FINAL PROGRESS RDU140378

Turbocharger Performance Map and Engine Modeling for Turbo Engine

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TABLE OF CONTENT

CHAPTER 1

1.1 INTRODUCTION

Nowadays, the environmental aspect will be the main factor in every development of engine technology. This can be justifying the great effort to develop technological solutions to limit pollutant emissions while reducing engine fuel consumption, according to the requirements of the recent European Commission Regulation on the carbon dioxide emissions for new registered passenger cars [1]. The reduction of carbon dioxide goals usually contributed by the Europe increase the automotive industry market and by using several automotive technologies like turbocharging system [2].Turbocharging technique in conjunction with the downsizing concept seems to be the most promising way to achieve this target [3]. A turbocharger is a device that invented in order to achieve that particular specification by recycling exhaust air to drive a turbine connected with compressor to compress air and turbocharger forcing compress air to the combustion chamber. Turbocharger is a device invented by the Swiss engineer on 18's centuries [wiki]. Firstly use at a diesel engine like aircrafts, ships and locomotives. After that, car and commercial vehicles started to widely use the technology of turbochargers. With increasing focus on engine downsizing, high performance and low fuel consumption, turbocharger technology must address several design challenges to reach consumer expectations of improvements to automotive engine performance [4] Furthermore, prior research demonstrates that pollutant emissions reduction and higher engine efficiency can be achieved through a proper combination of turbocharging technique and engine downsizing [5].

1.2 PROBLEM STATEMENT

Same goes to combustion system turbocharger system also have performance and efficiency. The efficiency and performance of turbocharger will effect by many aspect. The compressor of turbocharger is some of the aspect that will affect turbocharger performance rate. This project will focus on the effect of compressor blade vane outlet angle due to its pressure ratio.

1.3 OBJECTIVE

The objective of this project is to model a compressor blade with different vane outlet angle and conduct flow analysis by using the VISTA CCD ANSYS software.

1.4 SCOPE

The scope of this project is to design a blade model with 50, 55, 60, 65 and 70 degree of vane outlet angle using Blade Modeler and conduct flow analysis using VISTA CCD to produce a speed line graph and then comparing the most efficient blade outlet angle.

CHAPTER 2

LITERATURE REVIEW

2.0 CHAPTER OVERVIEW

This chapter explains the flow of turbocharger and the parameter of the studies. Besides that will explain and review the software use to run the analysis process.

2.1 TURBOMACHINERY SYSTEM

Alfred Buchii Swiss engineer is the inventor of turbocharger [Wikipedia]. Turbocharger is a device used to increase internal combustion engine efficiency and power input [Wikipedia]. Turbochargers contain several components which are divided into two sections. First section is a turbine section consist turbine wheel. In this section, extra gas in the exhaust produce by the engine flow through the inlet port. In inlet port, the turbine housing guides the gas flow to spin the turbine wheel. At that point the thermal energy converts into kinetic energy to drive the turbine wheel. The second section is the compressor section consist the compressor wheel. Because of the turbine wheel share same shaft, when the turbine spin the compressor also spin into the same speed. Consequently, the compressor will compress the air and the guide by the compressor housing to the outlet port. The compressed air then flow through the intercooler to cool down the air temperature and increase volumetric efficiency which is more oxygen and then supply to the intake for better efficiency and performance.

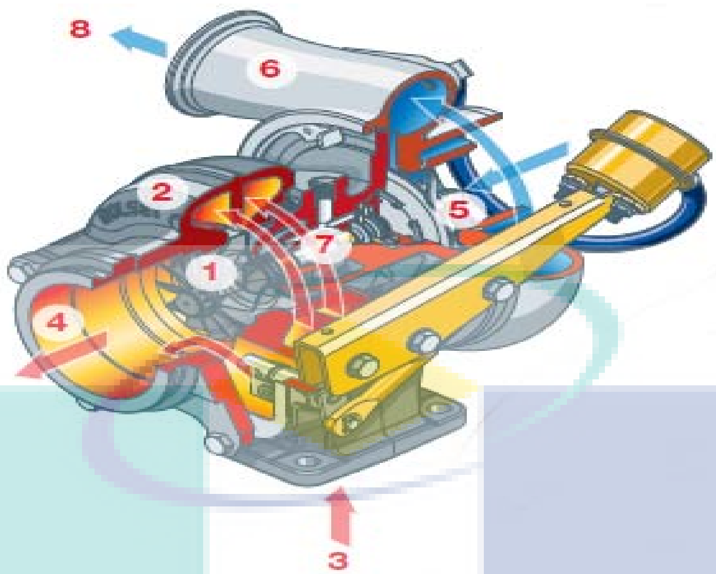

Figure 1

(http://www.cumminsturbotechnologies.com/ctt/)

Figure 2.1a shows the main part of turbocharger and the flow of the turbocharger. (1) is the turbine wheel and (2) is the turbine housing. (5) and (6) is the compressor wheel and compressor housing. (7) is the shaft connecting the turbine wheel and the compressor wheel. (3) and (4) is the flow of air in high temperature. (8) is compressed air.

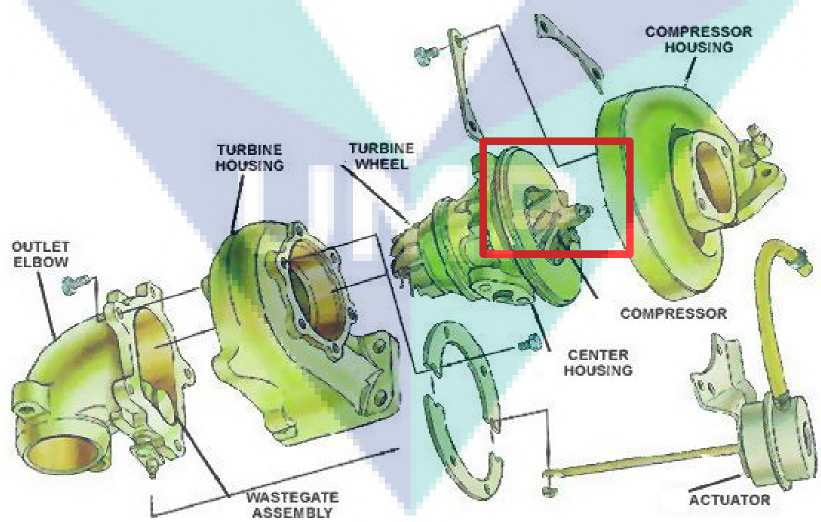

Figure 2

Figure 2.1b shows the exploded view of the turbocharger the highlight one is the parameter of this project studies

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2.2 TURBOCHARGER COMPRESSOR

Figure 3

Figure 3 shows the 3D model of type compressor that is use in the turbomachinery system.There are many type of compressor invented based on functioning. Radial flow compressor or also known as centrifugal compressor type of compressor use in the turbomachinery system. Based on the name radial, it implies that the gas entering is in a radial flow. The gas flow perpendicular to the axis of rotation. In the turbomachinery system the compressor by the turbine connected together with a shaft that have bearing system. Basically the compressor consists of an impeller blade and diffucer. The impeller blade functioning to collect the air from the ambient inlet air and then accelerate it outward to the diffuser. Rotation of the impeller blade create the force to the collected air which is stacked up together. When the collected air are forced to each others it will increase the pressure. The higher the speed of the compressor the higher the pressure increase. The centrifugal compressor known as the compressor that deliver high flow capacity with good reliability and required less maintanance. Futhermore, most of it made up from alluminium alloy due to the of high temperature resistance which is increasing of the pressure will lead to the temperature increase from the flow of air in the compressor.

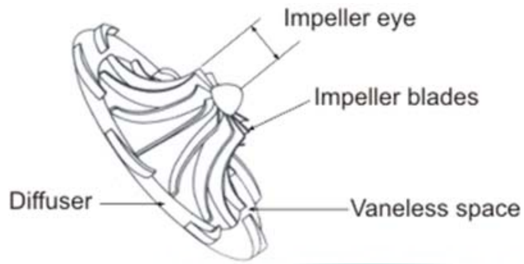


Figure 4

Figure 4 shows the labeled part for the centrifugal compressor.

2.3 COMPRESSOR MAP

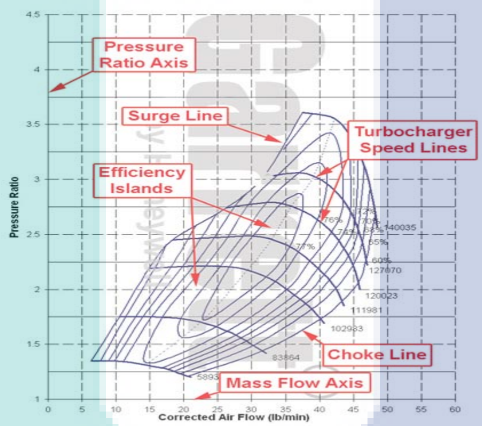


Figure 5

Figure 5 shows the example of the compressor map that is used in the industry for turbocharger in Garret Company which is one of the companies producing various size and type of turbocharger. Performance and the efficiency of a compressor can be measure by using the compressor map. On the horizontal or x-axis of the map indicate amount of the air flow which is **the mass flow rate** on the inlet of the compressor impeller and the vertical or y-axis indicate the **pressure ratio** of the compressor. The pressure ratio is the ratio of the pressure outlet and inlet. The map plotting data is based on the experimental or analysis data of the particular compressor which create several of **speed line** from the various rotating speed of the compressor. The plotting region in the speed line is called the **efficiency island** which is indicating the efficiency of the compressor. The center smallest region in the compressor map is where the highest compressor efficiency point. The further point from the region will drop or decrease the compressor efficiency until reaching the surge lines or choke line. In the **surge line** is where every surge point of every speed line are connected together which is the compressor operate in the highest peak of capability and occurs at low flow rate. This will cause the reversed flow of the air flowing in the compressor and should be avoid. Moreover the choke line occurs when the mass flow is very higher exceeding the amount of the maximum the compressor can handle. In the turbomachinery system this compressor map is use to check the capability for selecting the size of the turbocharger based on the size of engine.

2.4 BLADE ANGLE

Compressor efficiency is influenced in many factors. One of the factors is the based on the geometry factor. There are a lot types of geometry involve one of it is the blade angle. The blade of angle will affect the flow of the air in the compressor either in the inlet or outlet vane of the blade.

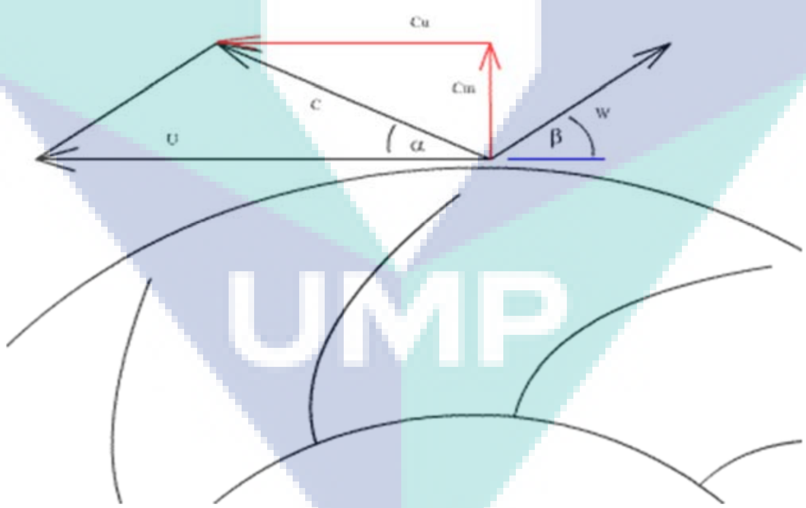


Figure 6

Figure 6 shows the angle C is the velocity vector of the air outlet when leaves compressor blade tip. To resolve the component respect to the blade itself with the blade W and with the peripheral direction that will form the sum of the vectors which is the Cu and Cm.

Cu and Cm is the velocity vectors.

β is the angle between blade tip angle.

U is peripheral speed of compressor (rpm).

P is power from the turbine shaft calculation (W).

$$Power, P = \dot{m} \times U \times Cu$$

$$Cu = \frac{P}{\dot{m} \times U}$$

Therefore the equation of geometry shows that $Cm = (U - Cu) \tan \beta$ and then substitute Cu into the equation $Cm = \left(\frac{U-P}{\dot{m} \times U}\right) \tan \beta$.

2.5 ANSYS

ANSYS Inc. is software that is categories as computer aided for the engineering software. The software involves in designing any type of engineering design and analyzes it in many type of aspect which is computational fluid dynamics, finite element analysis, structural analysis, explicit and implicit element and heat transfer. For analysis the turbocharger compressor blades there are two aspects need to be considering which are the ANSYS Mechanical and ANSYS Fluent. The ANSYS Mechanical aspect will involve in simulate finite element analysis which to analyze the material and the failure on the maximum force the blade can withstand. In additional, the ANSYS Fluent involve in simulate the fluid flows through the blade. The studies of this paper will focus in fluid dynamics flow. In ANSYS Fluent the computational fluid dynamics or also known as CFD will analyze the flow path of the fluid.

2.6 VISTA CCD

To solving the analysis in turbomachinery cases, ANSYS now introduce new features special for the turbomachinery system which is the **VISTA CCD** or visual turbomachinery analysis for centrifugal compressor design. The features involve in designing the blade of the turbocharger compressor in 2D and then proceed with the 3D modeling in **Blade Modeler** features which is available in VISTA CCD. In the Blade Modeler features the geometry of the compressor can be adjust into the desired parameter. Moreover, the VISTA CCS also can be used to specify and defined the parameter involve in turbomachinery system before run the simulation and analysis process. Therefore, the designing of the blade for the turbocharger compressor will be easier and all the parameter aspect can be consider in order to analysis the design before proceeding to the fabrication process. The figure 7 below the layout of the VISTA CCD features in the ANSYS software.

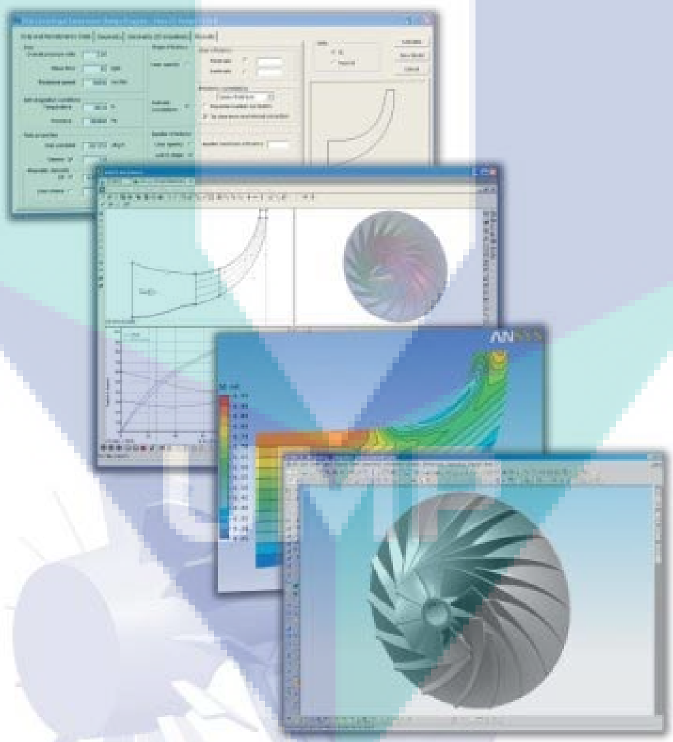


Figure 7

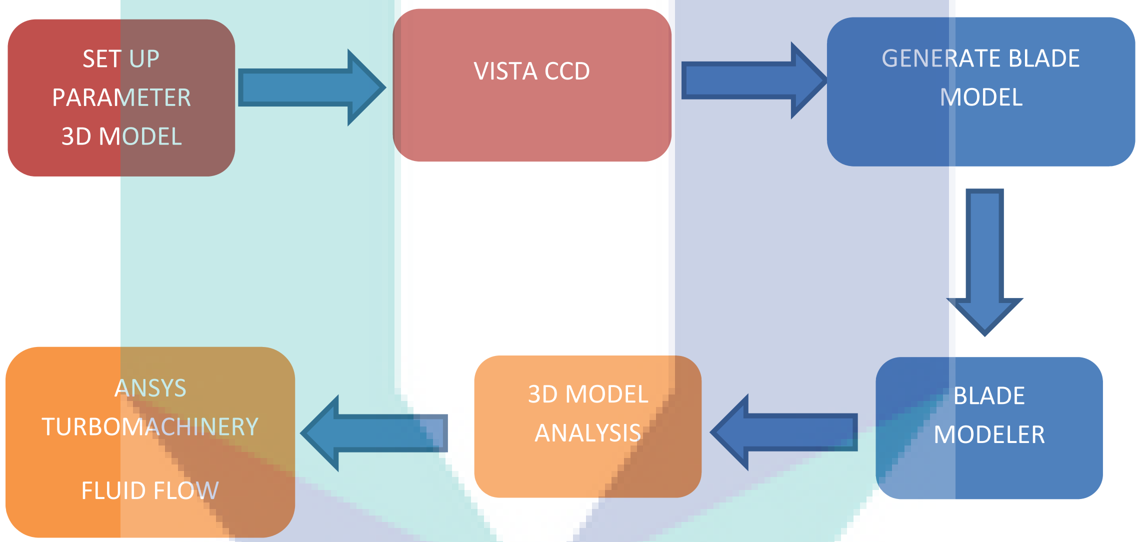
CHAPTER 3

METHODOLOGY

3.0 CHAPTER OVERVIEW

This chapter will explain the flow of analysis process. There are many step involve in order to generate the model and then conducting flow analysis. After the analysis done, proceed with collecting and analyze the data obtained.

3.1 FLOW OF MODELLING



The flow chart below shows the flow of modelling compressor blade. The first flow chart which is the red color is by selecting the parameter desired for the turbocharger studies using the vista CCD. The chart then flow to generate the 3D model of the blade by using blade modeler. The last part of the flow chart is to analysis the generated blade.

3.2 COMPRESSOR PARAMETERS

The parameter of compressor every design are constant to ensure accuracy of the analysis data by only manipulated the vane outlet angle of the compressor blade. The table below is the main fixed parameter of the compressor.

NAME	PARAMETER	VALUE
Diameter exit impeller	Millimeter	113.71mm
Vane	Vaneless	12
Inlet temperature	Kelvin	288.15K
Inlet pressure	PASCAL	101353Pa
Mass Flowrate	Mass flow rate	0.6kg/s
Pressure Ratio	-	4.5
Rotational Speed	RPM	90000

3.3 GEOMETRY MODELLING

3.31 INPUT INITIAL SIZING IN 1D VISTA CCD

Figure 8

The figure 8 above show the blade design layout for the VISTA CCD of centrifugal compressor design which is use to setup all type of configurations to the compressor. To generate the 2D model, firstly key in the desired duty of the compressor into the duty and aerodynamic data. This will give initial idea to generate Figure 9 below show the interface of the setup for the duty and aerodynamic data for the compressor. After that, set up the parameter for the gas properties of the compressor. This is where the working fluid or air driven by the compressor is setting up. There are real gas modeling system can be used for refrigerant or other real gasses. The figure 10 shows the gas properties interface which is containing the critical parameter of the properties. Then set up the others geometry constraint of the compressor desired by key in the parameter which shows in figure 11. The geometry constraint that allow to modified is configures of compressor scantlings, vane inlet and exit angles, velocity triangles.

DUTY AND AERODYNAMIC DATA INTERFACE

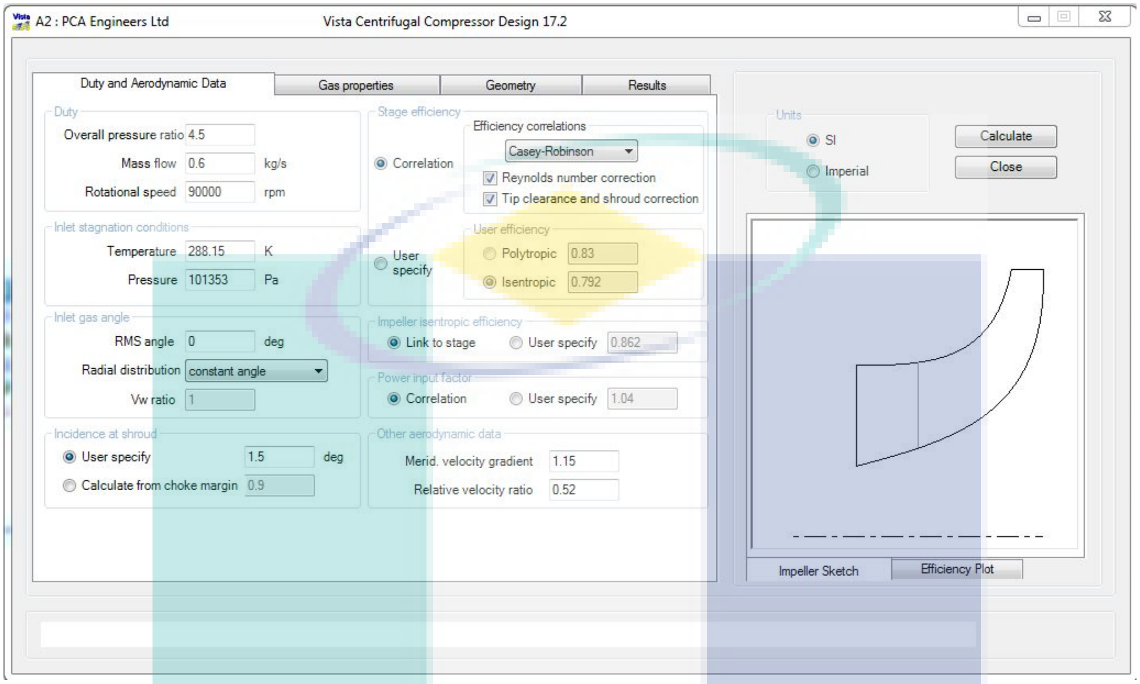


Figure 9

GAS PROPERTIES INTERFACE

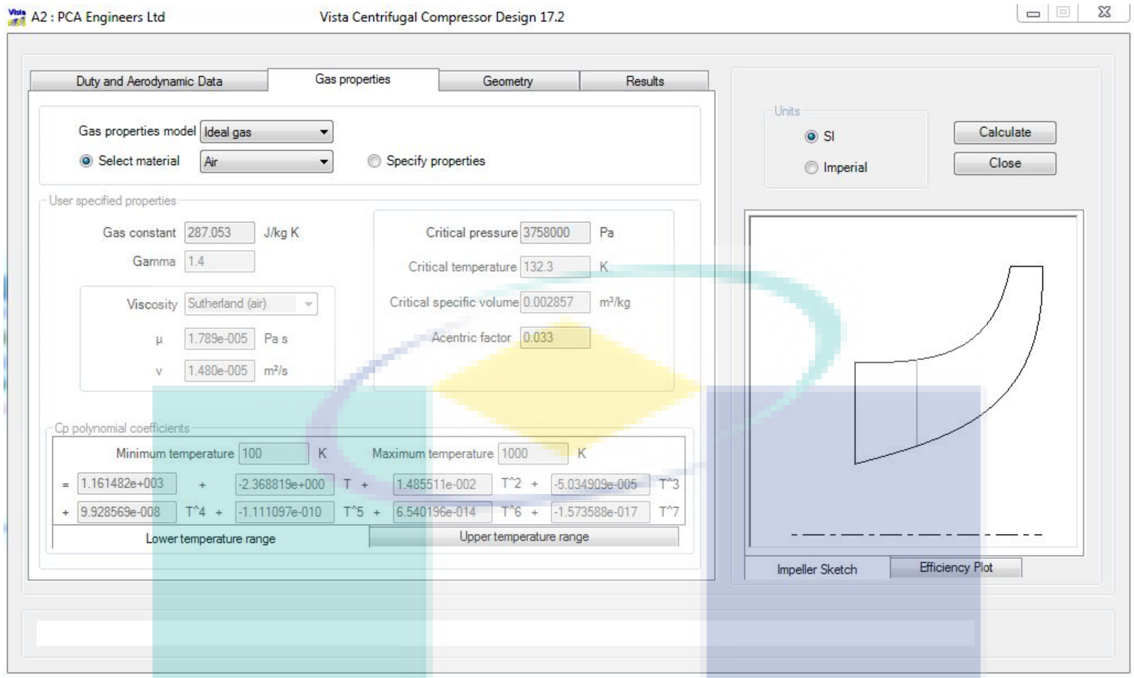


Figure 10

GEOMETRY INTERFACE

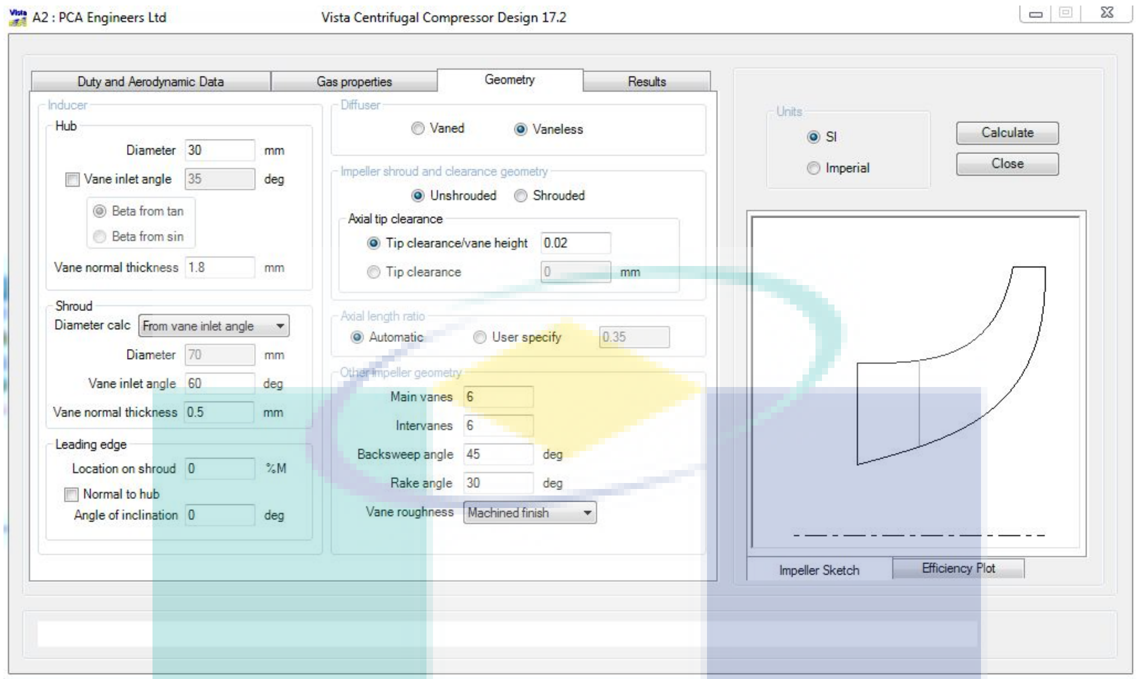


Figure 11

3.32 OUTPUT CALCULATED PARAMETERS IN 1D VISTA CCD

This is where the idea of initial desired configuration of compressor then been calculated and the VISTA CCD will generate 1D model of the blade with the estimation value to the desired configuration value. It will produce a table will all of the new value of all configuration of the compressor. The figure 12 below shows interface of the table containing all the new configuration value and the 1D impeller sketch. Besides that it also provide the efficiency plot which is show in figure 13 below. The efficiency plot shows a graph of Casey Robinson which is showing the pressure ratio are reliable predicted to the correlation of design point.

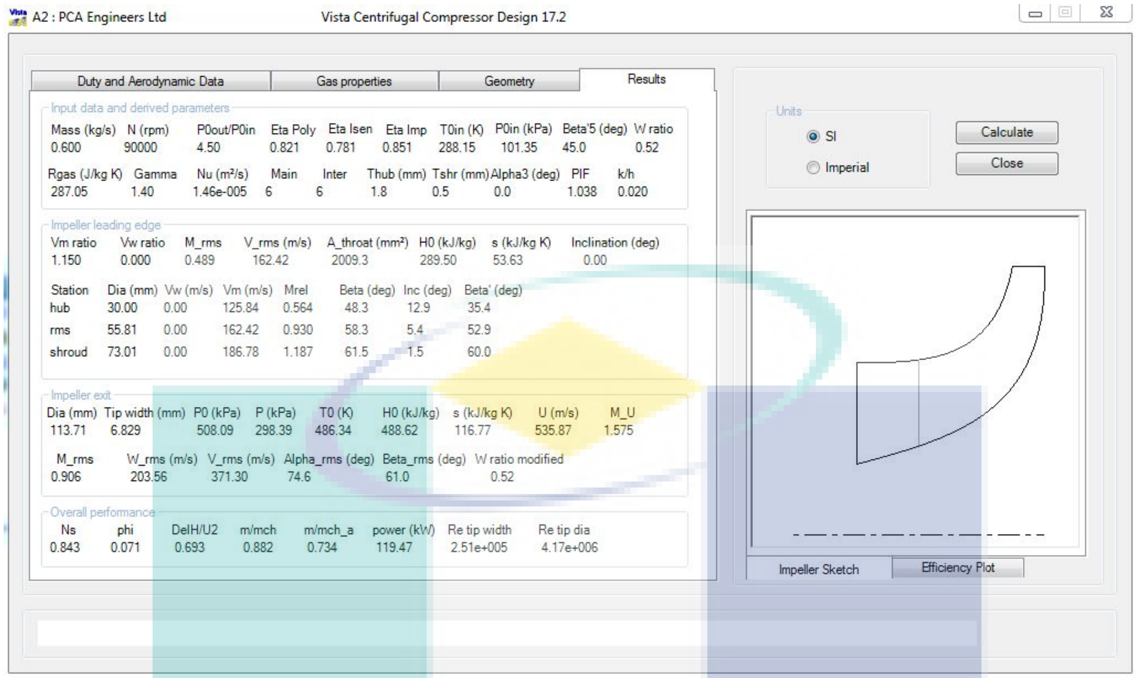


Figure 12

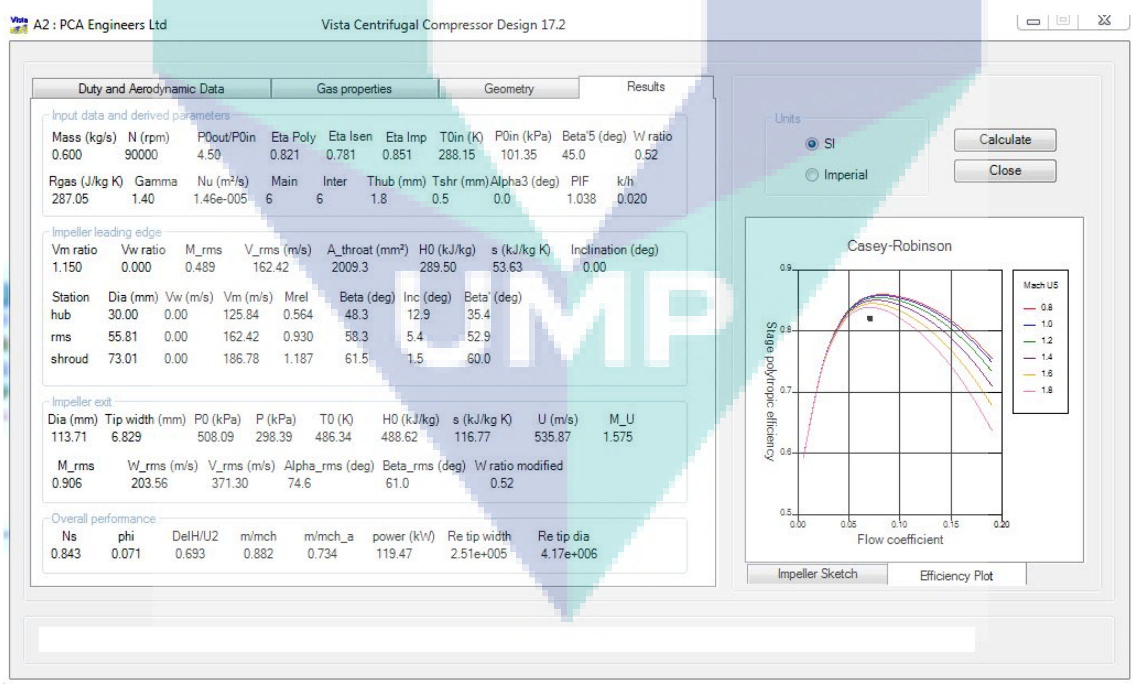


Figure 13

3.4 GENERATE 3D MODEL OF COMPRESSOR BLADE IN BLADE MODELER

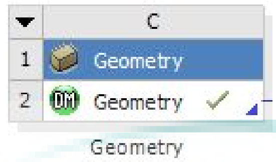


Figure 14

The figure 14 above shows the layout for geometry design of the compressor. The layout should be connected with the previous layout which is the blade design toolbar. In this section the setting up of the 1D parameter and then generated into full 3D model. These features allow the user to make further modification on the blade design. The figure 15 below shows the layout of the Blade Modeler which is the option in the geometry layout. There for the further modification can be adjust using this standalone form. After desired modifications have been made, the model can be generating back based on the updated modification. There are many type of geometry can be modified such as the blade thickness and the blade angle. The figure 16 below shows that the blade angle that can be modified into desired angle. By modified the certain geometry constraint of the compressor, this will allow the users to optimize their own blade angle. Moreover the generated blade design can be display into the desired view so that every specific part of the blade design can be view. In this study the blade angle is the manipulated variables of the data. Therefore, five different blade angles have been selected to be analyst which is the blade angle of 50, 55, 60, 65, 70 degree.

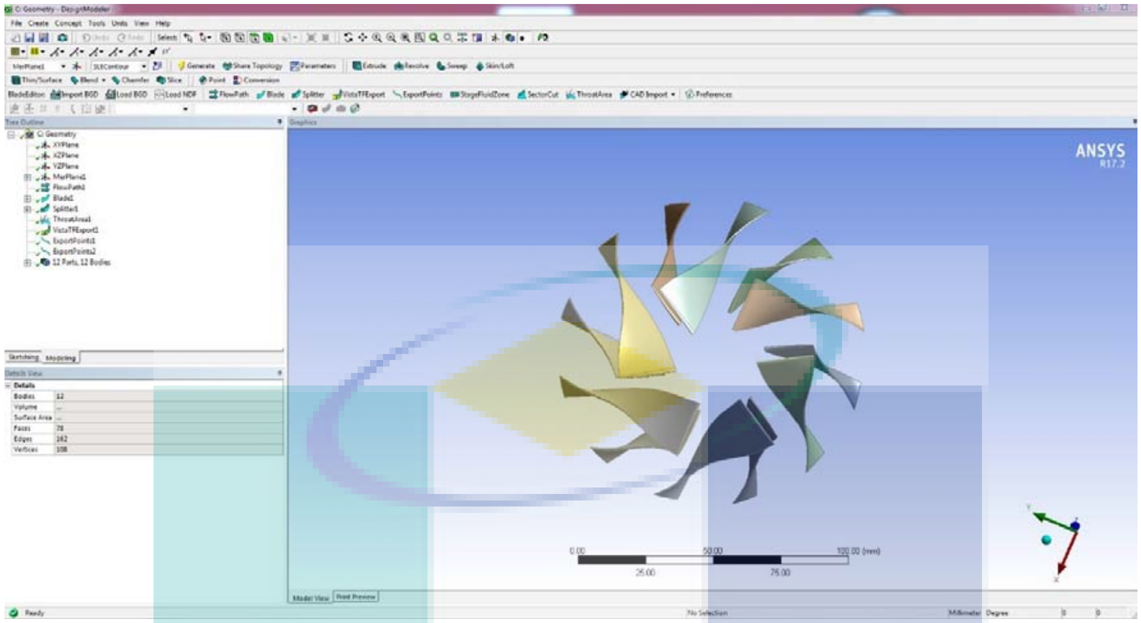


Figure 15

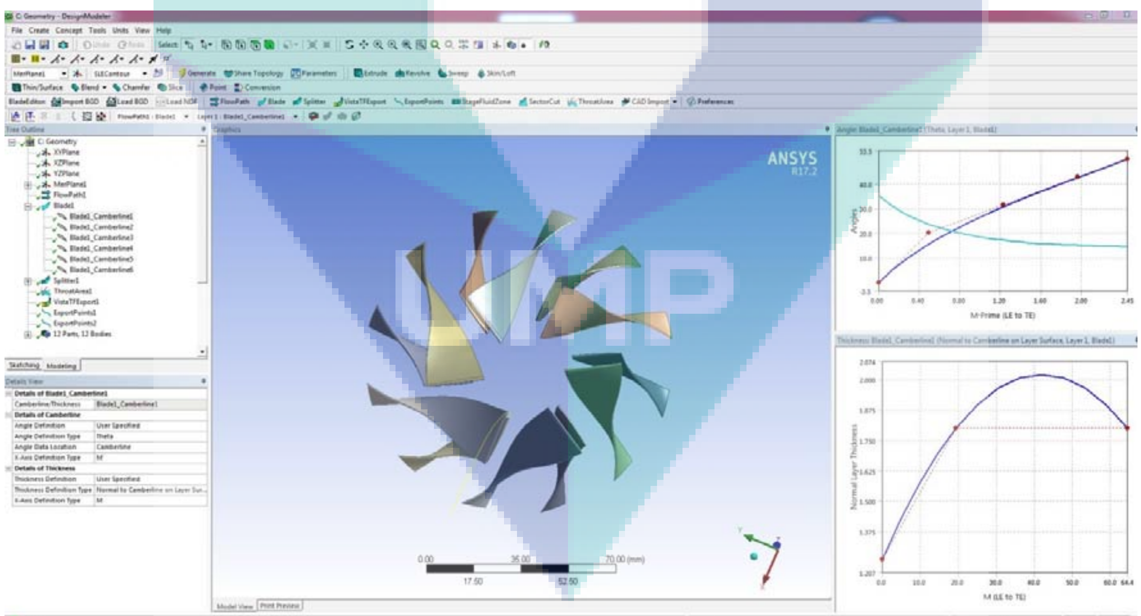


Figure 16

3.5 TURBO SETUP

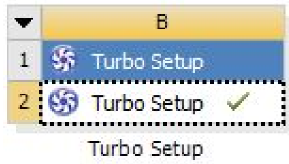


Figure 17

The next layout that is connected between blade design and geometry layout is the turbo setup toolbar. In this layout contain 3 part of setup. First the Basic Setup which is show in the figure 18 below. In this setup is where the setup for the working fluid or air before to analyzing the data. Secondly is the Operation Condition Setup, this is where the working fluid or air been setting up to flow through the compressor with the value of mass flow rate show in figure 19 below. There are ten different value of mass flow rate have been setup to analysis of the study within 0.4 to 0.7 kg/m^3. Thirdly, the last setup for analysis is the performance map of the compressor which is shows in the figure 20. This graph can only be obtained after the last analysis is run. After that is performing map can only be obtain when full analysis are complete.

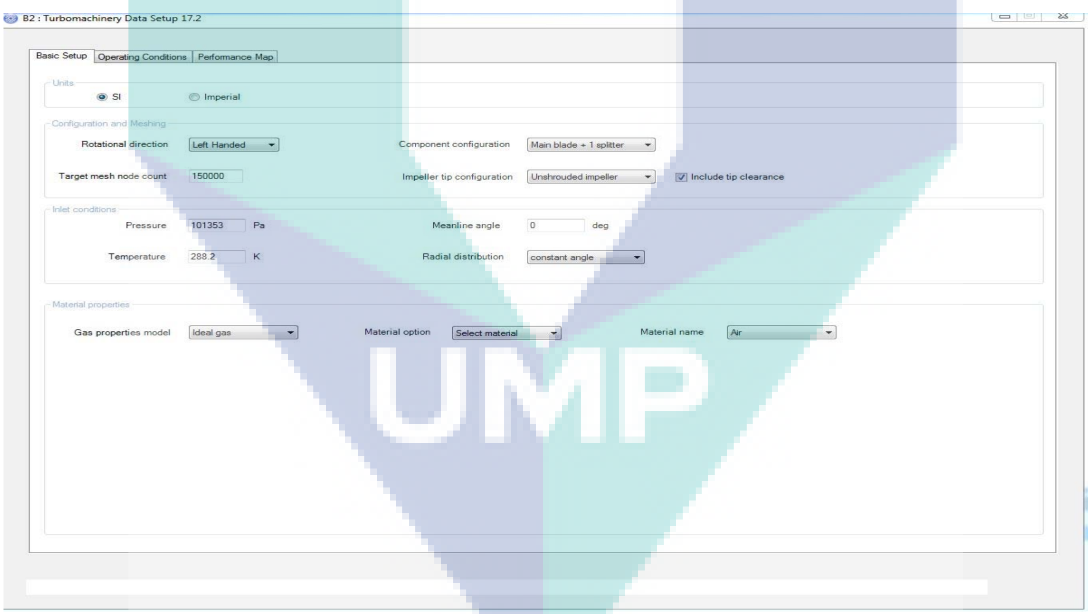


Figure 18

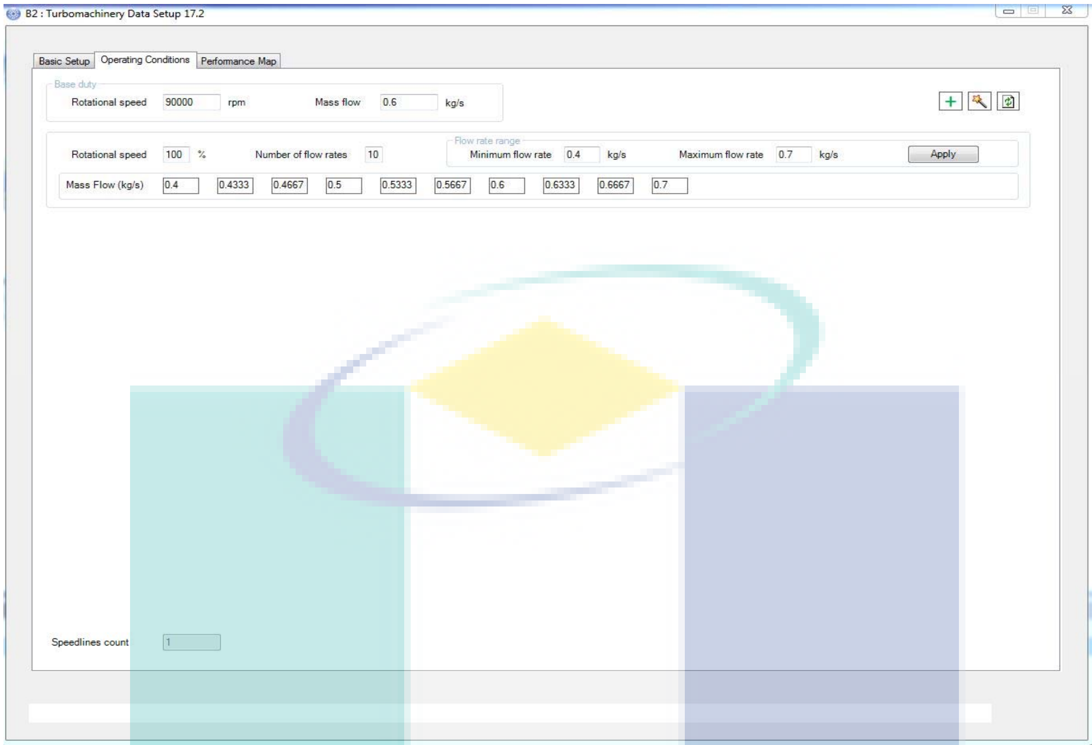

B2 : Turbomachinery Data Setup 17.2
Basic Setup
Operating Conditions
Performance Map
Base duty
Rotational speed
90000
rpm
Mass flow
0.6
kg/s
Rotational speed
100
%
Number of flow rates
10
Flow rate range
Minimum flow rate
0.4
kg/s
Maximum flow rate
0.7
kg/s
Apply
Mass Flow (kg/s)
0.4
0.4333
0.4667
0.5
0.5333
0.5667
0.6
0.6333
0.6667
0.7
Speedlines count
1

Figure 19

3.5 ANALYSIS TURBOMACHINERY FLUID FLOW

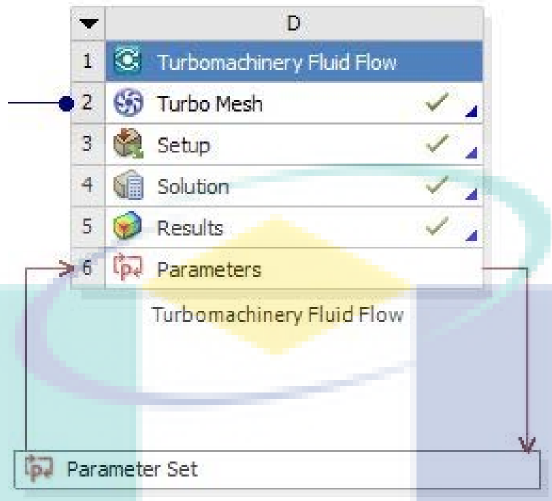


Figure 20

The turbo setup layout and then been connected to the last layout which is shows in the figure 20. This is where the generated 3D be analyze all of the duty, gas properties and geometry constraint been analyze one by one by calculating all of the parameter aspect. Firstly analyses the turbo mesh of the design point. The turbo mesh is where hexahedral mesh is produce to automatically predict the performance between designs. The Setup option is to setup CFD analysis or computational fluid dynamic in CFX which the software tool that are deliver reliable and accurate solution quick robustly across a wide range of CFD can be shows in figure 21. Then the CFD will use the exit corrected outlet condition to the design. After that run the simulation until finish. The result of the simulation due to the geometry condition can be review in CFD Post in figure 22. By setting up the working air flow inlet through the compressor which the ten value of mass flow rate which is 0.4 to 0.7 kg/m^3 the solution will obtain the sort of table that shows in figure 23. The table is sequence of operation point which is the duty of the air flowing through the compressor and will obtain the other data from the simulation. The data will obtain the value of pressure ratio and isentropic efficiency. From all of the data, the speed line will be defined. The performance maps that are allocated the mass flow rate of inlet compressor with pressure ratio or the isentropic efficiency by using the speed line. The figure 24 below shows the interface of the compressor performing maps.

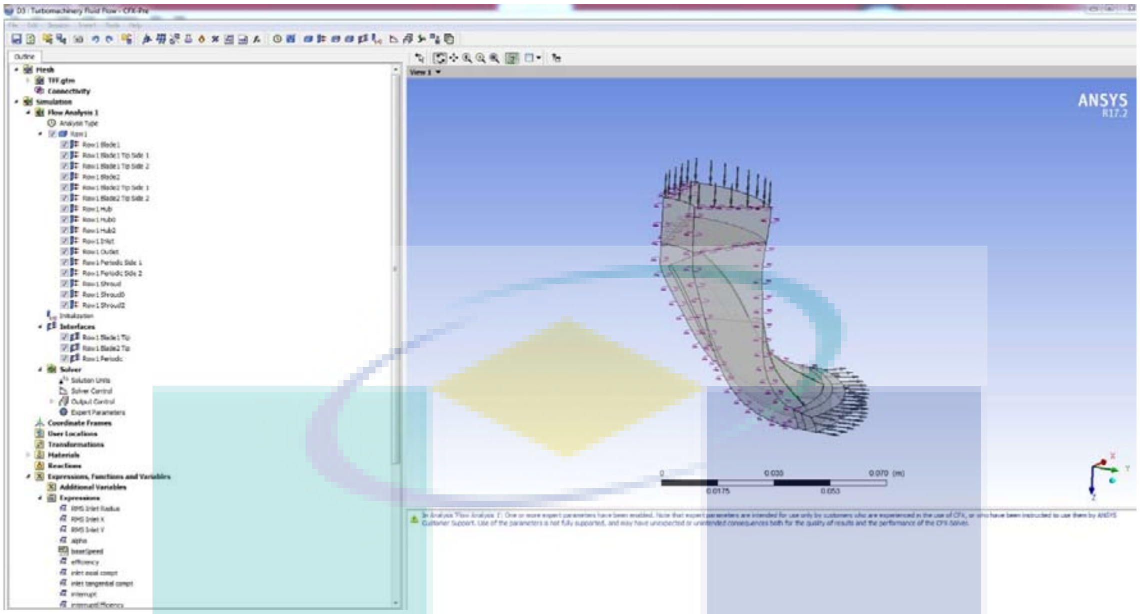


Figure 21

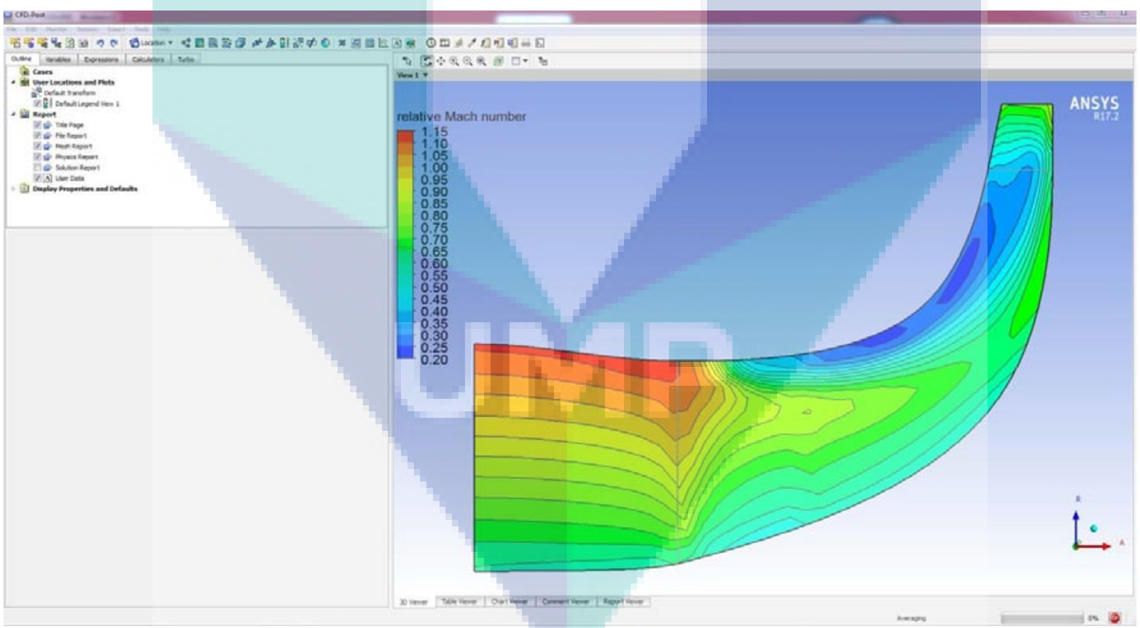


Figure 22

Table of Design Points

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	Name	Update Order	P1 - Max Iterations	P2 - Base Duty Speed	P3 - Mass Flow	P4 - Percent Speed	P5 - Max Iterations	P6 - baseSpeed	P7 - massflow	P8 - percentSpeed	P9 - Current Time Step	P10 - Isentropic Efficiency (t-t)	P11 - P0 Ratio (t-t)
2	Units			rev min^-1	kg s^-1			radian s^-1	kg s^-1				
3	DP 0 (Current)	1	200	90000	0.6	100	200	9424.8	0.6	100	116	85.916	5.1066
4	DP 1	2	200	90000	0.7	100	200	9424.8	0.7	100	141	84.651	4.5028
5	DP 2	3	200	90000	0.6667	100	200	9424.8	0.6667	100	58	86.113	4.8863
6	DP 3	4	200	90000	0.6333	100	200	9424.8	0.6333	100	55	86.31	5.0422
7	DP 4	5	200	90000	0.6	100	200	9424.8	0.6	100	82	85.906	5.0965
8	DP 5	6	200	90000	0.5667	100	200	9424.8	0.5667	100	80	85.105	5.1696
9	DP 6	7	200	90000	0.5333	100	200	9424.8	0.5333	100	80	83.956	5.219
10	DP 7	8	200	90000	0.5	100	200	9424.8	0.5	100	95	82.599	5.2236
11	DP 8	9	200	90000	0.4667	100	200	9424.8	0.4667	100	93	81.081	5.1141
12	DP 9	10	200	90000	0.4333	100	200	9424.8	0.4333	100	103	79.603	4.9608
13	DP 10	11	200	90000	0.4	100	200	9424.8	0.4	100	129	78.207	4.9011
*													

Figure 23

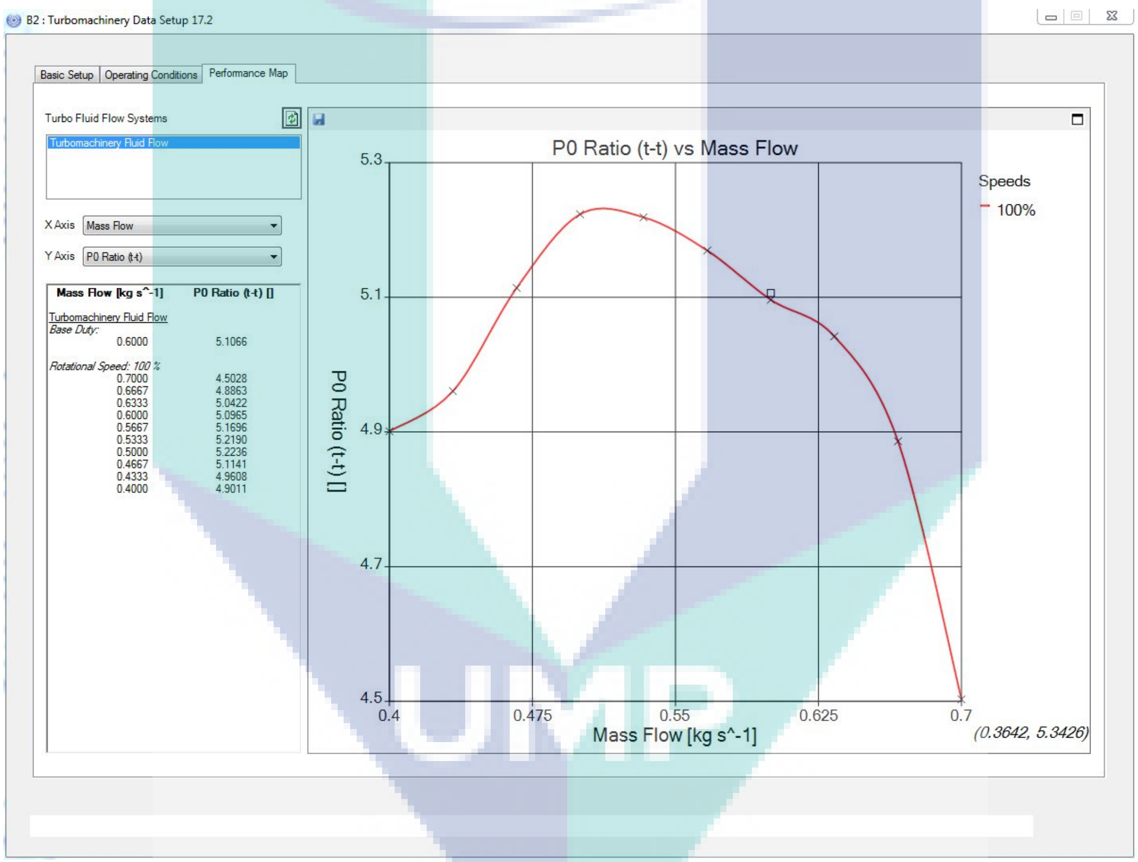
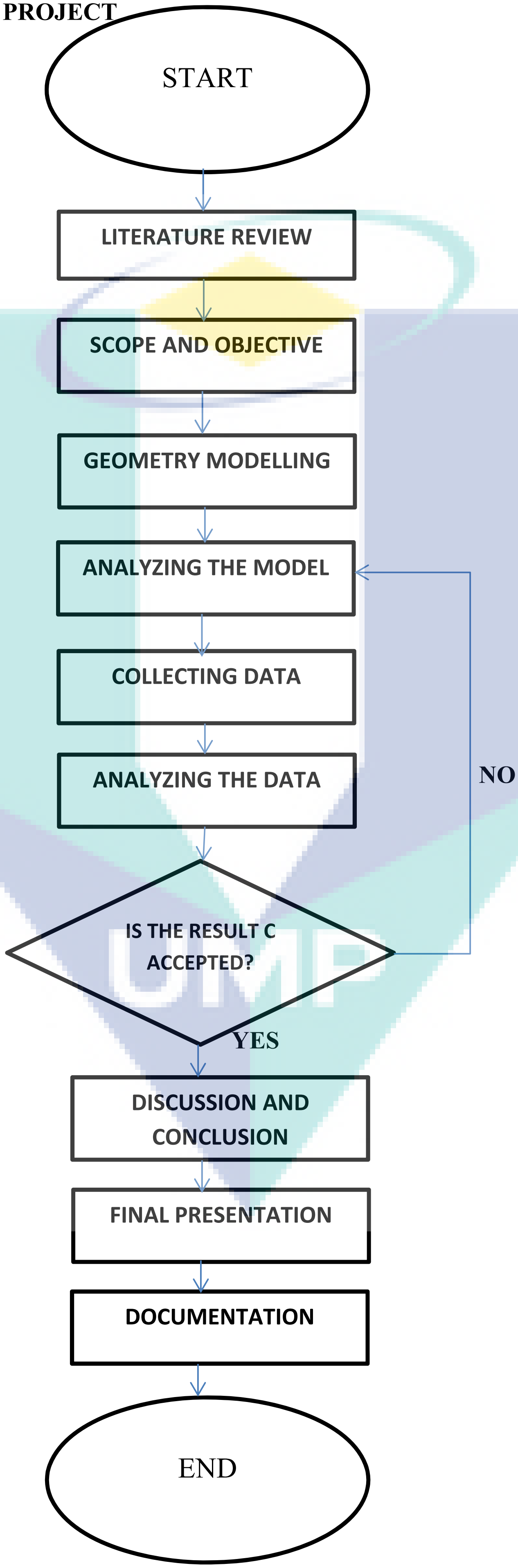


Figure 24

3.1 FLOW CHART PROJECT



CHAPTER 4

RESULT AND DISCUSSION

4.0 CHAPTER OVERVIEW

This chapter provides the analysis result of the turbocharger. The analyze result obtain by collected value of fixed and manipulated parameter and analyze the result.

4.1 3 DIMENSIONAL DESIGN OF THE COMPRESSOR.

After all of the parameter have been setup which is the by fixed all others parameter and manipulated the blade outlet vane angle the analysis have been conduct. There are five value of the vane inlet angle have been analyze which is the 50 degree to 70 degree. Every design that have different

All figures below shows the design of the blade with selected angle of the outlet vane angle.

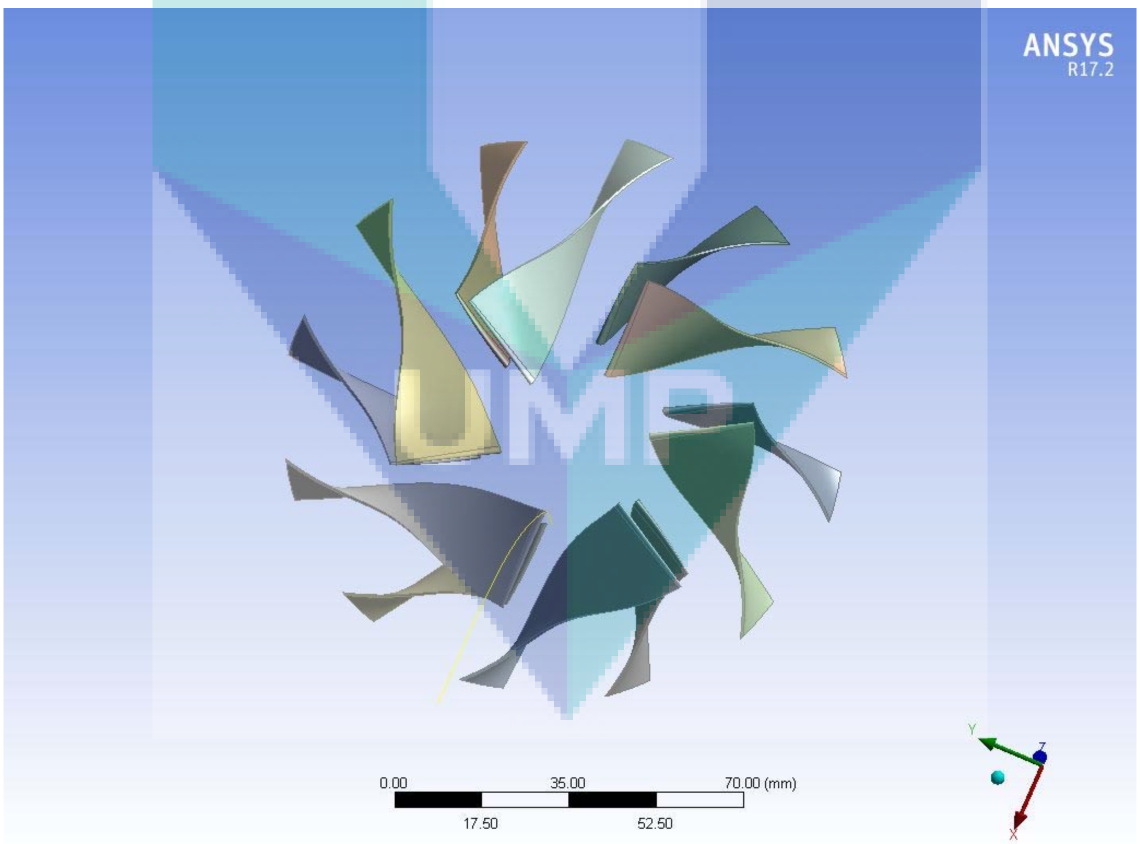


Figure 25

Figure 25 above show the design of compressor blade with 50 degree of vane outlet angle.

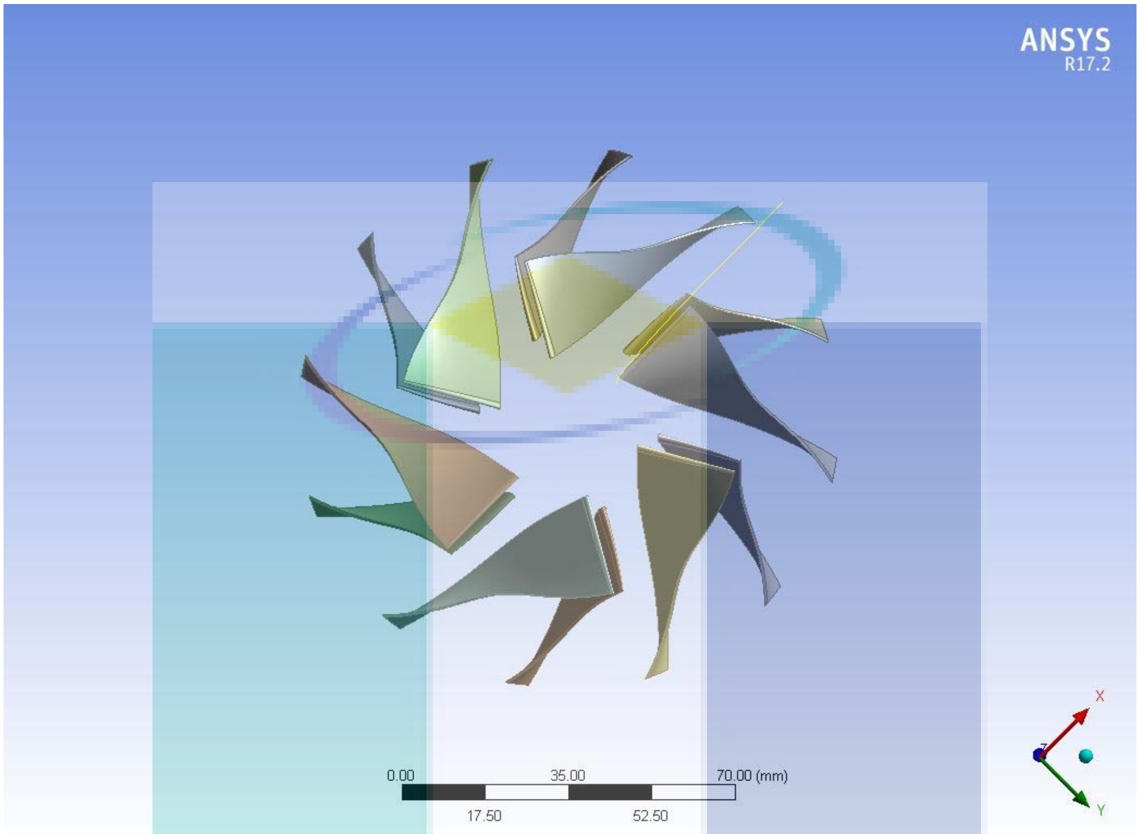


Figure 26

Figure 26 above show the design of compressor blade with 55 degree of vane outlet angle.

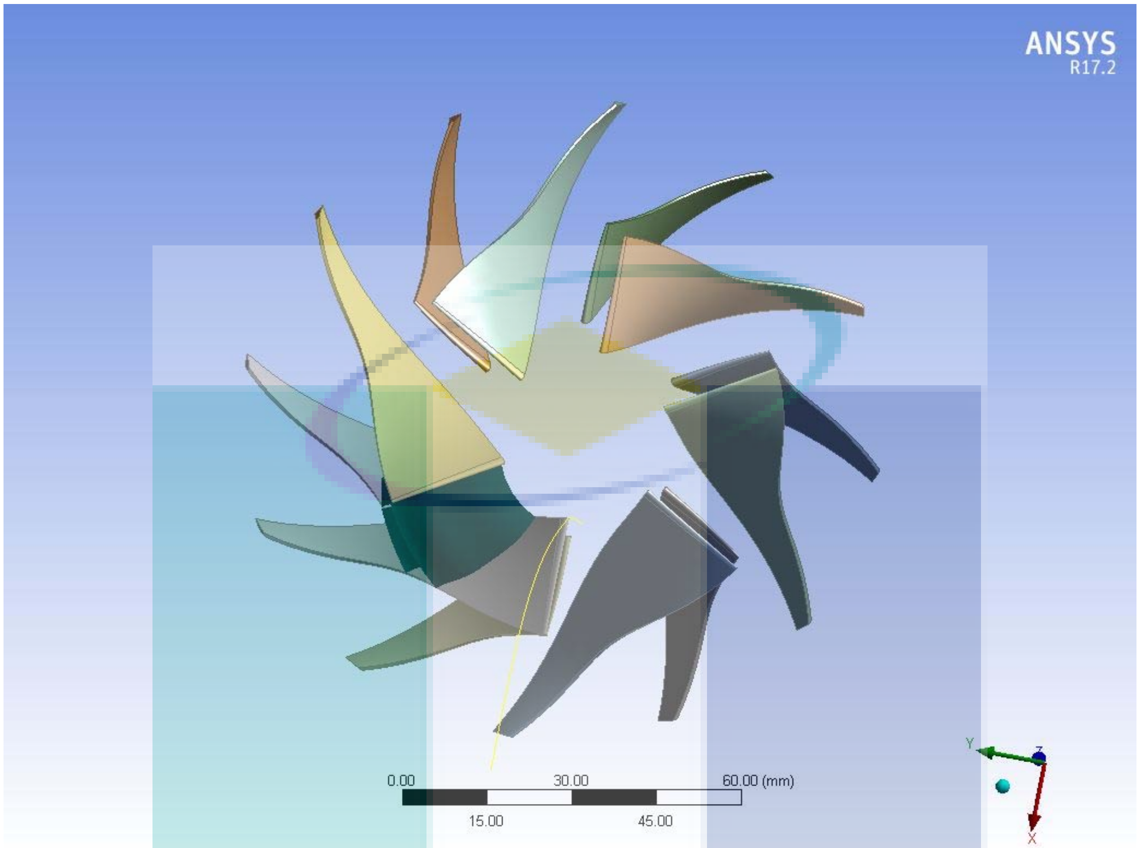


Figure 27

Figure 27 above show the design of compressor blade with 60 degree of vane outlet angle.

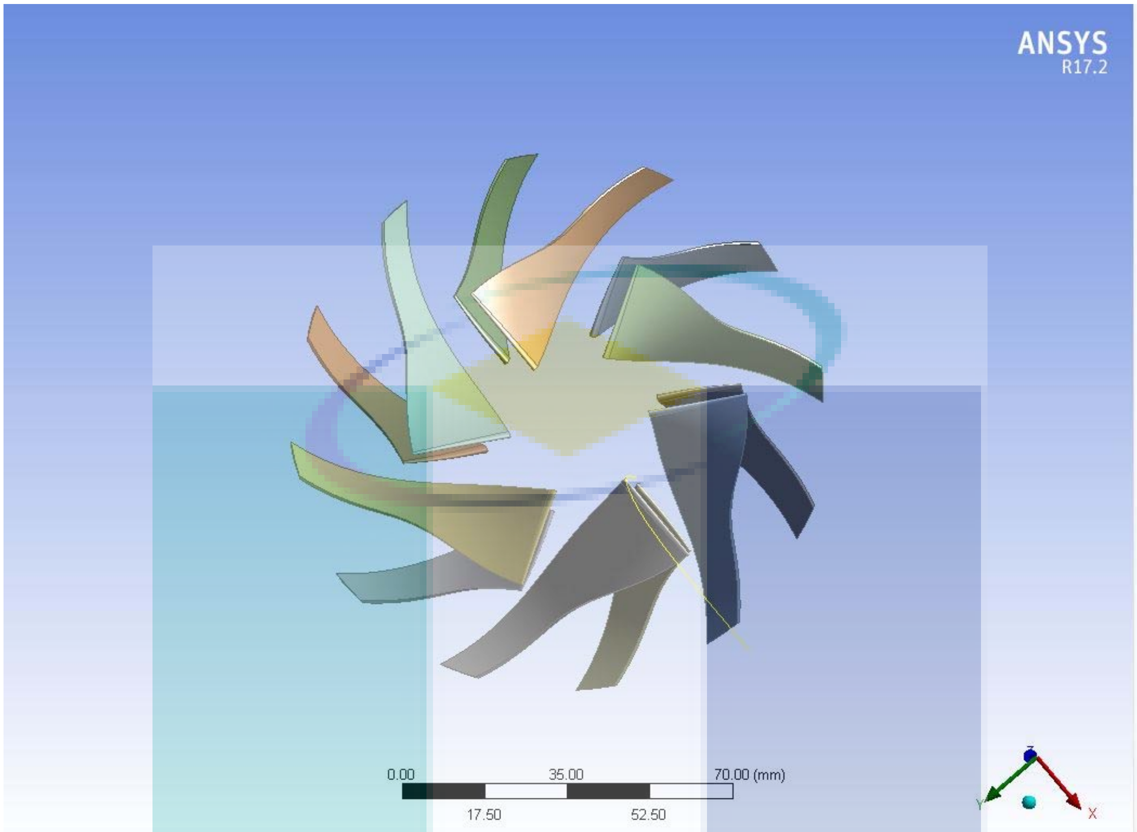


Figure 28

Figure 28 above show the design of compressor blade with 65 degree of vane outlet angle.

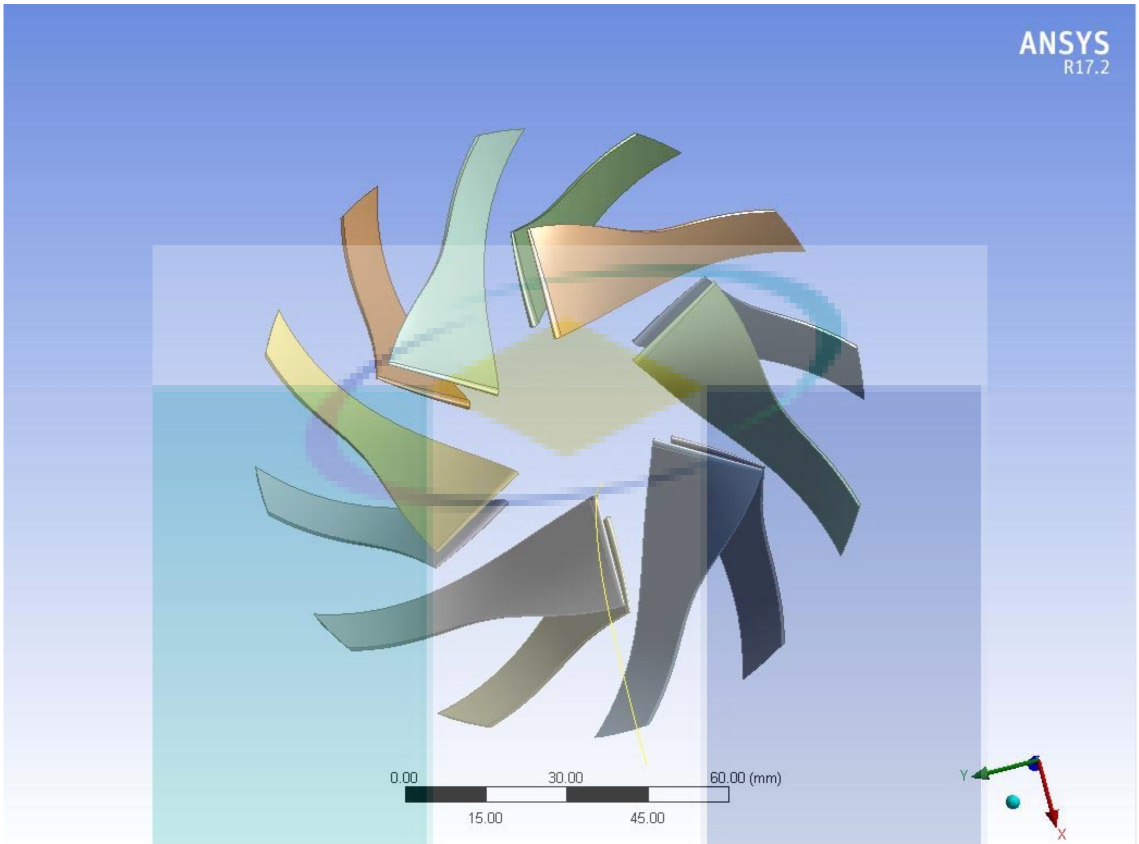


Figure 29

Figure 29 above show the design of compressor blade with 70 degree of vane outlet angle.

4.2 ANALYSIS DATA OF THE DESIGNED COMPRESSOR.

The data obtain from the analysis is from the given mass flow rate for the inlet vane of the compressor. There are 10 value of the mass flow rate is flowing through the vane inlet of the compressor blade. From the given flow rate the data of the pressure ratio will obtain. The table below shows the results obtain for the different blade vane outlet angle.

MASS FLOW RATE (kg/s)	(lbs/min)	VANE OUTLET ANGLE 50^{o}	55^{o}	60^{o}	65^{o}	70^{o}
0.7000	92.59415	4.50283	4.49622	4.43753	4.22576	4.16286
0.6667	88.18931	4.88628	4.88879	4.83523	4.63717	4.57328
0.6333	83.77125	5.04217	5.08339	5.05292	4.84994	4.78192
0.6000	79.36641	5.09650	5.1627	5.15222	4.95197	4.87735
0.5667	74.96158	5.16957	5.20046	5.1829	4.98183	4.8993
0.5333	70.54351	5.21901	5.196	5.12879	4.91783	4.83447
0.5000	66.13868	5.22355	5.13435	4.99749	4.81809	4.72894
0.4667	61.73384	5.11405	4.97639	4.91576	4.70863	4.61343

By connecting every inlet mass flow rate with the obtain value by analysis of pressure ratio will create a speed line. The speed line will shows how much pressure ratio that the compressor will produce every given mass flow rate flowing through the compressor. The figures 33 until 33 below shows that speed line produce for every angle of the vane outlet angle. The figure 35 shows the comparison of each speed line.

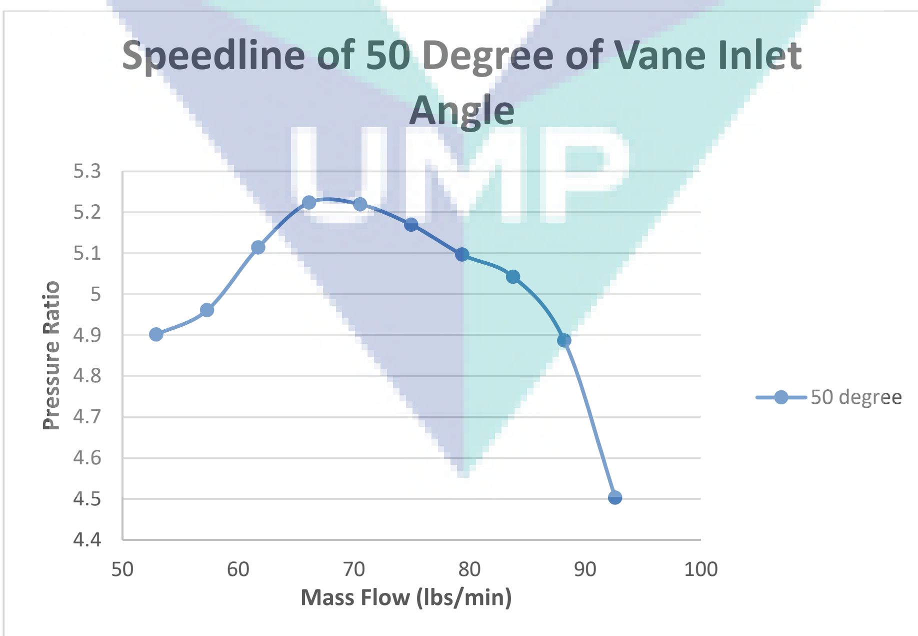


Figure 30

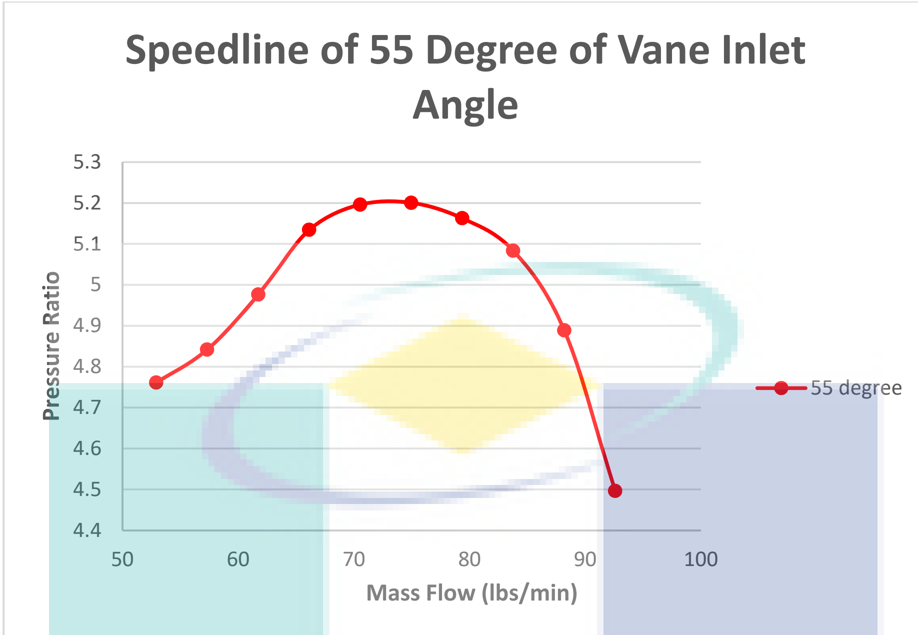


Figure 31

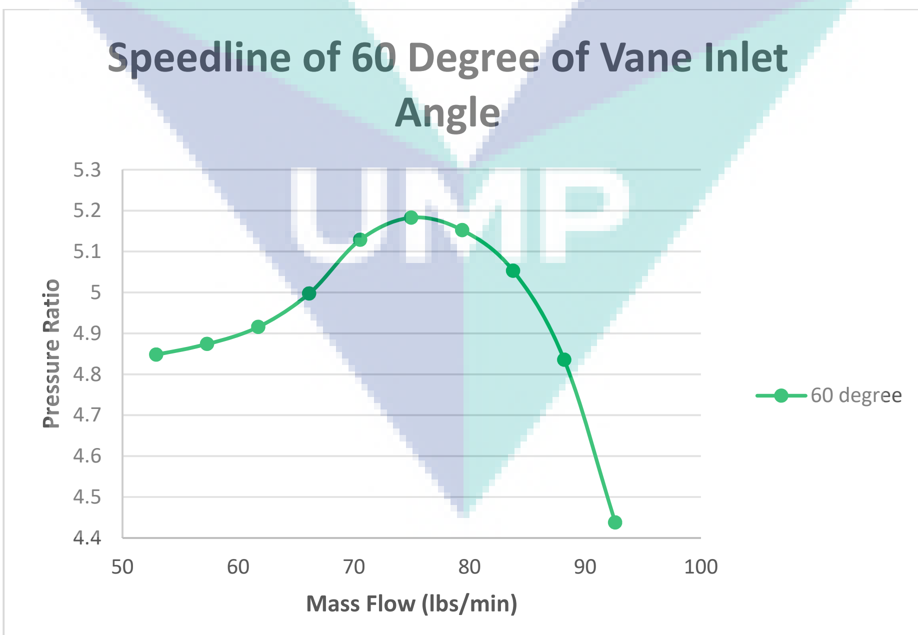


Figure 32

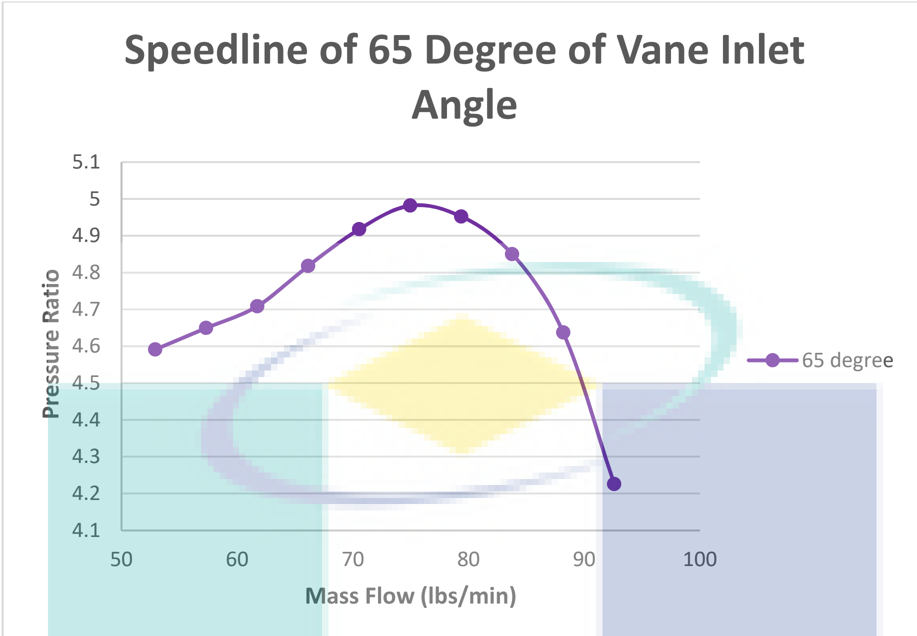


Figure 33

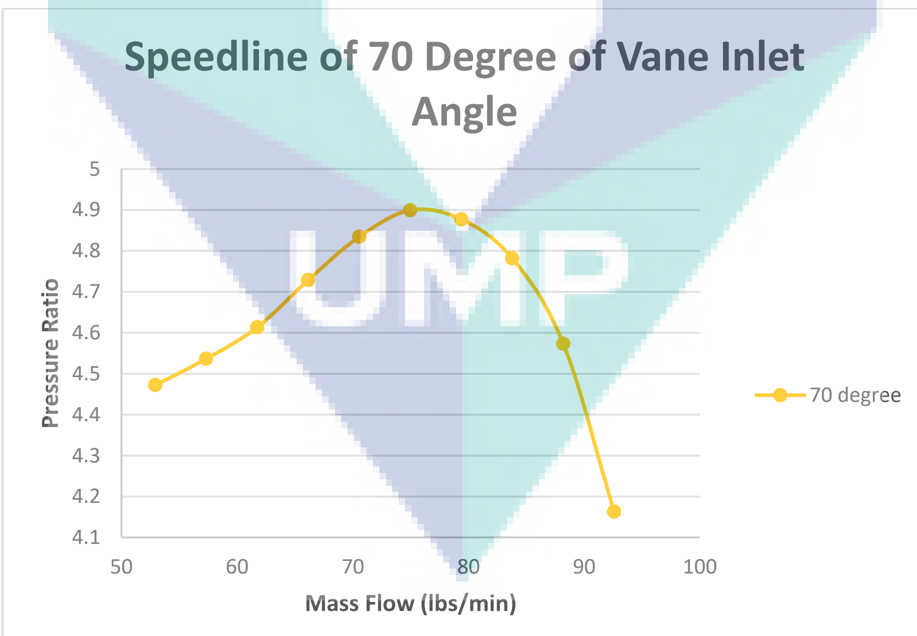


Figure 34

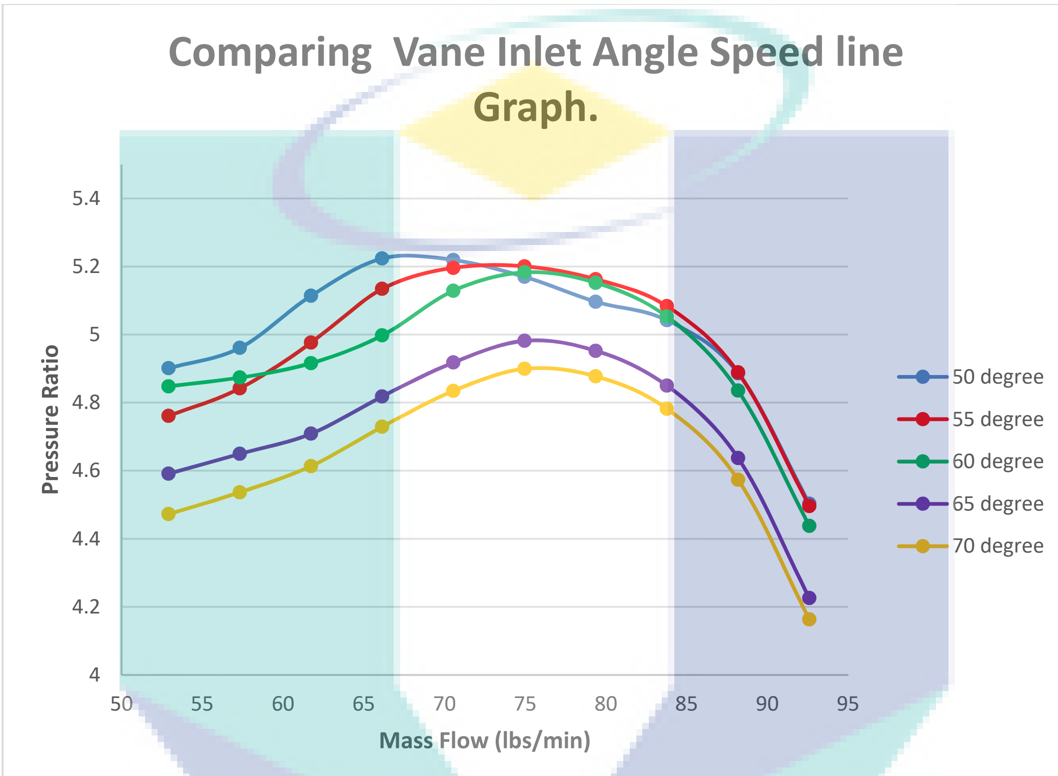


Figure 35

4.3 DISCUSSION

To analyze each of the blade angle of then vane outlet angle it cause almost one of half day to finish. It was difficult to select the parameter into specific value to be fixed and manipulated the vane outlet angle because sometimes it will obtain error result. Therefore it will need to start over again with different value of the fixed parameter. Besides that, that the Ansys Turbomachinery only can generate the turbocharger compressor or turbine with initial value by the user not the actual value desired. This is because the calculation or solution provide by the Ansys Turbomachinery will generate the most closed value to the desired. Besides that, it is possible to the user to replicate the compressor design with the compressor that have in the market. This is because the user need to know the every detail value of the turbocharger compressor geometry design. This will be possible if the user can get all of the detail from the company that manufacture the turbocharger compressor. The Ansys turbomachinery can be used to obtain the specific target of performance of the compressor but sometime it not fit to the desired design. Furthermore if the turbocharger geometry is impossible to be generate it will highly to obtain error in generate and the solution flow.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.0 CHAPTER OVERVIEW

This chapter describe the overall conclusion of the analysis result obtained for this project. Furthermore, it also provide the recommendation that can be made to improve the project result and studies.

5.1 CONCLUSION

Based on the project title which is the 3D modelling and analysis blade with different vane outlet angle of the turbocharger compressor needs review on the compressor maps. The compressor maps helps to identify the specified mass flow rate will produce the efficient compressor.

This project start with defining the problem statement which is to increase efficiency of the turbocharger. The compressor have own efficiency and performances that will affect the turbocharger performances. Therefore by manipulating the blade geometry will affect the turbocharger efficiency. The objective of the project have been selected which to design a blade model with different of vane outlet angle using the Blade Modeler and conducting flow analysis using Vista CCD or Vista centrifugal compressor design. By using the analysis data plot a speed line graph that will obtain different value of pressure ratio. Based on the result shows that the 55 degree angle of the vane outlet angle showing the most stable speed line between others.

5.2 RECOMMENDATION

To make sure the project can be use into further research, improvement should be implement improvement and awareness. Firstly for the ANSYS Turbomachinery features the software should be in full licenses to analyze the compressor. The Ansys provide the student features same goes to the Faculty of Mechanical University of Malaysia Pahang computer lab but it cannot be used for the analysis purpose because it requires full licenses. Therefore I decide to download the Ansys with full licenses for the research purpose. Moreover, it also need aware that the ANSYS Turbomachinery only provide the design with nearest to the initial design point only. It cannot be used to design with actual desired parameter given. Therefore, if the user manage to replicate the design that have in the market, they need to know every exact detail of the turbocharger geometry that only can be obtain from the company manufacture the compressor wheel.