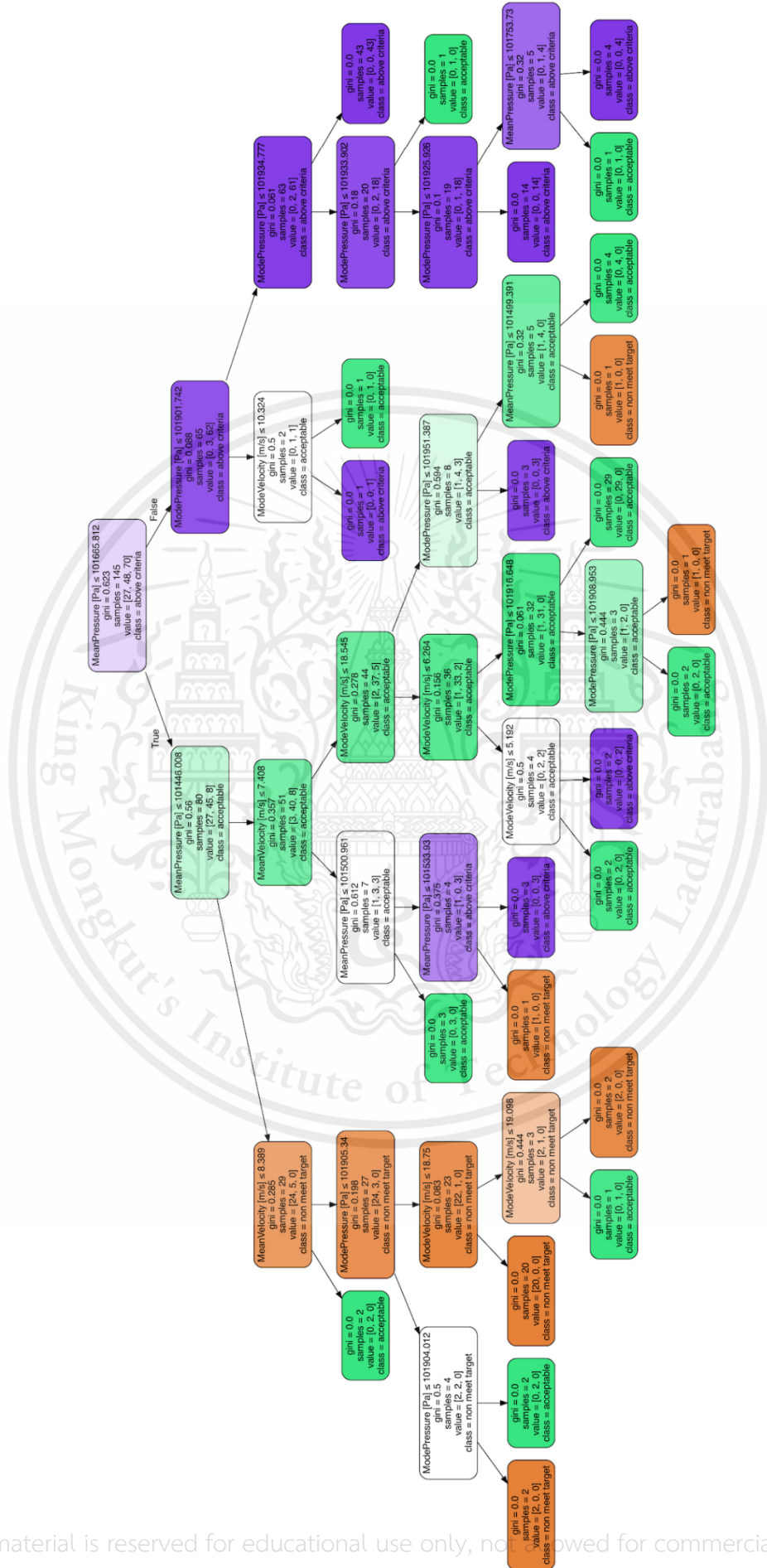
▶ ▶ M4
from sklearn.metrics import classification_report, confusion_matrix

print(classification_report(y_test, y_pred))

```

	precision	recall	f1-score	support
0	0.64	0.75	0.69	12
1	0.75	0.58	0.65	26
2	0.79	0.92	0.85	25
accuracy			0.75	63
macro avg	0.73	0.75	0.73	63
weighted avg	0.75	0.75	0.74	63

Classification Model report



Result of Impurity data classification by Decision Tree algorithm



This material is reserved for educational use only, not allowed for commercial use.

Forbidden to modify the content, and cite the document when use

```

import pandas as pd
import numpy as np
import matplotlib.pyplot as plt
import seaborn as sns
import matplotlib.pyplot as plt #for plotting purpose
from sklearn.linear_model import LinearRegression
from sklearn.metrics import mean_squared_error, r2_score
from sklearn.preprocessing import PolynomialFeatures
#PolynomialFeatures
%matplotlib inline
stdFactor = 0.5
import operator
polyDeg = 3
DesignCandidate = 3
RawData = pd.read_excel('KTM690PlenumDesign1.xls', sheet_name = 'Summary')
EssData = RawData.drop(columns=['Test ID', 'RandomFactor', 'Volume [m^3]',
'Output [HP]'])
# seaborn histogram
sns.distplot(EssData['ModePressure [Pa]'], hist=False, kde=True,
             bins=int(180/5), color = 'blue',
             hist_kws={ 'edgecolor':'black'},
             kde_kws={ 'linewidth': 4})
# Add labels
plt.title('Histogram of ModePressure [Pa] in Plenum')
plt.xlabel('Pressure')
plt.ylabel('Number of event')
o1 = EssData['ModePressure [Pa]'].mean()+(EssData['ModePressure [Pa]'].std() *stdFactor)
o2 = EssData['ModePressure [Pa]'].mean() -(EssData['ModePressure [Pa]'].std() *stdFactor)
plt.axvline(EssData['ModePressure [Pa]'].mean(), color='red')
plt.axvline(o1, color='green')
plt.axvline(o2, color='green')
EssData.std(axis=0, skipna=True)
modeSTD=EssData['ModePressure [Pa]'].std()
modeSTD
EssData.mean(axis=0, skipna=True)
meanSTD=EssData['ModePressure [Pa]'].mean()
meanSTD
EssData_1 = EssData[EssData['ModePressure [Pa]'] <= o1]
EssData_filtered = EssData_1[EssData_1['ModePressure [Pa]'] >= o2]
plt.scatter(EssData_filtered['ModePressure [Pa]'],EssData_filtered['TestOutput[HP]'])
plt.show()
X = EssData_filtered[[
'MeanPressure [Pa]',
'ModePressure [Pa]',
#MeanVelocity [m/s]',
#ModeVelocity [m/s]'
]]
#
Y = EssData_filtered[['TestOutput[HP]']]

X = X.iloc[:, -1].values

```

This material is reserved for educational use only, not allowed for commercial use.

Forbidden to modify the content, and cite the document when use

```

Y = Y.iloc[:, -1].values
X = X[:, np.newaxis]
Y = Y[:, np.newaxis]
poly_reg = PolynomialFeatures(degree = 2)
print(X)
X_poly = poly_reg.fit_transform(X)
lin_reg = LinearRegression()
lin_reg.fit(X_poly, Y)
y_pred = lin_reg.predict(X_poly)
X_grid = np.arange(min(X), max(X), 0.1)
X_grid = X_grid.reshape((len(X_grid), 1))
plt.scatter(X, Y, color = 'red')
plt.scatter(X, y_pred, color = 'green')
plt.plot(X_grid, lin_reg.predict(poly_reg.fit_transform(X_grid)), color = 'black')
plt.title("Polynomial Regression")
plt.xlabel("Pressure")
plt.ylabel("Power")
plt.show()
rmse = np.sqrt(mean_squared_error(Y,y_pred))
r2 = r2_score(Y,y_pred)
print(rmse)
print(r2)
print(" Single Variable Coefficient : ",lin_reg.coef_)
print(" Single Variable Intercept : ",lin_reg.intercept_)
XpolyFit = EssData.drop(columns=["TestOutput[HP]"])
XpolyFit = EssData.iloc[:,0:-1].values
polyFit = PolynomialFeatures(polyDeg)
XtrP = polyFit.fit_transform(XpolyFit)
print(XtrP)
OutputPoly = EssData[["TestOutput[HP]"]]
print(OutputPoly)
OutputPoly = OutputPoly.iloc[:, -1].values
#OutputPoly = OutputPoly[:, np.newaxis]
OutputPoly
PolyOutFit = LinearRegression()
PolyOutFit.fit(XtrP,OutputPoly)
r_sq = PolyOutFit.score(XtrP, OutputPoly)
print('coefficient of determination:', r_sq)
PolyOutFit.intercept_
PolyOutFit.coef_
y_pred_poly = PolyOutFit.predict(XtrP)
X_polyPlot=np.arange(0,len(XpolyFit),1)
plt.scatter(X_polyPlot, OutputPoly)
#pl.plot(x_train, ols.predict(x_train))
plt.xlabel('x')
plt.ylabel('y')
from sklearn.svm import SVC
from sklearn.preprocessing import StandardScaler
from sklearn.datasets import make_classification
from sklearn.model_selection import train_test_split
from sklearn.pipeline import Pipeline

```

This material is reserved for educational use only, not allowed for commercial use.

Forbidden to modify the content, and cite the document when use

```

OutputPoly.transpose()
X_grid = np.arange(min(X_polyPlot), max(X_polyPlot), 0.1)
X_grid = X_grid.reshape((len(X_grid), 1))
plt.scatter(X_polyPlot, OutputPoly, color = 'red')
plt.scatter(X_polyPlot, y_pred_poly, color = 'green')
plt.title("Polynomial Regression")
plt.xlabel("Normalized Parameter")
plt.ylabel("Power")
plt.show()
from sklearn import linear_model
regr = linear_model.LinearRegression()
regr.fit(XpolyFit, OutputPoly)
print(regr.coef_)
print(regr.intercept_)
r_sq = regr.score(XpolyFit, OutputPoly)
print(r_sq)
var_holder = {}
#Xr = {}
for i in range(1,(DesignCandidate+1)):
    SheetID = 'P0'+str(i)
    Xr = pd.read_excel('TestPlenumSummary.xls', sheet_name = SheetID)
    Xr = Xr.drop(columns=['Aresv'])
    Xr = Xr.values
    var_holder[i] = Xr
locals().update(var_holder)
print(var_holder[2])
print(regr.predict(var_holder[1]))
from sklearn.tree import DecisionTreeClassifier, export_graphviz
from sklearn import tree
from sklearn.datasets import load_wine
from sklearn.model_selection import train_test_split
from sklearn import metrics
from IPython.display import SVG
from graphviz import Source
from IPython.display import display
RawData = pd.read_excel('KTM690PlenumDesign1.xls', sheet_name = 'Summary')
EssData = RawData.drop(columns=['Test ID', 'RandomFactor', 'Volume [m^3]', 'Output [HP]'])
XpolyFit = EssData.drop(columns=['TestOutput[HP]'])
labels = list(XpolyFit.columns)
XpolyFit = EssData.iloc[:,0:-1].values
X=XpolyFit
labels
OutputPoly = EssData[['TestOutput[HP]']]
#-----Data manual categorizing-----#
OutputPoly.loc[OutputPoly['TestOutput[HP]'] < 65, 'TestOutput[HP]'] = 0
OutputPoly.loc[OutputPoly['TestOutput[HP]'] >= 70, 'TestOutput[HP]'] = 2
OutputPoly.loc[OutputPoly['TestOutput[HP]'] >65, 'TestOutput[HP]'] = 1
OutputPoly = OutputPoly.iloc[:, -1].values
y = OutputPoly.astype("int")
y

```

This material is reserved for educational use only, not allowed for commercial use.

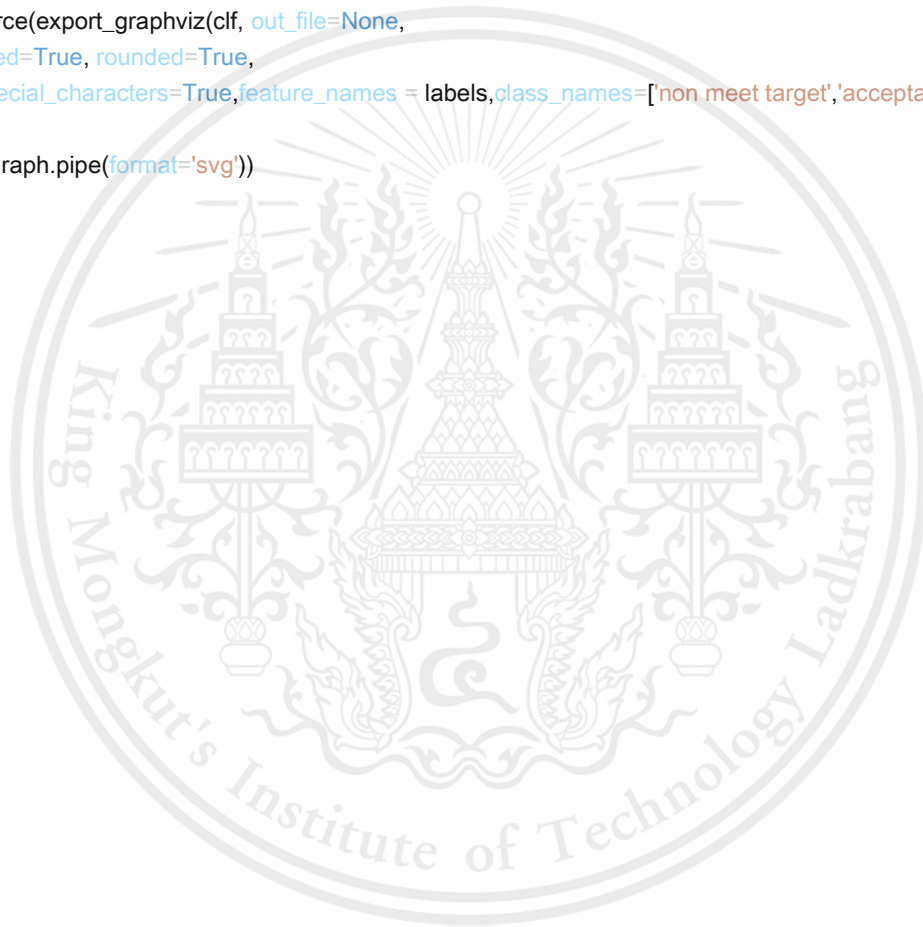
Forbidden to modify the content, and cite the document when use

```

X_train, X_test, y_train, y_test = train_test_split(X, y, test_size=0.3, random_state=1) #split data to 70% training and 30% test
# Create Decision Tree classifier object
clf = DecisionTreeClassifier(criterion="gini", max_depth=None)
# Train Decision Tree Classifier
clf = clf.fit(X_train,y_train)
#Predict the response for test dataset
y_pred = clf.predict(X_test)
y_score = clf.score(X,y)
from sklearn.metrics import classification_report,confusion_matrix

print(classification_report(y_test,y_pred))
from IPython.display import Image
graph = Source(export_graphviz(clf, out_file=None,
                              filled=True, rounded=True,
                              special_characters=True,feature_names = labels,class_names=['non meet target','acceptable','above c
riteria]))
img = SVG(graph.pipe(format='svg'))
display(img)

```





APPENDIX C

Engine power to manifold absolute pressure characteristic

Test ID	MeanPressure [Pa]	ModePressure [Pa]	MeanVelocity [m/s]	ModeVelocity [m/s]	TestOutput [HP]
1	101633.1784	101974.3342	15.41183395	12.9319644	64.33601132
2	101627.9248	101933.4381	16.90174097	19.05474166	62.35144467
3	100953.8183	101990.5152	11.52846149	14.8060661	59.40103355
4	101392.5194	101906.9644	9.924343949	9.180743815	63.06404113
5	100964.1404	101954.2255	11.85971422	7.510394223	59.20624264
6	101070.3225	101960.9414	17.14287851	8.822093819	60.83581673
7	100845.8859	101957.0951	15.74425338	18.98917255	63.32554298
8	101765.4121	101928.8399	8.796353816	10.26019162	61.47659567
9	101579.4162	101954.5311	17.84993612	11.02275138	60.29623752
10	101045.4743	101964.3372	7.392034143	6.847500782	65.66305931
11	101995.1642	101911.7432	18.21155245	6.851787024	63.16903429
12	100873.3002	101988.913	5.318616159	9.752669077	62.8614235
13	101894.3494	101998.4106	10.28162212	19.11870701	61.22369125
14	101088.4416	101984.612	15.45437845	13.32376655	65.66287894
15	101911.2137	101977.7182	7.755678245	13.82575378	61.75227202
16	101876.8798	101972.5837	17.70911955	10.5861598	64.48929951
17	100341.3434	101948.264	19.83931777	16.4277097	62.66055843
18	101113.3615	101941.2451	8.854509169	9.473428611	64.27132895
19	100602.3873	101966.396	12.31913293	19.96667742	63.86208016
20	100865.9717	101990.6274	15.43419491	8.291806285	66.28419974
21	100040.1666	101991.2983	9.878440707	10.82835206	62.8480194
22	101492.3481	101925.4491	18.63057177	7.564101022	63.29067462
23	101918.6745	101994.3003	8.528122925	7.96367983	62.27187465
24	100500.2055	101978.0366	13.32776194	8.032979812	64.84952845
25	101859.9438	101964.4888	17.59198007	19.73361006	62.58327734
26	100447.4479	101990.8114	9.475083558	14.39508344	60.88865532
27	100270.8197	101967.9106	19.23958401	9.79584217	65.51064934
28	101104.6179	101915.1395	8.441249174	9.631877481	62.21054046
29	101956.0432	101947.7235	9.378757882	6.729178139	66.12623731
30	101159.0281	101982.2475	8.388358996	18.76457077	61.98310732
31	101102.0991	101904.3607	7.10627996	12.70192546	65.75408574
32	100601.3431	101952.9191	9.195868373	6.153223694	64.4899277
33	100633.015	101994.1725	6.86992284	18.38478213	66.00188962
34	100006.2309	101983.134	13.04165485	13.64072353	64.5816408
35	100906.9481	101995.3758	5.857657996	8.600293324	63.7385508

This material is reserved for educational use only, not allowed for commercial use.

Forbidden to modify the content, and cite the document when use

36	101460.1132	101976.6304	8.880646518	10.000996	67.32770479
37	101419.2726	101946.1604	7.667657884	6.610335394	67.74244568
38	100783.0691	101982.7652	5.006959849	13.56040461	62.37750207
39	101359.9524	101950.8699	11.54458263	16.44668981	64.47743854
40	100967.6121	101998.8109	9.762107575	10.17281431	66.39655357
41	101196.5162	101916.4117	7.354367169	15.6591518	64.96303626
42	101206.4259	101926.635	14.77480855	19.99408116	67.8337699
43	100597.4452	101921.2793	19.42986696	16.38742498	67.63099325
44	100417.4596	101906.6662	17.17890854	10.01884825	66.48546452
45	100047.8784	101981.645	14.60070479	6.03042051	62.73245155
46	100112.7695	101901.8135	9.891960644	16.46411594	67.85509874
47	101376.671	101948.5787	18.90893088	8.355545446	64.50268054
48	100579.9406	101914.8875	19.77221114	8.513567468	63.93217385
49	100369.3787	101912.5299	16.65682265	18.20142042	66.20751579
50	100260.721	101935.5481	9.589801925	7.190258663	65.39071596
51	101867.4303	101917.0396	19.72830762	15.78103861	63.98479968
52	100374.1133	101906.9897	5.309665546	7.979365705	67.61925861
53	100148.141	101956.3173	5.711195222	16.4139015	67.42745465
54	101703.5395	101952.2766	5.030572653	7.92424021	65.67238398
55	100499.3156	101931.6972	18.37779311	9.55592473	67.38741766
56	100503.0863	101978.002	14.13895507	18.32209357	67.32035366
57	100957.5842	101954.1772	10.80522422	6.209513338	66.33957546
58	101855.6636	101972.6883	7.757947474	11.22998507	63.51894459
59	101582.1171	101978.4135	14.72667284	11.75565174	63.83172247
60	100200.8876	101958.425	5.587635409	5.39309275	67.37724845
61	100703.9216	101991.6215	6.971710938	5.913137927	69.95339405
62	100212.6147	101975.0481	14.19305837	9.092658208	65.2295316
63	101538.7418	101910.367	7.455238855	14.59682925	63.72352766
64	100617.7767	101924.0402	13.30508404	13.6020827	67.91341675
65	100487.1109	101990.531	5.1036196	14.14667717	64.17402702
66	101174.0227	101929.71	13.60892171	17.42063902	67.8796011
67	101135.6244	101966.4816	12.40631366	17.95717517	64.50423849
68	100212.2781	101957.9938	6.75489303	5.293405773	68.92156893
69	100485.3973	101958.9939	19.17582384	5.78345472	68.06244283
70	100884.4906	101913.8719	7.283651453	17.72325649	68.50872402
71	100755.7215	101938.8193	16.82078796	7.622001693	70.25075759
72	100092.7604	101976.7219	14.30998036	16.65222974	65.20762452

This material is reserved for educational use only, not allowed for commercial use.

Forbidden to modify the content, and cite the document when use

73	100222.1971	101975.4226	19.18405024	18.45969154	70.5762587
74	101630.4224	101959.095	19.14962683	16.11082269	69.52521553
75	100484.8052	101997.5585	13.5479942	13.47486233	70.43038413
76	101129.6571	101970.4941	15.20399889	6.014148775	67.70781958
77	100977.9796	101959.5474	15.52701887	9.594545777	70.82497574
78	101892.0918	101927.9708	8.872240054	17.76529914	70.44905112
79	101644.92	101917.5811	18.95726456	5.629823238	64.65383195
80	101168.8536	101910.8787	17.53178442	17.49251725	70.47572776
81	100846.33	101949.2129	10.2911349	15.83383575	67.30086545
82	100261.2703	101965.4232	15.24260591	18.34703559	66.9505853
83	100474.7359	101906.4076	7.040140259	18.87771275	65.71200078
84	101238.9669	101915.665	18.54250973	17.35664913	66.8261114
85	100969.9525	101935.7165	17.36424582	12.28810086	65.89237893
86	101782.2099	101923.8541	17.85464856	11.89636288	67.20680498
87	100417.2999	101929.1707	18.79451728	17.3908642	71.34447001
88	100679.6	101953.3032	9.422972395	11.35741179	69.90853654
89	101257.7085	101994.8354	12.89569277	6.520088116	68.47696262
90	100951.2234	101928.5564	19.3377367	10.04848747	70.65822648
91	100744.0917	101906.0875	7.079390426	12.80236858	70.73851816
92	100780.3942	101945.0748	13.46075503	16.55392591	65.97123051
93	100839.5657	101960.9174	10.8509466	14.32928295	68.15599768
94	100806.0016	101977.4382	7.8256094	14.22357581	68.97240028
95	100703.1618	101990.3843	12.79501678	17.05389127	71.30846314
96	101428.163	101943.0681	10.37834597	13.31592833	67.96846987
97	101084.6027	101989.7562	19.61705978	7.183833769	70.90837972
98	100195.1422	101973.4015	7.018714002	18.09183515	67.5207656
99	100025.7563	101963.5077	7.59971709	14.03607039	67.39988655
100	101481.0028	101978.6753	11.94673735	16.06876181	73.04486072
101	101094.6907	101986.6512	6.915878176	14.66378705	70.81848211
102	100787.6077	101987.4107	7.671275145	19.29622184	73.27477325
103	100585.2053	101994.1796	12.54676403	7.992354172	68.33136406
104	100815.6821	101966.5264	9.897191288	5.763910362	70.95933306
105	100693.9959	101963.8635	7.656490078	12.45279864	68.10824798
106	100632.7641	101947.17	14.8742771	10.15734527	68.52856763
107	100325.7411	101918.1112	19.44293188	17.92794167	67.27917588
108	101921.9091	101908.3962	11.0001268	15.71748291	69.83452204
109	100573.0654	101907.6481	13.86647221	13.63574174	70.63813884

This material is reserved for educational use only, not allowed for commercial use.

Forbidden to modify the content, and cite the document when use

110	100985.8397	101959.8963	18.72324455	6.489148833	71.06991082
111	100631.0656	101901.7152	17.24444177	6.338298986	71.81486835
112	100212.0251	101907.5614	10.66914637	6.047530032	72.38031796
113	100339.3484	101943.1307	12.76705481	18.62095628	68.76420318
114	101411.4664	101905.5948	12.26581572	11.61748638	69.05291559
115	100921.8598	101936.6162	15.32943841	12.34864259	67.79272074
116	100867.4464	101950.5197	10.60991347	19.18989609	70.49487405
117	100783.1148	101943.8534	17.44778471	12.12411411	67.6776931
118	101191.5412	101912.4822	9.697739622	16.84215993	70.31807253
119	100937.0791	101980.1999	16.25605224	18.29748675	69.59225623
120	100328.7579	101901.489	5.766783339	11.66217526	74.73659065
121	101487.5933	101956.1767	14.24049159	8.567505834	74.14473413
122	100271.8311	101919.9164	8.569967815	12.71868678	70.32906815
123	101684.5148	101940.864	11.75288136	7.480944242	73.90228582
124	100055.0063	101965.8909	9.571823413	8.620824921	71.60088189
125	100661.5488	101927.7833	14.63521514	14.06028107	74.822721
126	101004.8629	101982.3034	14.50905417	19.13948608	71.19708361
127	100592.7997	101912.2564	14.33554052	19.18942051	69.00308664
128	100401.4914	101970.2444	10.94603642	10.82996865	74.19587051
129	101575.0605	101997.1444	8.637763755	7.546922382	72.70120768
130	101187.5963	101900.5056	13.69519585	6.780712971	74.09309823
131	101023.5212	101945.5314	17.05997278	5.845781579	75.27105722
132	100964.6727	101937.1274	6.929283772	7.984787398	73.34278637
133	101063.4953	101905.8044	16.0554412	7.107253058	72.24928222
134	100685.8367	101930.0774	9.435486958	11.3299921	74.88716564
135	101437.8836	101989.9513	10.65501232	9.629958465	72.71528732
136	100421.0625	101920.5951	15.40322075	5.50868366	70.83897701
137	101311.0034	101932.6578	19.14610877	11.21788861	71.19419188
138	100864.3938	101958.3586	8.339787766	10.83167735	69.14218185
139	101986.1771	101947.8821	12.88959448	10.72801511	75.33162736
140	101482.68	101926.5052	6.275348406	9.210319848	76.01601765
141	100319.6324	101981.8673	19.98597664	5.406300022	70.44647225
142	100399.8902	101965.3241	6.458348584	19.12565985	70.0802253
143	101747.3205	101961.1784	14.15954493	19.84319916	73.74124883
144	100511.6925	101962.3337	15.10451089	5.845621472	73.51403685
145	100177.5165	101938.2522	14.70216584	13.89313087	75.69995776
146	100677.8066	101954.3756	19.99968663	8.496631182	72.87035839

This material is reserved for educational use only, not allowed for commercial use.

Forbidden to modify the content, and cite the document when use

147	100983.7948	101960.228	15.70581362	14.11432499	70.97781581
148	101718.5042	101917.34	11.62866558	11.86241741	72.05313996
149	101558.2228	101959.3998	19.97411865	9.914219245	74.35183444
150	100694.5716	101984.1603	10.69453849	9.382998386	70.41467656
151	101080.3463	101912.8138	13.75921122	10.38324243	73.96045848
152	100359.7876	101970.6568	17.74303471	11.95616372	76.0679448
153	100049.3029	101955.5214	19.61669812	18.04612882	76.11365087
154	100227.6969	101960.148	7.651036591	14.83547196	73.62339777
155	101599.1249	101956.2307	18.26793779	18.98217553	74.30630365
156	101600.5613	101953.2661	10.92997208	17.85204211	77.24882727
157	101586.0309	101941.1277	16.98857162	5.111752491	71.2887047
158	100810.4356	101958.1225	5.206386309	15.54781624	71.84257104
159	100045.6782	101973.716	5.423429913	15.87753173	71.77925377
160	101976.2783	101957.97	17.75035871	8.884369809	74.93788528
161	100601.7965	101954.2792	17.51966675	13.31926877	73.83993081
162	101848.5551	101945.6409	9.998779246	19.60495095	76.9015675
163	100808.0013	101967.1419	18.44020929	18.08861126	71.03951673
164	100409.0679	101941.1974	19.82379114	13.1899712	74.11631563
165	101718.6422	101964.2097	17.46222818	15.94042346	70.95266966
166	101385.4375	101999.8123	8.78504508	19.59628585	75.35913748
167	101772.454	101910.1126	6.814021721	11.22005203	72.68870632
168	100791.0831	101997.0331	12.62208532	13.06321387	77.5454289
169	101771.7276	101928.0276	11.18139671	9.712265977	77.12127671
170	100052.5806	101941.2901	7.488246266	16.23328423	75.20324269
171	100582.6716	101908.0719	18.68684469	13.96067163	72.18530727
172	101378.333	101975.0513	7.270099099	17.514828	76.21840225
173	101847.4607	101924.8779	8.719585827	8.382336853	72.55832558
174	101429.5722	101917.2737	11.72739938	14.5880547	76.3741212
175	100727.0652	101988.7614	16.11351417	8.226983966	74.91275668
176	100940.8222	101985.0745	9.114285029	9.147014985	79.19473347
177	101667.7438	101986.4246	6.588155264	5.678870757	76.15587423
178	100113.7213	101912.4334	16.82063161	13.23335647	78.60584731
179	100517.0123	101980.2473	16.55311596	16.81349983	74.45433404
180	101355.1686	101918.5073	5.409835606	17.07546873	73.34008144
181	100983.2443	101930.397	18.63547803	9.805936327	79.4361214
182	101647.046	101928.5786	7.719022905	8.269168462	79.3080854
183	101821.536	101904.7511	10.19818258	10.03084268	76.70368687

This material is reserved for educational use only, not allowed for commercial use.

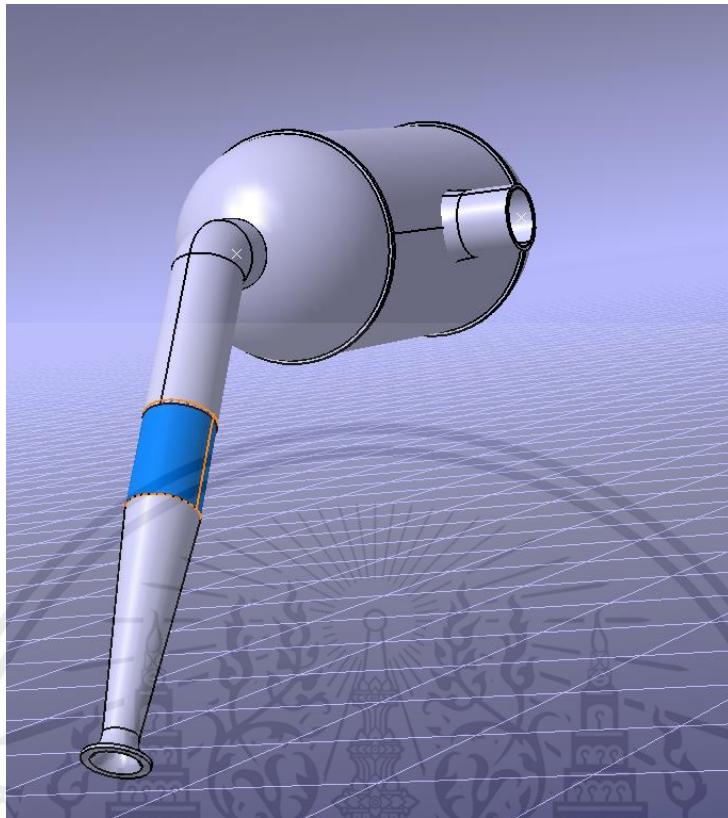
Forbidden to modify the content, and cite the document when use

184	101381.8087	101987.1889	14.17027317	19.82678167	78.34571529
185	100249.895	101985.0992	15.57821255	14.52356782	72.68086663
186	100491.8449	101927.3782	9.933581944	5.111156804	73.15009502
187	101108.8854	101973.5688	7.743101335	5.356281619	77.86858475
188	101376.0249	101920.6933	13.04448917	18.45391179	75.85734439
189	101283.809	101961.6912	19.36611366	11.04444358	72.87467119
190	100703.5097	101986.3166	8.712557237	12.07247997	77.37333207
191	101105.7495	101945.0742	18.11505055	5.216211839	74.14689789
192	101875.2147	101995.5425	15.63589506	16.69746744	76.07838412
193	101842.2298	101964.8994	18.23752303	8.76072828	77.9189576
194	100868.4555	101985.1254	16.98046887	14.05619318	75.14864022
195	101505.5732	101938.4709	17.23023515	17.21349646	75.16051692
196	100461.6475	101917.449	12.22217263	13.82804131	80.65221424
197	101461.5303	101940.2463	18.55925339	14.24928907	79.98186507
198	101324.504	101918.266	19.02224757	11.03475405	79.24563903
199	101278.5523	101940.6709	16.26690211	5.74491909	76.00488853
200	100671.9566	101968.531	17.57814791	12.07203519	76.07520024
201	101878.053	101914.4253	18.65803692	17.20933316	79.74747579
202	100189.3599	101987.2658	7.93354776	18.25968826	76.04697751
203	101875.7691	101921.2738	11.11883796	10.28547201	79.35850374
204	100191.4357	101961.749	16.13511218	12.3720344	77.57302327
205	100192.4157	101999.6431	14.98039734	18.90293455	77.66070773
206	101631.5576	101951.5192	12.86608031	5.723580037	80.08379983
207	101267.9139	101970.1464	7.438307902	18.5448466	74.25667485
208	100988.7773	101911.1006	14.83038061	5.624223437	74.95708315

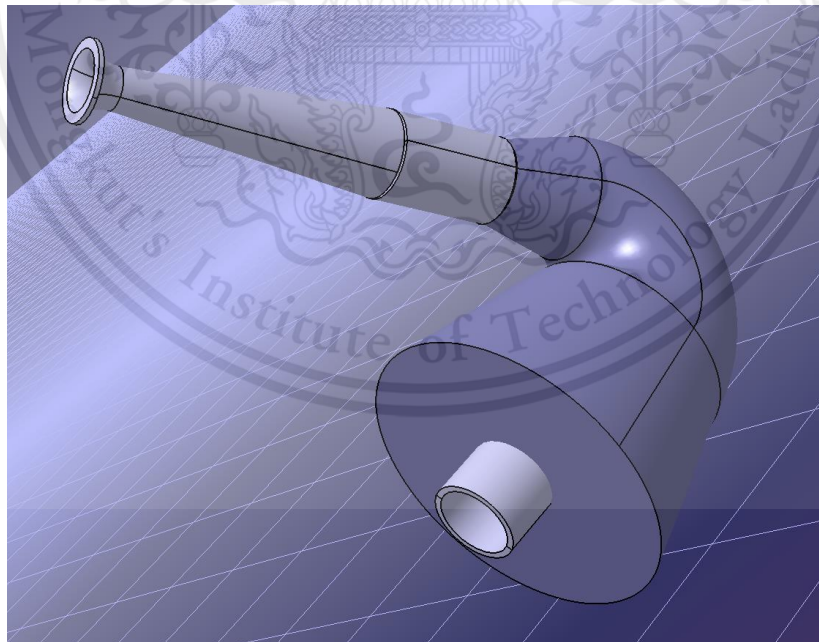


This material is reserved for educational use only, not allowed for commercial use.

Forbidden to modify the content, and cite the document when use



Geometric design of plenum 1



Geometric design of plenum 2

This material is reserved for educational use only, not allowed for commercial use.

Forbidden to modify the content, and cite the document when use



Geometric design of plenum 3

