

Design and Analysis of Run-of-River Water Turbine

By

Muhammad Afif bin Ilham

Dissertation submitted in partial fulfilment of the requirements for the

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SEPTEMBER 2011

Universiti Teknologi PETRONAS

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CERTIFICATION OF APPROVAL

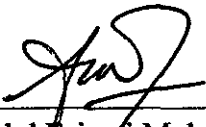
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A project dissertation submitted to the
Mechanical Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfillment of the requirement for the
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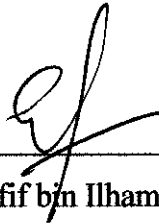
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CERTIFICATION OF ORIGINALITY

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Muhammad Afif bin Ilham

ABSTRACT

This paper discussed on the project entitled, “Design and analysis of run-of-river water turbine”. It consists of project background, objectives, problem statements, and the relevance of the project, literature reviews, and the methodology which is the flow of the project and finally the result and discussion before the conclusion. In this project the author design a run of river water turbine and analyze the power that can be generated by the turbine.

The study is about gathering all possible information about river water turbine for further studies which will lead to the result of the design of the water turbine and the power generated by the turbine. The main objective of this project is merely to prove that the author’s design of the vertical axis run of river water turbine can generate power in form of electric. Water turbines can be classified depending on the direction of rotational axis relative to water flow direction. Axial flow water turbines have their axis of rotation parallel to water stream direction. Other turbines such as cross flow water turbines or Darrieus type water turbines (from Jean-Marie Darrieus, inventor of first vertical axis wind turbine, have rotational axis perpendicular to current direction. A vertical-axis turbine is able to extract power from any direction without adjustment.

At the end of this research, the conclusion that can be obtained is the run-of river water turbine can generate power. In order to provide such conclusion, the data that need to be considered are the river water velocity, the cross sectional area of the augmentation channeling, and the height of the augmentation channel that would be immersed in the water.

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CHAPTER 1

INRODUCTION

1.1 Background of Study

The power from running river has been interest for electricity production for many years. This project will focus on small scale river current turbine with the output of 0.5-5 kW. This turbine is to be used for domestic electricity application such as lighting and battery charging in rural area that uses electricity for basic application.

Water current turbine generates power from the river current kinetic energy without using a dam. This type of turbine is low in cost and continuously supply electrical energy is the advantage compared to solar power.

There are many river exist in Malaysia especially in the East – Malaysia. There are 12 rivers in Sarawak and 9 rivers in Sabah. This is the source of power that can be used to supply the needed electricity to small communities and villages.

1.2 Problem Statement

1.2.1 Problem identification

Hydroelectric energy is being used widely in generating electricity now days. However, it is done is large scale using dams to produce megawatts of electricity in order to cater for the current energy demand all around the country. Is there any possibility to extract this kind of energy in a small scale? Is energy can be extract from flowing water streams? This is the questions that will be answered through this project.

1.2.2 Significant of the project

By referring to the problem identification, this project is to study about the small scale run-of-river water turbine in terms of its design to generate power output from flowing river stream. Thus, the author need to come out with a design and also analyzed the design using Computational Fluid Dynamic (CFD) software as well as with anticipated power calculations before fabrication and testing.

1.3 Objective

1. To design the small scale vertical axis run-of river water turbine.
2. Analyze the power output generated from the turbine that been designed.

1.4 Scope of study

The scope of study is mainly focusing on the design of the turbine for generate electricity from the kinetic energy from flowing river. The velocity of the river will be determining the power that can be generated. The power available from the river can be worked out using the following formula. $P_a = \frac{1}{2} \times C_p \times \rho \times A \times v^3$. The power will increased in a cubed relationship to the velocity of the flow of water past turbine.

This project will be divided into two stages; the first stage will involves on researching and study thoroughly about run-of river water turbine. Then with the help and assist from supervisor, the most suitable design will be used for fabrication. It takes into consideration the concepts of the turbine and the buoyancy of the turbine.

The second stage will focus on the fabrication of the turbine and the analysis of the turbine. The fabrication will be performed in the lab and the analysis will be performed at the river itself. The efficiency of the turbine will be monitored.

1.5 The relevancy of the project

Water current turbine has received an increasing interest in many part of the world. The small scale hydropower is considered environmentally friendly, meaning that the water that passing through the turbine is going back to the stream with small impact on surrounding. Small scale current turbine is a solution for power supply in rural area because of the low cost and maintenance fees.

1.6 Feasibility of the project

This project will need an experiment in order to complete it. In the time given, the project could be done within time given provided that everything goes according to the plan. The objective can be achieved if the procedures are closely followed.

CHAPTER 2

LITERATURE REVIEW

2.1 Flowing River

Usage of river current kinetic energy is an alternative approach to hydro power where there is no head. The kinetic energy usually converted electricity form or directly power a mechanical water pump for irrigation.

The power that can be extracted from the river current can be determine using the following formula.

$$. Pa = \frac{1}{2} \times C_p \times \rho \times A v^3 [1]$$

A = area in meters squared (m^2)

ρ = density of water (kg / m^3)

V = velocity of water (m/s)

C_p = the power coefficient

The significant of this equation is that the power increase in cubed with increase in velocity of the flowing water. It is best to find the best spot to get the maximum power output.

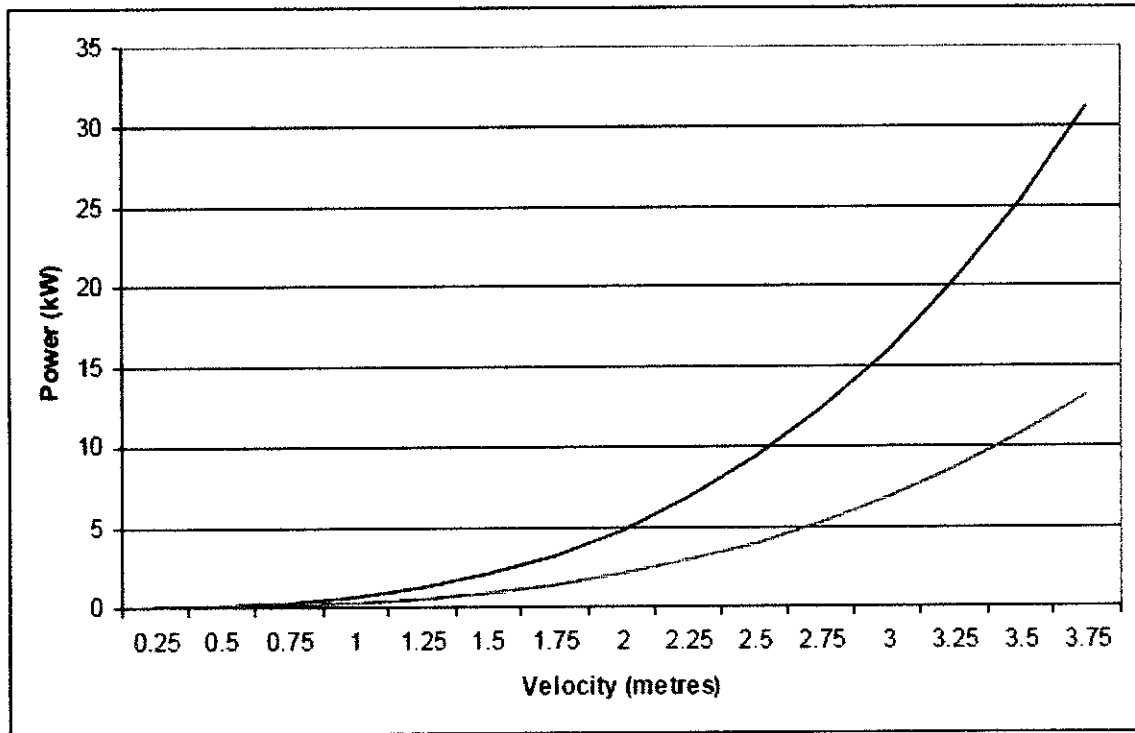


Figure 1: Relationship between speed of river and power available. [1]

Legend:

- Power in the river
- Power extracted by turbine

2.2 Run – of river water turbine

Water turbine is a rotary engine that takes energy from moving water.[2] Run – of river water turbine is a turbine that takes energy from flowing stream river. Water current turbine can be placed mainly in two areas that can be used for power generation purpose which are tidal current and river stream. Water current turbine can be installed in any flow with a velocity greater than 0.5m/s. [3]

2.3 Vertical axis run – of river water turbine

Throughout the years, several hydrokinetic conversion concepts have been developed. There are two common small scale hydrokinetic turbine concepts which are the axial flow turbine or horizontal turbine and cross-flow turbine. The vertical axis turbine is in the cross flow turbine family. This type of turbine has an axis vertical to the water plane. There are various design in the vertical axis water turbine such as H- Darrieus, Darrieus, Gorlov, and Savonius turbine. The advantage of this type of turbine is they can rotate unidirectional even with bi-directional fluid flow.

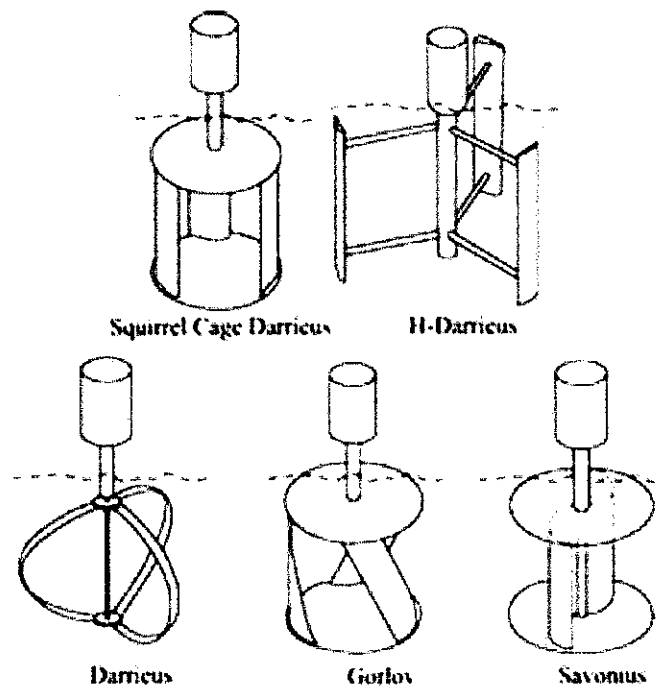


Figure 2: Vertical axis turbines [3]

Table 1: Comparison between horizontal and vertical turbine. [4]

<u>Factor</u>	<u>Vertical axis</u>	<u>Horizontal axis</u>
Design symmetry	Symmetric	Asymmetric
Durability	Higher	Lower
Efficiency	Claimed higher	Lower
Water sealing	Less need	Required
Fish passage	Wider	Constrained
Alignment/Yaw	No need	Required
Direction of rotation	Unidirectional	Bidirectional
Availability of literature	Significant	Scarce

2.4 Fluent Software

The modeling capabilities of FLUENT have been applied to industrial applications in the range of air flow over an aircraft wing to combustion in furnace, bubble columns to glass production, water flow to semiconductor manufacturing and clean room to wastewater treatment plant. Main advantage of FLUENT is it allows reproducing physical unsteady flow around turbine using sliding mesh methodology.

2.5 Material Selection

An incorrectly chosen material can affect not only to failure of the part also to unnecessary life-cycle cost. Also, the properties of the material can be enhanced or diminished by processing and that may affect the service performances of the part. There are enormous amount of materials available to be chosen from and the selection can only be done by simplification and systemization. At the concept level of design, essentially all materials and processes are considered rather broadly. One of the ways to select whether each design concepts will be made from metal, plastics, ceramic, composite, or wood and narrow it down into a group material is by referring to the Ashby charts in Figure 2.4. The material selection methodology and charts developed by Ashby are highly appropriate at this stage. [8]

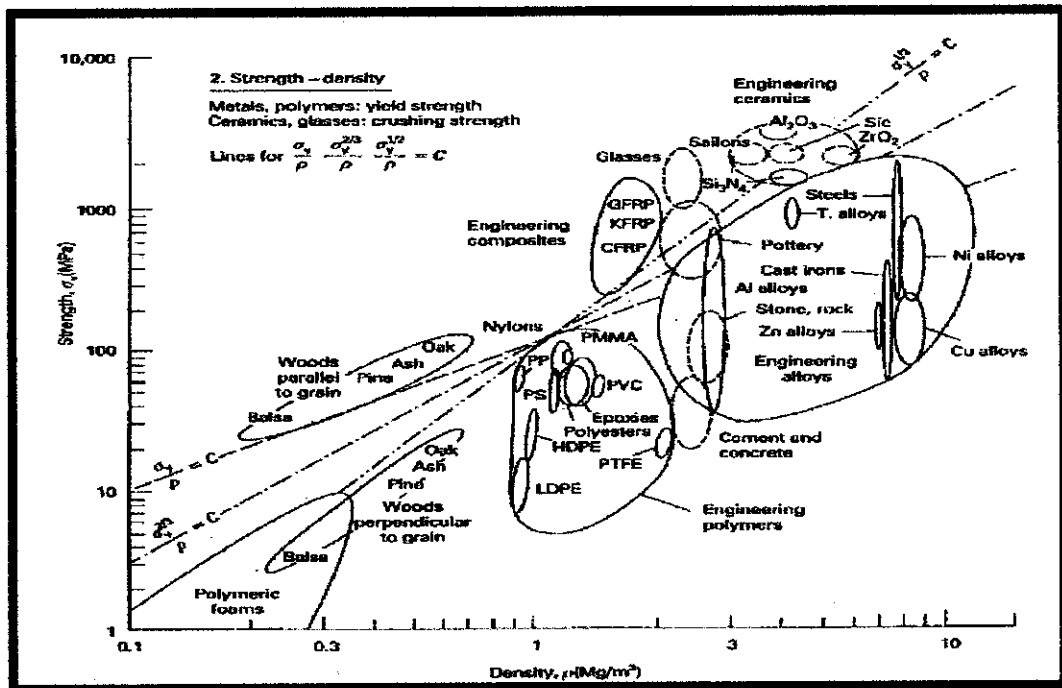


Figure 3: Ashby material selection chart: strength vs. density [8]

The figure above plots the strength against density for a variety of materials. Depending on the geometry and type of loading, different $\sigma - \rho$ relationship applies as shown as shown in the Table 2.2.

Table 2: Performance indices [8]

Design objective: minimum weight for different shapes and loadings	To maximize strength	To maximize stiffness
<i>Bar in tension:</i> load, stiffness, length are fixed; section area is variable	σ_f/ρ	E/ρ
<i>Torsion bar:</i> torque, stiffness, length are fixed; section area is variable	$\sigma_f^{2/3}/\rho$	$G^{1/2}/\rho$
<i>Beam in bending:</i> loaded with external forces or self-weight; stiffness, length fixed; section area free	$\sigma_f^{2/3}/\rho$	$E^{1/2}/\rho$
<i>Plate in bending:</i> loaded by external forces or self-weight; stiffness, length, width fixed; thickness free	$\sigma_f^{1/2}/\rho$	$E^{1/3}/\rho$
<i>Cylindrical vessel with internal pressure:</i> elastic distortion, pressure, and radius fixed; wall thickness free	σ_f/ρ	E/ρ
Other design objectives, as stated below	Maximize	
<i>Thermal insulation:</i> minimize heat flux at steady state; thickness given	$1/\kappa$	
<i>Thermal insulation:</i> minimum temperature after specified time; thickness given	$C_p\rho/\kappa$	
<i>Minimize thermal distortion</i>	κ/α	
<i>Maximize thermal shock resistance</i>	$\sigma_f/E\alpha$	

σ_f = failure strength (yield or fracture stress as appropriate to problem); E = Young's modulus; G = shear modulus; ρ = density; C_p = specific heat capacity; α = thermal expansion coefficient; κ = thermal conductivity.

CHAPTER 3

METHODOLOGY

3.1 Research Methodology

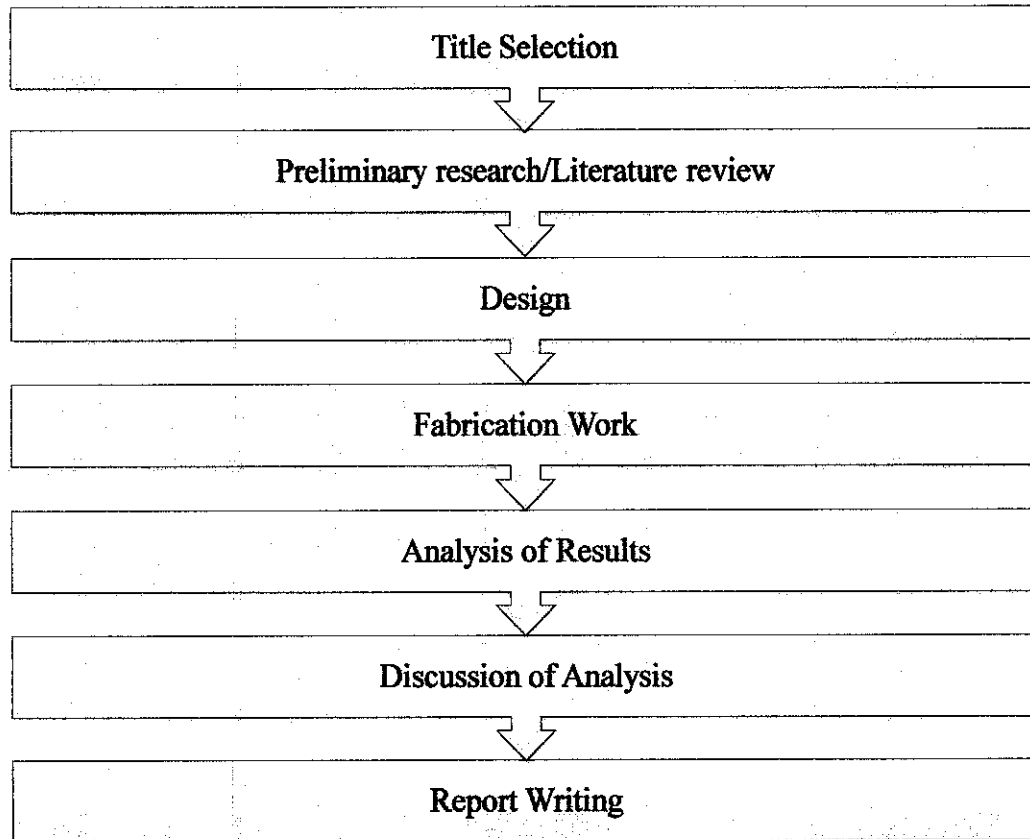


Figure 4: Flow chart of the research methodology

Title Selection: after discuss with the supervisor, It is decided to design the small vertical axis water turbine.

Preliminary research/Literature review: Before proceed with the project, I need to cover all the basic understanding about rive power, water turbine, the possible output, and others related to project

Design: There are several aspects that have to be designed, such as

1. Vertical axis water turbine
2. Floating device

Analysis of result: Analysis been made on this parameter:

1. Power output in form of electricity (kW)

3.2 Project Activities

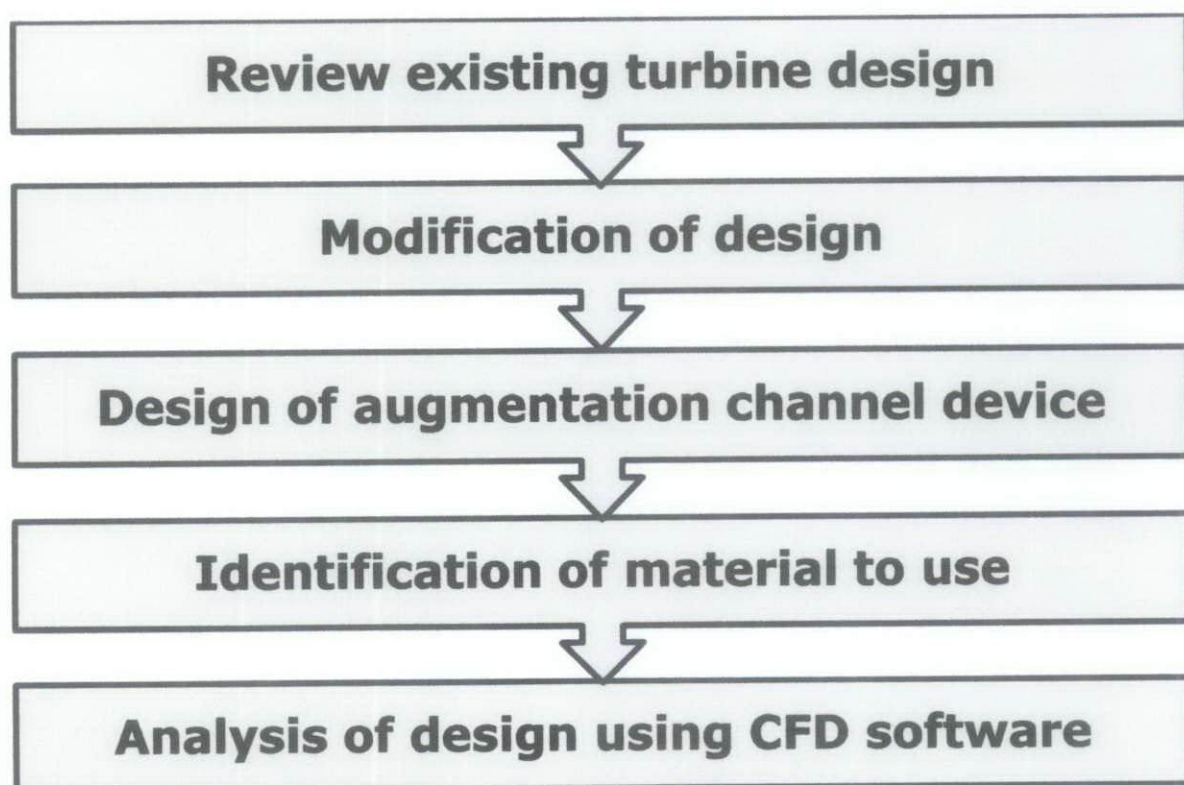


Figure 5: Flow chart of the project activities.

3.2.1 Review Existing Turbine Design.

The vertical axis turbine is in the cross flow turbine family. This type of turbine has an axis vertical to the water plane. There are various designs in the vertical axis water turbine such as H- Darrieus, Darrieus, Gorlov, and Savonius turbine.



Figure 6: Gorlov Helical Turbine



Figure 7: Pelton Turbine



Figure 8: Turgo Turbine

3.2.2 Modification of Design

In this project I had chosen Banki turbine as blade design. The Banki turbine is an atmospheric radial flow wheel which derives its power from the kinetic energy of the river flow. The Banki turbine consists of two parts, a nozzle and a turbine runner. The runner is built up of two parallel circular disk joined together at the rim with a series of curved blades. Its blades are modified to be curved and the quantity is also doubled to be 16 instead of 8 blades. The turbine will be placed vertically to the water plane like the vertical water wheel.

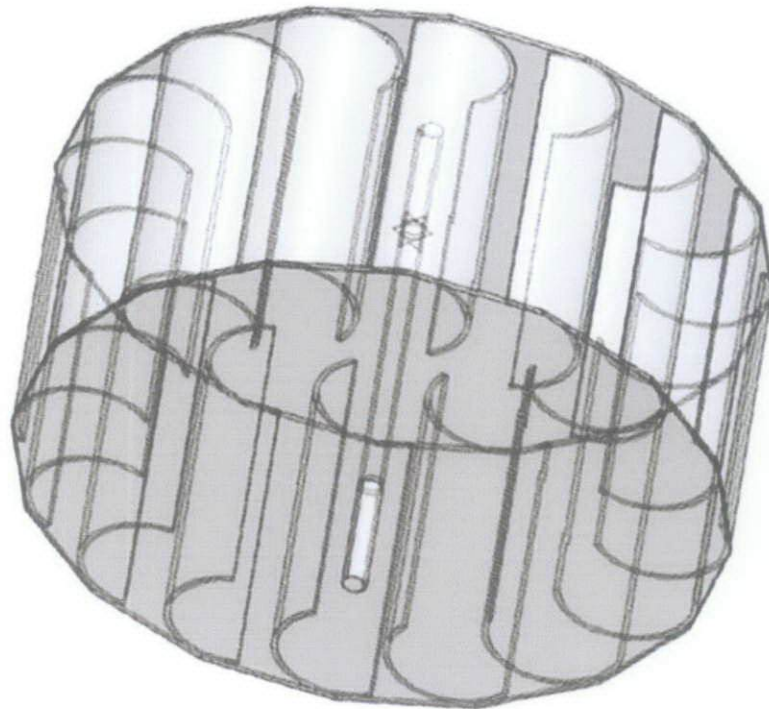


Figure 9: Design of Water Wheel

3.2.3 Design of Augmentation Channel

The Banki turbine consists of two parts, a nozzle and a turbine runner. However, as we are doing a run of river application with zero head of water, we replace the nozzle with an augmented venturi to increase the flow rate of the river at the inlet of the turbine. In this project, a hybrid type (venturi ducting) of augmentation channel will be designed. This venturi ducting will act as a base where the turbine will be placed in between and at the center of the channel. Below is the dimension of the venturi ducting.

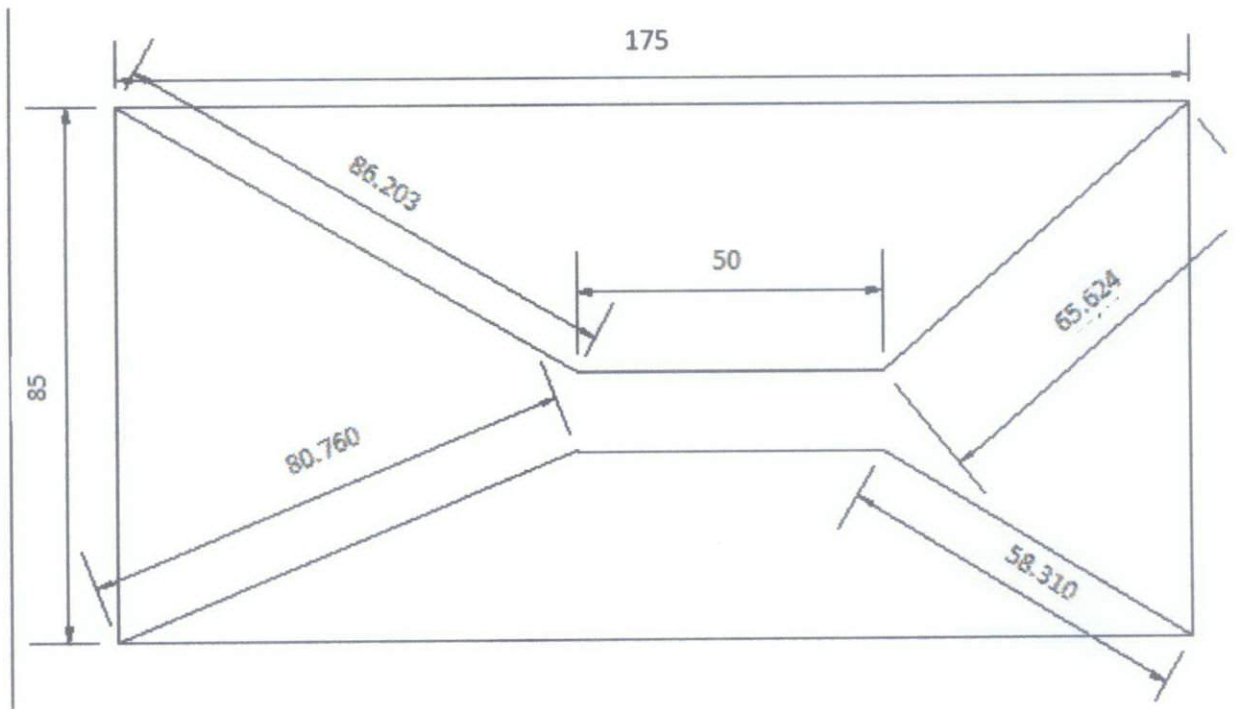


Figure 10: Design of Augmentation Channeling

3.2.4 Material Selection

The run of river turbine is divided into three main parts which are the turbine runner and venturi ducting. The ducting is designed so that it can float on the water surface with half of the runner is submerged in the water.

Table 3: Available Material

Part	Option 1	Option 2	Option 3
Turbine Runner	<p><u>Aluminum</u></p> <ul style="list-style-type: none"> • Strong in tension & compression • Corrosion Resistance • Low density • Heavier • Cost: moderate 	<p><u>Steel</u></p> <ul style="list-style-type: none"> • Highest strength to weight ratio • Not retain moisture • High density • Heaviest • Susceptible to corrosion • Cost: less expensive 	<p><u>Stainless steel</u></p> <ul style="list-style-type: none"> • Impact resistance • Strength-to-weight • Corrosion resistance • Cost: expensive
Venturi (Casing)	<p><u>Aluminum</u></p> <ul style="list-style-type: none"> • Strong in tension & compression • Corrosion Resistance • Low density • Heavier • Cost: expensive 	<p><u>Steel</u></p> <ul style="list-style-type: none"> • Highest strength to weight ratio • Not retain moisture • High density • Heaviest • Susceptible to corrosion • Cost: less expensive 	<p><u>Stainless steel</u></p> <ul style="list-style-type: none"> • Impact resistance • Strength-to-weight • Cost: expensive
Venturi (inside)	<p><u>Rubber</u></p> <ul style="list-style-type: none"> • Good in hardness • High friction • Not widely use • Cost: moderate 	<p><u>Plastic</u></p> <ul style="list-style-type: none"> • Tough & durable • Light weight • Economical • Cost: moderate 	<p><u>Polystyrene</u></p> <ul style="list-style-type: none"> • Light-weight • Low density • Less force transfer • Cost: less expensive

The table below shows the material selected for this project.

Table 4: Material Chosen

Part	Material
Turbine Runner	<p><u>Aluminium</u></p> <ul style="list-style-type: none"> • Strong in tension & compression • Corrosion Resistance • Low density • Heavier • Cost: moderate
Venturi (Casing)	<p><u>Aluminium</u></p> <ul style="list-style-type: none"> • Strong in tension & compression • Corrosion Resistance • Low density • Heavier • Cost: expensive
Venturi (inside)	<p><u>Polystyrene</u></p> <ul style="list-style-type: none"> • Lightweight • Low density • Less force transfer • Cost: less expensive

3.2.5 Analysis Using CFD Software

Computational Fluid Dynamic (CFD) analyses using fluent software on the prototype of the Run-of-River Water Turbine done with the boundary conditions as per below:

- a) Velocity inlet is 1m/s
- b) The depth of the river is 500mm
- c) The pontoon is immersed in the water with the depth of 250mm
- d) The river is assumed to be 8500mm x 17500mm

3.3 Gant Chart

Table 5: Gant Chart

Activity	FYP1				FYP2			
	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DIS
Early stage documentation								
Research literature review related to run-of river water turbine								
Studies on related theories to apply								
Design								
Analysis of result								
Final stage documentation								

3. 4 Key Milestones

Table 6: Key milestone

Key Milestones	FYP1				FYP2			
	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DIS
Completion of fabrication								
Analysis of result								
Project Dissertation								

CHAPTER 4

RESULT & DISCUSSION

4.1 Proposed Design

4.1.1 Water Wheel

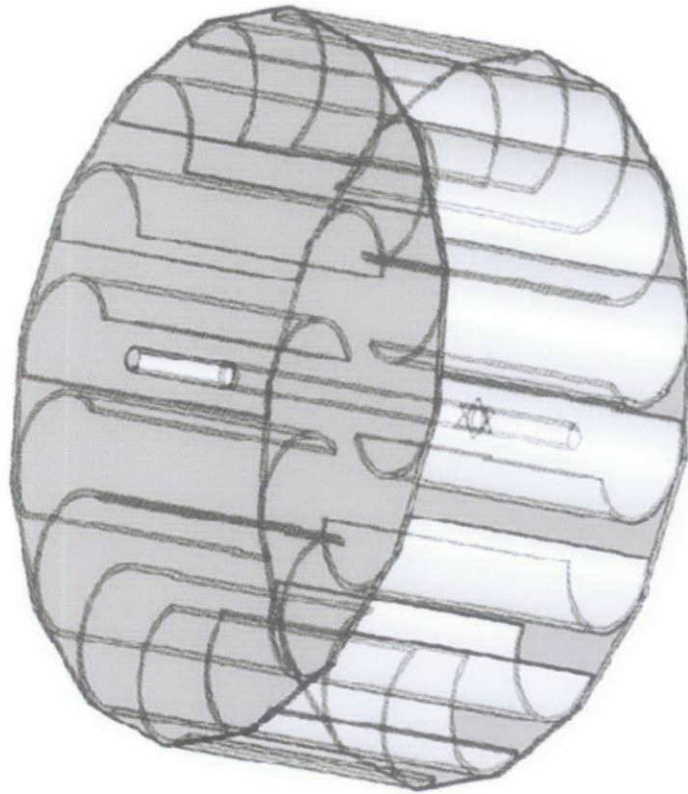


Figure 11: Water Wheel

The runner is built up of two parallel circular disk joined together at the rim with a series of curved blades. Its blades are modified to be curved and the quantity is also doubled to be 16 instead of 8 blades, thus it is roughly estimated that the efficiency will be doubled.

4.1.2 Augmentation Channeling

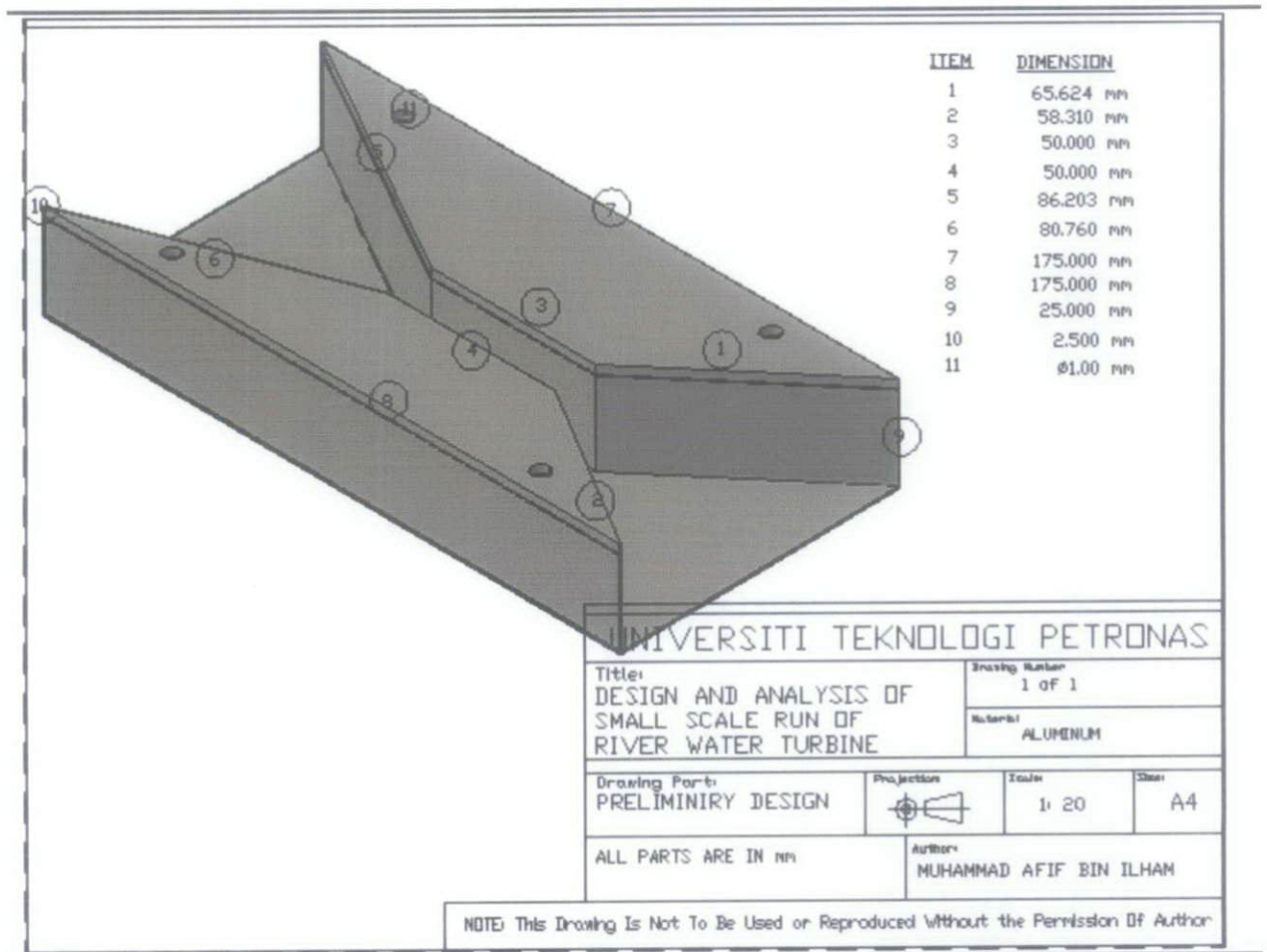


Figure 12: Augmentation

The augmentation channeling device is used as the base of the turbine and the replacement for nozzle. It has been designed at ratio of 1:20 for fabrication usage. The cross sectional area of the channel of this device is going to be:

$$\begin{aligned}
 A &= h_{\text{channel}} \times W_{\text{channel}} \\
 &= 0.55 \text{ m} \times 0.1 \text{ m} \\
 &= 0.05 \text{ m}^2
 \end{aligned}$$

The cross sectional area influence the velocity of the of the water entering channel, thus effect the amount of power that can be generated.

4.2 Analysis of Result

4.2.1 Velocity Profile

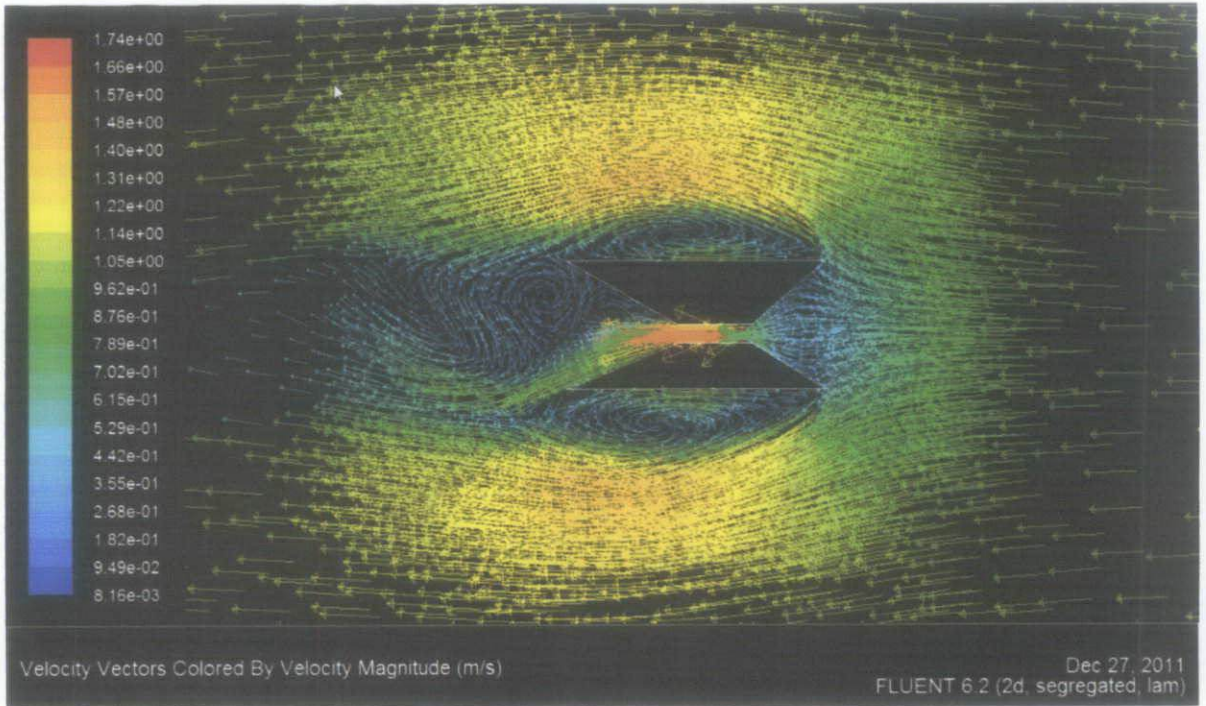


Figure 13: Velocity Profile

Figure 13 shows how the movements of the water flow in run-of-the-river water turbine. This also shows how the water is forced into the turbine and also the highest point of velocity.

4.2.2 Velocity Contour

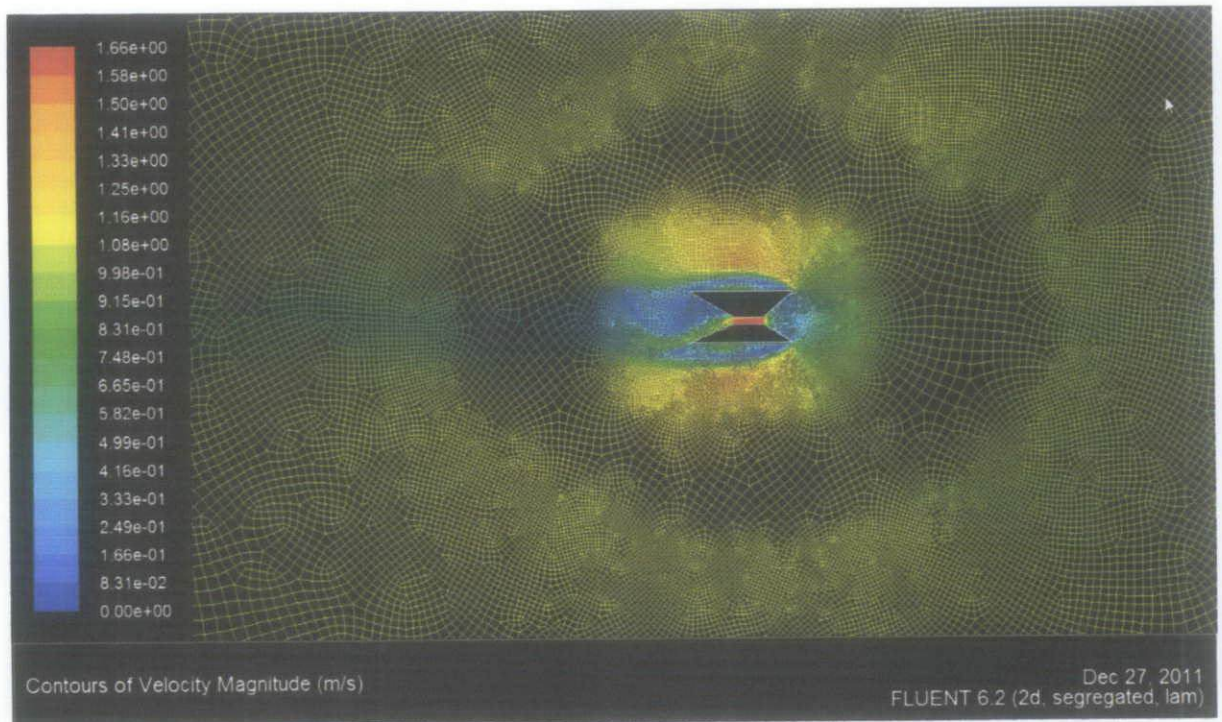


Figure 14: Velocity Contour

This velocity contour shows the point where the highest velocity of the water can be achieved in this run-of-river-water turbine. Here, we can see that the highest velocity of the water can be achieved at its turbine blades, which are approximately about 1.66m/s.

4.2.3 Pressure Contour

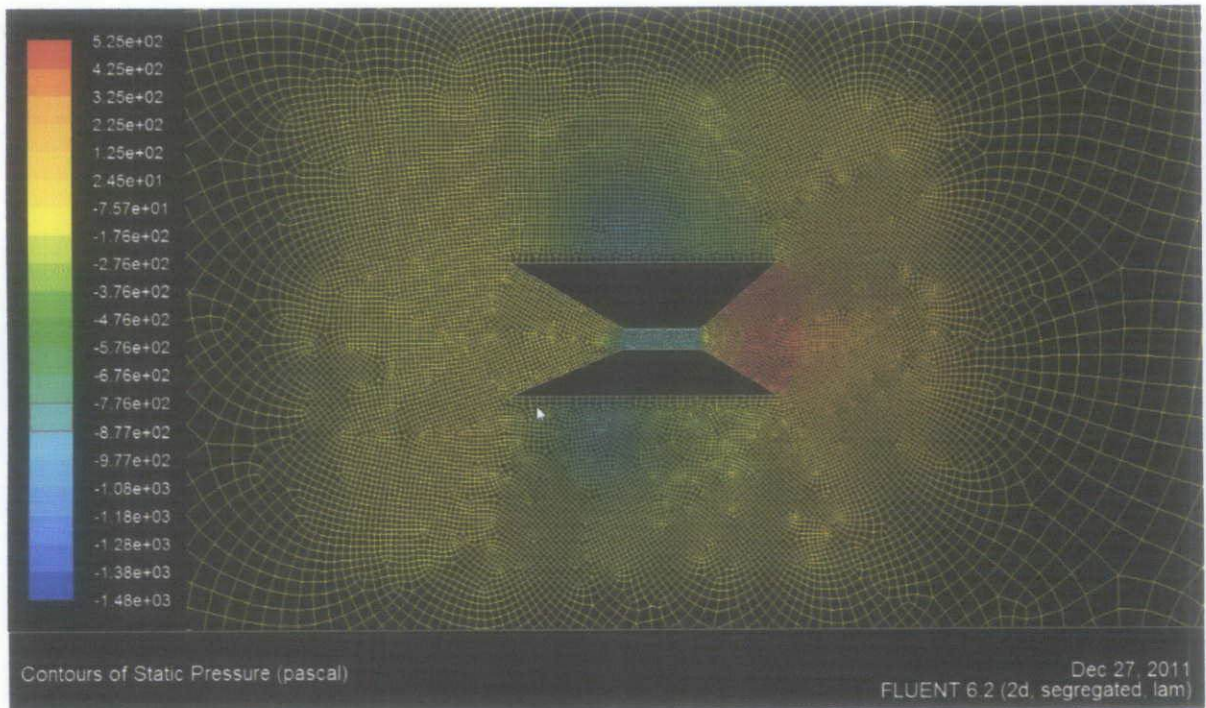


Figure 15: Pressure Contour

This pressure contour shows the point where the highest pressure exerted by the water can be achieved in this run-of-river-water turbine. Here, we can see that the highest pressure exerted by the water is at tip of the pontoon, which is 525.0 Pascal.

4.3 Calculation

For run of river type of hydro electrical generation, the equation to calculate the total available hydropower including both static (PE) and dynamic (KE) contribution is given by:

$$\begin{aligned} \text{Power} &= (\text{total hydraulic head}) \times (\text{volumetric flowrate}) \times (\text{efficiency}) \\ &= \left(\rho g Z + \frac{1}{2} \rho \Delta (v^2) \right) \times Q \times \epsilon \end{aligned}$$

Thus, taking several estimations of the river velocity and head, a table is constructed to calculate the maximum theoretical power available before taking the efficiency into account:

Table 7: Power Generated without turbine efficiency

v (m/s) / Z (m)	0.01	0.1
1	1.50ε W	3.70ε W
2	10.5ε W	15ε W
3	34.5ε W	41ε W
4	80.1ε W	89.8ε W

$$\begin{aligned} Q_1 &= vA \\ &= 1(0.05)^2 \\ &= 0.0025 \text{ m}^3/\text{s} \end{aligned}$$

$$\begin{aligned} P_1 &= \left((1000)(9.81)(0.01) + \frac{1}{2} (1000)\Delta(1^2) \right) \times 0.25 \times \epsilon, \\ &= 1.50\epsilon \text{ W} \end{aligned}$$

It is evident that the power largely depends on the river velocity and head. By choosing locations with sufficient values of these factors, the powers that can be generated are considered moderate. However, the other factor now comes into play which is efficiency. The actual power will be less as it is not possible to achieve 100% efficiency. Thus, the next step is maximizing it to be as optimum as possible.

The average undershot waterwheel efficiency is about 20 %, but with the modification that being used, the efficiency is estimated to be improved. Its blades are modified to be curved and the quantity is also doubled to be 16, thus it is roughly estimated the turbine able to raise its efficiency to 40%. For the self-fabricated generator, 40% efficiency would be a safe estimation. Therefore, we would obtain:

Table 8: Power Generated with turbine efficiency

v (m/s) / Z (m)	0.01	0.1
1	0.6 W	1.48 W
2	4.2 W	6 W
3	13.8 W	16.4 W
4	32 W	35.9 W

$$P_1 = 1.5 \text{ W} \times 0.4$$

$$= 0.6 \text{ W}$$

The average electricity usage of a lamp is 10W. So, with by choosing the location of the turbine will sufficient for usage for rural area people.

CHAPTER 5

CONCLUSION & RECOMMENDATION

5.1 Conclusion

As a conclusion, this project has successfully met the objectives which are design of the vertical axis run-of- river water turbine and analysis of the power can be generated by the turbine. However, the power that can be generated by this turbine is relatively small compared to the existing turbine that generate power at range of 0.5 – 5.0 kW. Although electric that can be generated is considered quite small but it all depends to the velocity of the river and the height of the immersed augmentation channel. As the average electricity usage of a lamp is only 10W, this turbine is considered sufficient to the usage at rural area. This project will provide a way to have a small scale electric provider in the rural are. The efficiency of the turbine also is an important aspect in generating electricity. The efficiency of turbine differs from one to another. The selection of turbine to be use is important in this project. This also gives option to the conventional way of generating hydro electric which is the usage of a dam. The option of not using dam will help the planet to save the forest from damaged.

5.2 Recommendation

For recommendation, it would be helpful if more time given to student so that student can be able to fabricate and have an actual analysis of the turbine that been designed. The understanding of water turbine and the understanding of generator will provide a powerful tool in the design and analysis of this project.

CHAPTER 6

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CHAPTER 7
APPENDIX

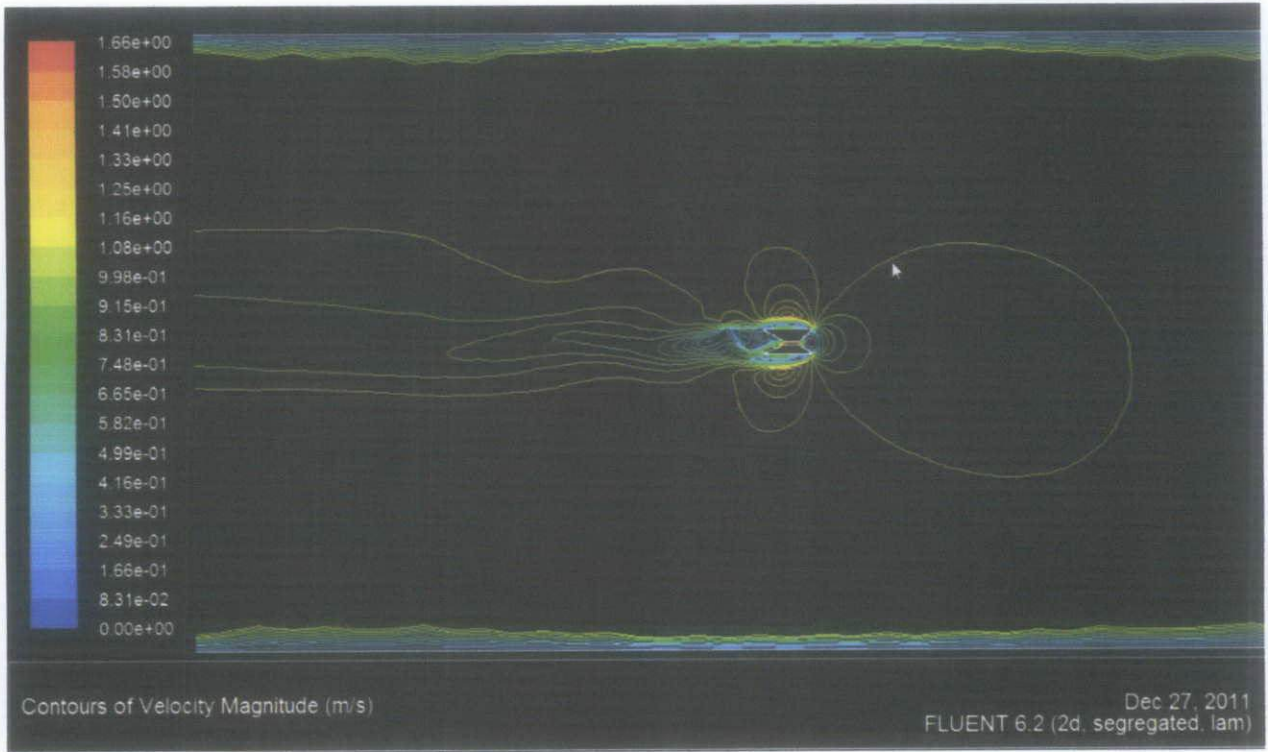


Figure 16: Velocity Magnitude Contour

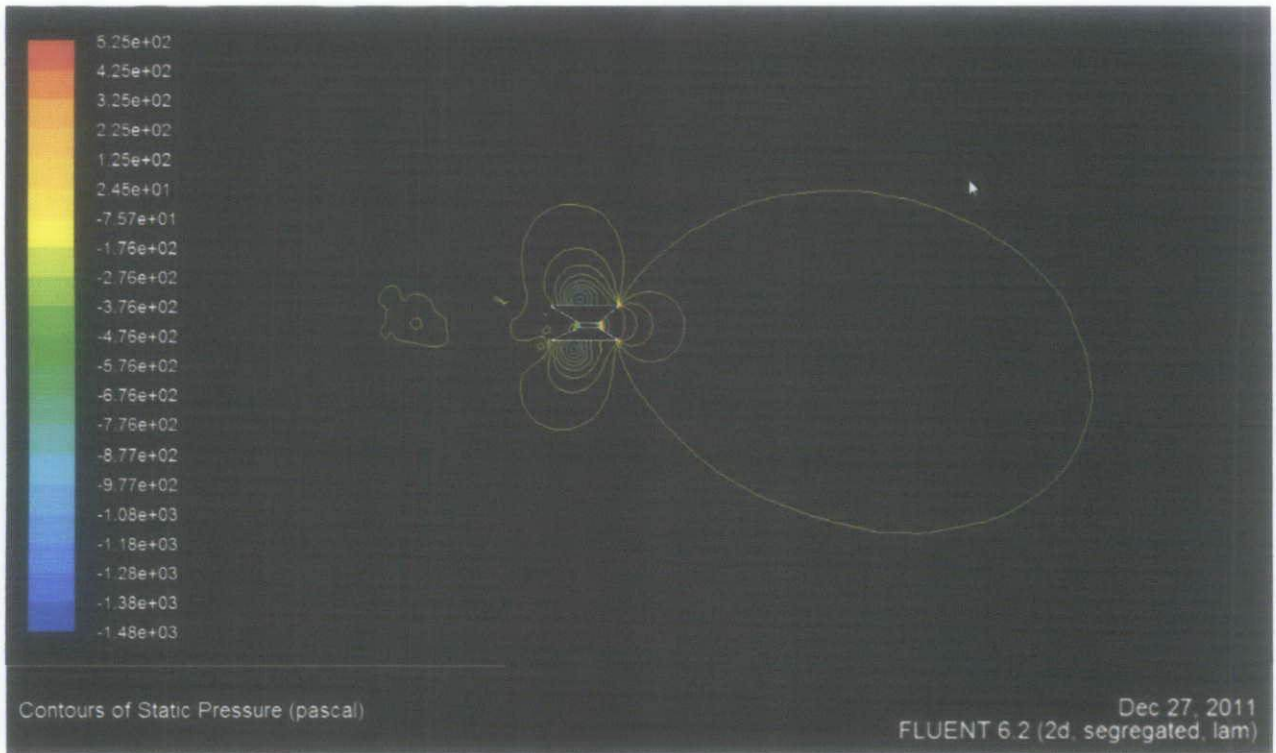


Figure 17: Static Pressure