CHAPTER 1

INTRODUCTION

1.1 Background of Study

Flow past a circular bluff body creates an unstable wake in the form of alternating vortices. They create periodically varying lift forces on the cylinder. In certain conditions vortices develop which are shed alternately from either side of the cylinder. The resultant lift and drag forces excite forced oscillations of the cylinder known as Vortex Induced Vibration (VIV). This is a complex interaction, dependent on both flow parameters and mechanical properties of the cylinder. When the vortex-induced vibration frequency nears one of the natural (normal mode) frequencies of the structure, a resonance phenomenon known as *lock-in* takes place, enhancing the vibration amplitude.

In normal conventional generator, the forcing element to generate power is just from the wave forces. Usually the wave force differs from time to time as it depends on the other factor such as the wind and monsoon. But underwater flow is much stable compare to the surface wave. Thus this gives the advantages to the project that uses the underwater current flow as their source of forces to generate electricity.

In linear generator, magnet needs oscillation so that the magnetic flux can be induced by the coil surrounding it. Then the induced magnetic flux will be converted to electricity. The project objective is to capture all vibration amplitude from the Vortex Induced Vibration (VIV) and also lift forces generated by the aerofoil shape and used it as a driven force to oscillate the magnet through the coil.

1.2 Problem Statement

Normal Tidal Energy Generator requires about 5 meter head to work with high efficiency. This kind of tidal can harm the marine life and also destroying the coral underneath the sea. In other hand, current energy converters such as water mills/turbines require at least 4 knots to be efficient. But Wave Induced Vibration Generator is one of the new technologies that give high and efficient energy without destroying the environment. It gives high energy density and also mechanically simple or in other word the total cost to built it is rather low compare to conventional generator.

In normal conventional generator, the forcing element to generate power is just from the wave forces. Usually the wave force differs from time to time as it depends on the other factor such as the wind and monsoon. But underwater flow is much stable compare to the surface wave. Thus this gives the advantages to the project that uses the underwater sea current flow as their source of forces to generate electricity.

By capturing the energy produce by the underwater sea current flow using suitable wing shape, the project can generate oscillation forces using Vortex Induced Vibration concept and also lift concept to power a linear generator.

1.3 Objective and Scope of Study

The objective of this project is to generate renewable energy using the ocean energy. This project differs than conventional Wave Generator where the wing was submerged underneath the sea where it uses the sea current flow that more stable than the normal wave height. The project capture the energy from the Wave-Induced Element and converts it into electricity. It uses the sea current flow and tidal waves to create a linear vertical motion to generate a small scale linear generator**.** The linear vertical motion generated by Wave Induced Vibration (WIV) is used as the force to translate magnet pack linearly within a stator coil to generate electricity. The concept behind the Wave Induced Vibration is all about the shape of the wing that generates induced forces.

Come to this, the design of the wing shape will determine the power generation by the linear generator. Analysis on the wing design will be done using the FLUENT and ANSYS software. From there, the best wing design will be selected and fabricated. The experiment start after all fabrication completed, the author will collect all the data gains from the project such as the amplitude gains, the power generated and also the efficiency of the project. The variable that will determine this result are by altering the value of the current velocity and also the shape of the wing.

The author also need to research possible location that suitable to locate the project. Those include the research on the sea current velocity around this country and also other possible location that might be good to set up the project.

CHAPTER 2

LITERATURE REVIEW

2.1 Lift Forces

A body immersed in a moving fluid experiences a resultant force due to the interaction between the body and the fluid surrounding it. The resultant force in the direction of the upstream velocity is term as *Drag, $\mathscr{D}$,* and the resultant force normal to the upstream velocity is term as the *Lift, $\mathscr{L}$.*

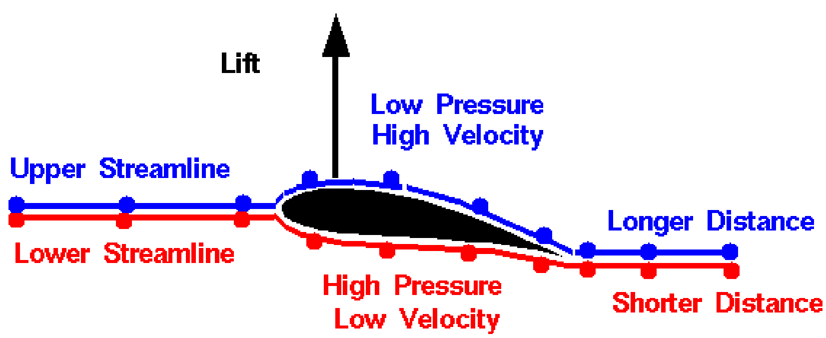


Figure 1: Lift Forces

From Figure 1, the lift force is generated by a small pressure differential between the upper and lower surfaces of the wing caused by the aerodynamic reaction to the wing motion through the atmosphere. Typically, the lift is given in terms of lift coefficient:

$$C_L = \frac{L}{\frac{1}{2}\rho U^2 A}$$

- C_L is the *lift coefficient*
- ρ is the density of the fluid (1.225 kg/m³ for air at sea level*, 1000 kg/m³ for fresh water)
- U is the freestream velocity
- A is the surface area of the lifting surface

There are many factors that affect the turning of the flow, which creates lift. We can group these factors into(a) those associated with the object, (b) those associated with the motion of the object through the air, and (c) those associated with the air itself:

1. **Object:** Shape of an object has a large effect on the amount of lift generated. The airfoil shape and wing size will both affect the amount of lift. The ratio of the wing span to the wing area also affects the amount of lift generated by a wing.
2. **Motion:** To generate lift, we have to move the object through the air. The lift then depends on the velocity of the air and how the object is inclined to the flow.
3. **Air:** Lift depends on the mass of the flow. The lift also depends in a complex way on two other properties of the air: its viscosity and its compressibility.

Aerofoil and the aerodynamic force

An **aerofoil** or **airfoil** or **wing section** or **wing profile** is an object, the shape of the cross section of the wing, with the function of producing a controllable net aerodynamic force by its motion through the atmosphere. To be useful this aerodynamic force must have a lifting component which is much greater than the resistance or drag component. In a powered aircraft the motion through the air is provided by the thrust so, in effect, the aerofoil is a device that converts thrust into lift.

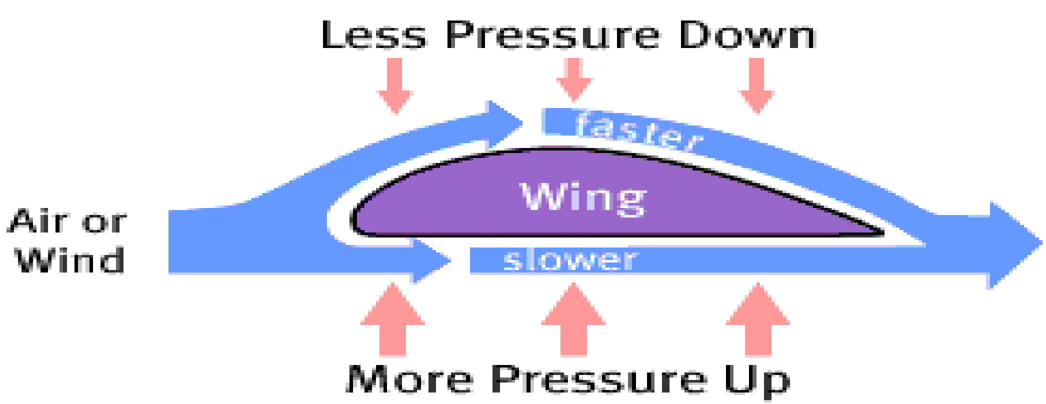


Figure 2: Aerofoil Wing Profile

In Bernoulli's Principle: Air moving over the wing moves faster than the air below. Faster-moving air above exerts less pressure on the wing than the slower-moving air below. The result is an upward push on the wing or we called as Lift Forces.

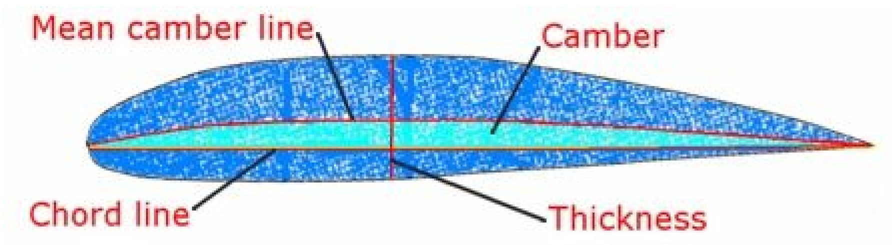


Figure 3: Aerofoil Characteristic

The various terms related to airfoils are defined below:

- The *mean camber line* is a line drawn midway between the upper and lower surfaces.
- The *chord line* is a straight line connecting the leading and trailing edges of the airfoil, at the ends of the mean camber line.
- The *chord* is the length of the chord line and is the characteristic dimension of the airfoil section.
- The *maximum thickness* and the location of maximum thickness are expressed as a percentage of the chord.
- For symmetrical aerofoil, both *mean camber line* and *chord line* pass from centre of gravity of the aerofoil and they touch at leading and trailing edge of the aerofoil.
- The *aerodynamic center* is the chord wise length about which the pitching moment is independent of the lift coefficient and the angle of attack.
- The *center of pressure* is the chord wise location about which the pitching moment is zero.

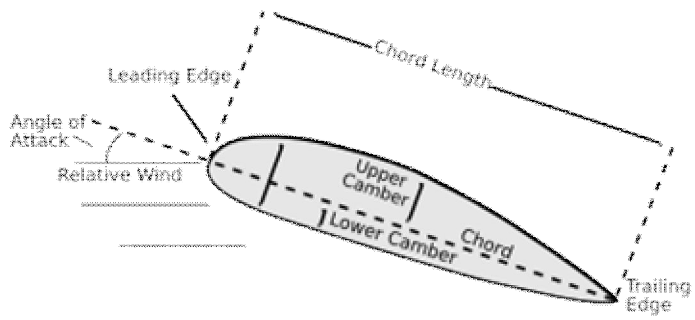


Figure 4: Angle of Attack

Angle of attack (**AOA**, α, Greek letter alpha) is a term used in aerodynamics to describe the angle between the chord line of an airfoil and the vector representing the relative motion between the airfoil and the air. It can be described as the angle between where the chord line of the airfoil is *pointing* and where the airfoil is *going*.

In aviation, **angle of attack** is used to describe the angle between the chord line of the wing of a fixed-wing aircraft and the vector representing the relative motion between the aircraft and the atmosphere. In traditional British usage, the term *angle of incidence* is used instead of angle of attack.

As the angle of attack on the wing of a fixed-wing aircraft increase, separation of the airflow from the upper surface of the wing becomes more pronounced, leading to a reduction in the rate of increase of the lift coefficient. At the critical angle of attack the wing is unable to support the weight of the aircraft, causing the aircraft to descend which, in turn, causes the angle of attack to increase further. This leads to stall of the aircraft.

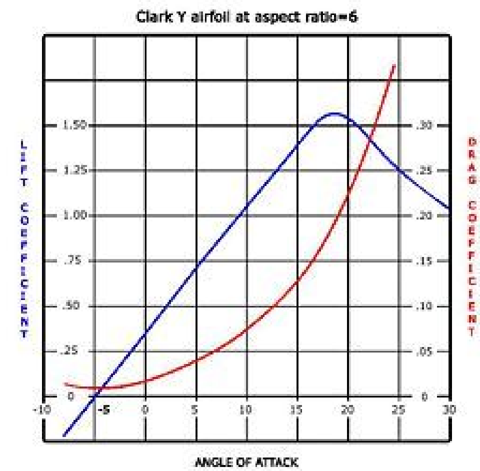


Figure 5: Lift and Drag Curves

From the figure, the curve represents an airfoil with a positive camber so some lift is produced at zero angle of attack. With increased angle of attack, lift increases in a roughly linear relation, called the *slope* of the lift curve. At about eighteen degrees this airfoil stalls and lift falls off quickly beyond that. Drag is least at a slight negative angle for this particular airfoil, and increases rapidly with higher angles.

Aspect ratio is the wing span divided by the mean wing chord. An aircraft with a rectangular wing of area 12 m^2 might have a wing span of 8 m and wing chord of 1.5 m. In this case the aspect ratio is 5.33. If the span was 12 m and the chord 1 m then the aspect ratio would be 12. However because wings have varied plan forms it is usual to express aspect ratio as:

$$\textbf{Aspect Ratio} = \frac{\text{Wing Span}^2}{\text{Wing Area}}$$

2.2 Vortex Induced Vibration

Vortex-induced vibrations (VIV) are motions induced on bodies facing an external flow by periodical irregularities on this flow. The classical example is the Vortex Induced Vibration (VIV) of an underwater cylinder. You can see how this happens by putting a cylinder into the water (a swimming-pool or even a bucket) and moving through the direction perpendicular to its axis. Since real fluids always present some viscosity, the flow around the cylinder will be slowed down while in contact with its surface, forming the so called boundary layer.

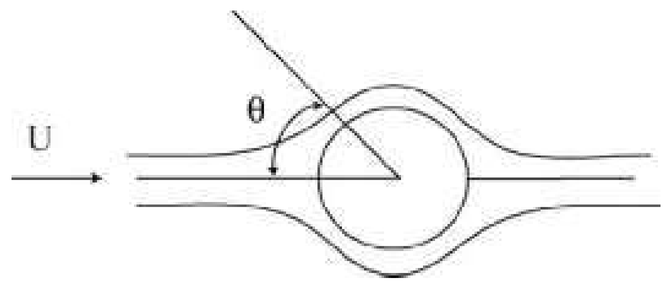


Figure 6 : Boundary Layer Flow

At some point, however, this boundary layer can separate from the body because of its excessive curvature. Vortices are then formed changing the pressure distribution along the surface. When the vortices are not formed symmetrically around the body (with respect to its midplane), different lift forces develop on each side of the body, thus leading to motion transverse to the flow. This motion changes the nature of the vortex formation in such a way as to lead to a limited motion amplitude (differently, then, from what would be expected in a typical case of resonance).

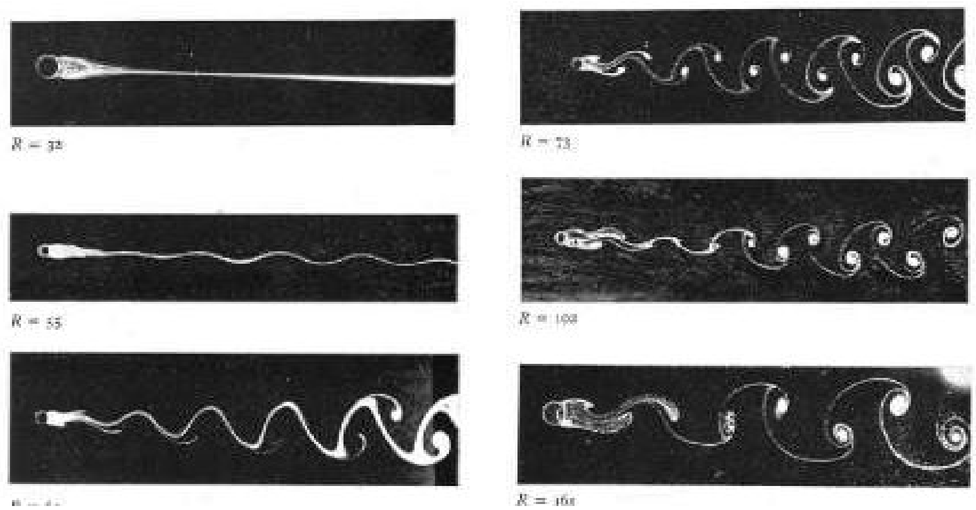


Figure 7 : Vortices at Different Reynolds Number

The shear layer instability causes vortex roll-up due to :

- Flow speed outside wake is much higher than inside
- Vorticity gathers at downcrossing points in upper layer
- Vorticity gathers at upcrossing in lower layer
- Induced velocities (due to vortices) cause this perturbation to amplify

Usually Vortex shedding dictated by Strouhal number. In dimensional analysis, the **Strouhal number** is a dimensionless number describing oscillating flow mechanisms. Often, it is given as:

$$\mathrm{St} = \frac{fL}{V}$$

Where *St* is the dimensionless Strouhal number, f is the frequency of vortex shedding, L is the characteristic length (for example hydraulic diameter) and V is the velocity of the fluid.

In fact, it is the dimensionless frequency of a fluid flow problem. For spheres in uniform flow in the Reynolds number range of 800 < Re < 200,000 there co-exist two values of the Strouhal number. The lower frequency is attributed to the large-scale instability of the wake and is independent of the Reynolds number Re and is approximately equal to 0.2.

Additional Vortex Induced Vibration parameters are:

1. **Reynolds Number, Re =** $\frac{UD}{v} \approx \frac{inertial\ effect}{viscous\ effect}$

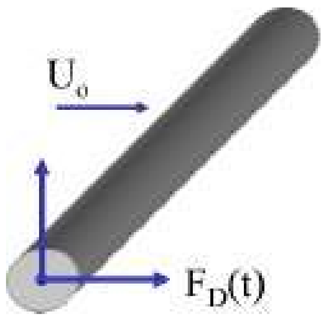
   -subcritical ($Re<10^5$) (laminar boundary)

2. **Reduced Velocity, Vrn** = $\frac{U}{fnD}$

3. **Vortex Shedding Frequency**, $fs = \frac{SU}{D}$

   $S \approx 0.2$ for subcritical flow

Due to the alternating vortex wake ("Karman street") the oscillations in lift force occur at the vortex shedding frequency and oscillations in drag force occur at *twice* the vortex shedding frequency.



Both Lift and Drag forces persist on a cylinder in cross flow. Lift is perpendicular to the inflow velocity and drag is parallel.

. And due to the vortex shedding frequency, Vortex Induced Forces occurred causes unsteady flow, forces, X(t) and Y(t), vary with time. The force coefficient can be stated as:

$$Cx = \frac{D(t)}{\frac{1}{2}\rho U^2 d} \qquad Cy = \frac{L(t)}{\frac{1}{2}\rho U^2 d}$$

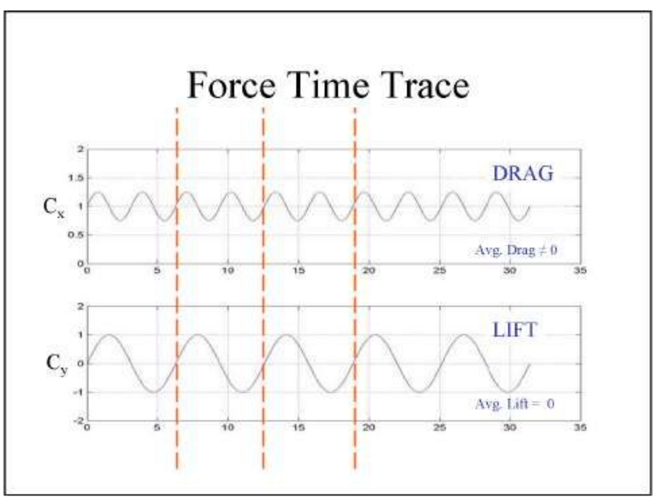
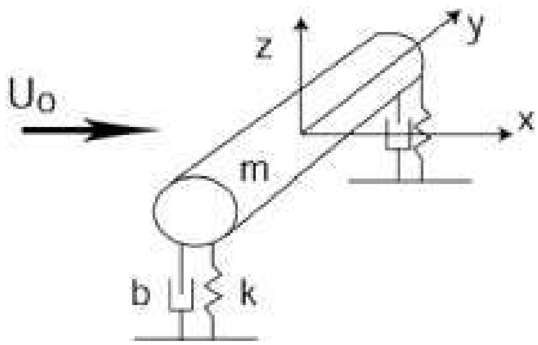


Figure 8: Force Time Trace for Drag and Lift

Alternate Vortex shedding causes oscillatory forces which induce structural vibrations. By using the rigid cylinder to find the motion, the rigid cylinder now can be set similar to a spring mass system with a harmonic forcing term.



Heave Motion Z(t)

$$Z(t) = Z_\circ Cos\omega t$$

$$\dot{Z}(t) = -Z_\circ \omega Sin\omega t$$

$$\ddot{Z}(t) = -Z_\circ \omega^2 Cos\omega t$$

Lift = L(t) = $L_\circ Cos(\omega_s t + \psi)$

Drag = D(t) = $D_\circ Cos(2\omega_s t + \psi)$

$$\omega_s = 2\pi f_s$$

When the vortex-induced vibration frequency nears one of the natural (normal mode) frequencies of the structure, a resonance phenomenon known as *lock-in* takes place, enhancing the vibration amplitude. A cylinder is said to be in '*lock-in'* when the frequency of vortex oscillation is same with vortex shedding. In this region, the largest amplitude oscillation occurs.

Shedding Frequency $\omega_v = 2\pi f_v = 2\pi S_t (U / D)$

Natural Frequency of Oscillation $\omega_n = \sqrt{\dfrac{k}{m + m_a}}$

Vortex shedding creates Vortex Induced Vibration where Drag and Lift force occurred. Lift force is sinusoidal component and residual force. Filtering the recorded lift data will give the sinusoidal term which can be subtracted from the total force. Using the formula, the Lift force on the cylinder can be calculated.

LIFT FORCE = $L(t) = L_{\circ} Cos(\omega t + \psi_{\circ})$ **if** $\omega \langle \omega_v$

$$L(t) = L_{\circ} Cos \omega t Cos \psi_{\circ} - L_{\circ} Sin \omega t Sin \psi_{\circ}$$

$$L(t) = \frac{-L_{\circ} Cos \psi^{\circ}}{z_{\circ} \omega^2} \ddot{z}(t) + \frac{L_{\circ} Sin \psi^{\circ}}{z_{\circ} \omega} \dot{z}(t)$$

Where ω_v is the frequency of the Vortex Shedding

Lift force can be divided into two components which are Lift in phase with acceleration and Lift in phase with velocity. Both components can be analyzed by:

Lift in phase with Acceleration (added mass),

$$M_a(\omega, a) = \frac{L_{\circ}}{a\omega^2} Cos \psi_{\circ}$$

Lift in phase with Velocity,

$$L_v = -\frac{L_{\circ}}{a\omega} Sin \psi_{\circ}$$

Where Total Lift,

$$L(t) = -M_a(\omega, a) \ddot{z}(t) + L_v(\omega, a) \dot{z}(t)$$

($a = z_o$ is cylinder heave amplitude)

MATHEMATICAL MODEL

In synchronization, typically we assume a simple linear model,

$$m_{osc}\ddot{y} + C_{total}\dot{y} + ky = F_{fluid}\hat{y}$$
$$m_{osc}\ddot{y} + C_{total}\dot{y} + ky = F_{viscous}\hat{y} + F_{inviscid}\hat{y}$$

y is transverse direction to flow

m is system mass

k is the stiffness

C_{total} is dimensional damping coefficient

F_{fluid} is the forced on the body exerted by the fluid. The fluid force is separated into viscid and inviscid component as follows.

$$F_{viscous}\hat{y} = -m_a\ddot{y} \qquad F_{inviscid}\hat{y} = \frac{1}{2}c_y(t)\rho U^2 DL$$

The added mass inclusion (from potential energy) on the left hand is still in debate.

$$y^* = y^*_{\max} \sin(2\pi f_{fluid} t) \qquad c_y(t) = C_y \sin(2\pi f_{fluid} t + \phi)$$

Fluid Energy in VIV,

$$P_{VIV-Fluid} = \frac{1}{T_{cyl}} \int_0^{T_{cyl}} \frac{2}{\pi D} c_y(t) m_d U^2 2\pi f_{fluid} y_{\max} \cos(2\pi f_{fluid} t) dt$$

Mechanical Energy in VIV,

$$P_{VIV-Mech} = \frac{1}{T_{cyl}} \int_0^{T_{cyl}} 4\pi(m_{osc} + m_a)\zeta_{total} y^2 f_{n,water} dt$$

Integrating L.H.S and R.H.S of the equation,

$$P_{VIV-Fluid} = \frac{1}{2}\rho\pi C_y U^2 f_{cyl} y_{\max} DL\sin(\phi)$$

$$2C_y U^2 f_{cyl} y_{\max} \sin(\phi) - 8\pi^3 (m^* + C_a)(\zeta_{tral} + \zeta_{sys} + \zeta_{gen})(y_{\max} f_{cyl})^2 f_{n,water}$$

Equating the integral,

$$C_y U^2 \sin(\phi) = 4\pi^3 D(m^* + C_a)\zeta_{total} y_{\max} f_{cyl} f_{n,water}$$

So, the energy we can harness is,

$$P_{VIV-Harn} = \frac{\pi}{4}\rho D^2 L\left(2C_y U^2 f_{cyl} y_{\max} \sin(\phi) - 8\pi^3 (m^* + C_a)(\zeta_{tral} + \zeta_{sys} + \zeta_{gen})(y_{\max} f_{cyl})^2 f_{n,water}\right)$$

Efficiency of the VIV-Gen,

$$\eta_{VIV-Gen} = \frac{P_{VIV-Harn}}{\frac{1}{2}\rho U^3 DL}$$

CHAPTER 3

METHODOLOGY

The methodologies for this project start from the preliminary research and collecting information about the Vortex Induced Vibration (VIV), lift concept and also any forces that can be generated using ocean energy. The researched will be based on how to manipulate the forces from the ocean to power a linear generator. From here, the linear generator that powered by the Vortex Induced Vibration motion will be design.

As the design was finished, the 2D and 3D drawing will be done before entering the next stage which is the fabrication stage. Lastly, the project will be test using the Water Tank available in Fluid Mechanics Lab. Figure 9 shows the methodology flowchart.

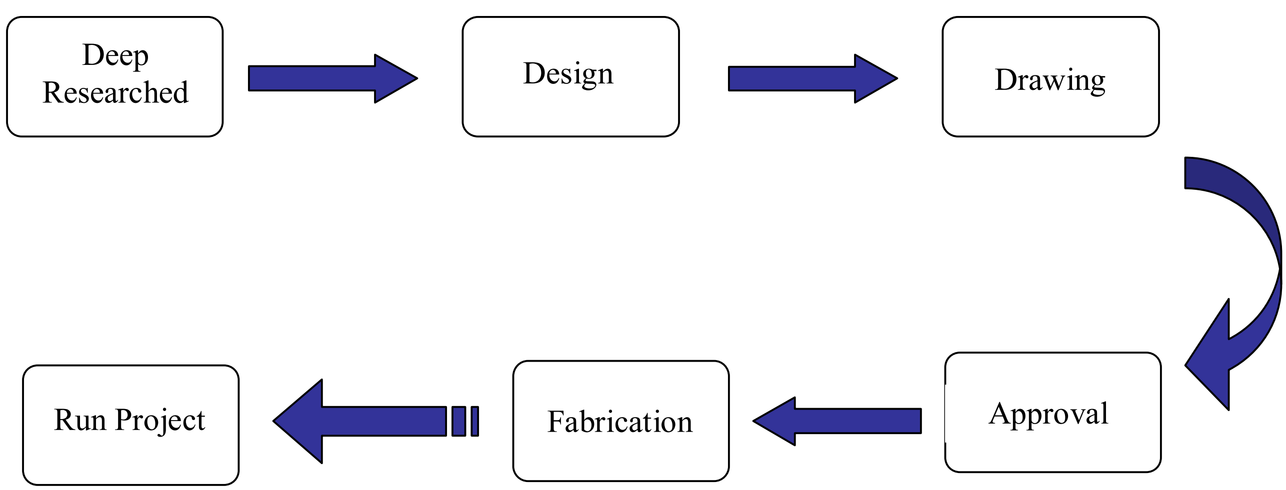


Figure 9: Methodology Flowchart

3.1 Deep Research

The methodologies for this project start from the preliminary research and collecting information about the Vortex Induced Vibration (VIV), lift concept and shape that suitable to be use for the project. The researched also will concentrate on the design shape of the wing that will be used to power the linear generator.

3.2 Project Design

During the early period of the project, the discussion about the conceptual design was held with AP. Dr Abd Rashid where here he gave some briefing on the project. The briefing was about the Vortex Induced Vibration (VIV) Generator and some theory behind it. The conceptual design was also being discussed during that session where some sketches was made. Shown below is the early conceptual design for the project.

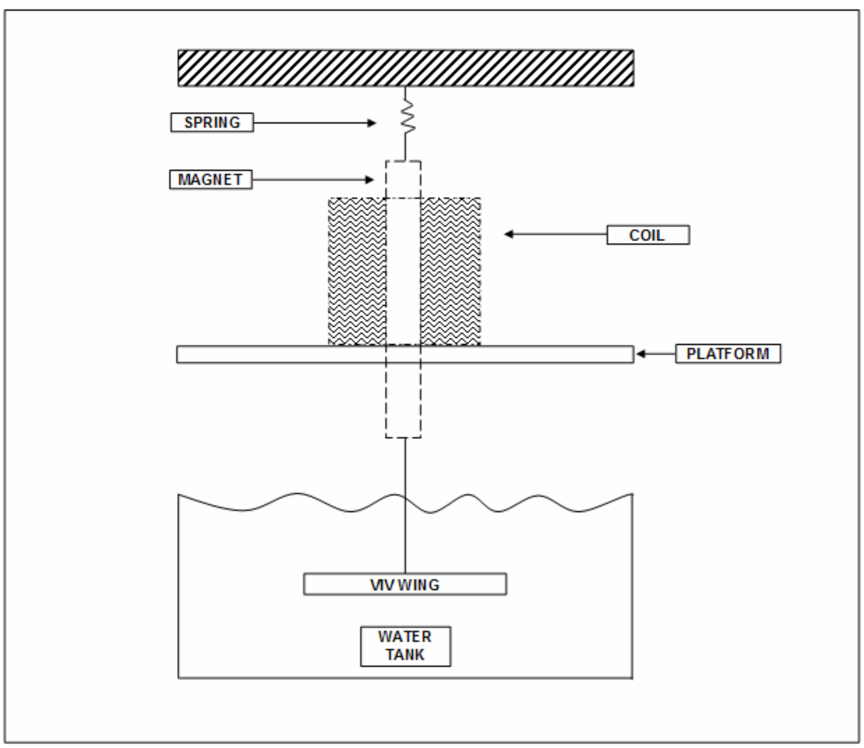


Figure 10 : Conceptual Design

3.3 Conceptual Design of Linear Generator

In order to converts the oscillations from the Vortex Induced Vibration (VIV) movement, the linear generator needs to be design. Shown below are two conceptual designs that can be use for the project:

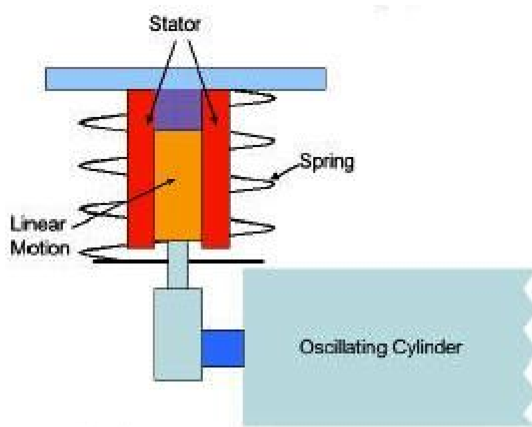


Figure 11: Linear Generator Conceptual Design I

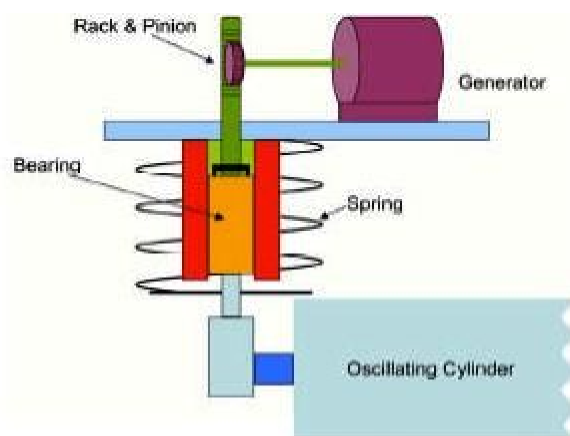


Figure 12: Linear Generator Conceptual Design II

3.4 Project 2D and 3D Drawing

After completing the conceptual design, the project continues by preparing the 2D and 3D drawing. The measurement of all parts needs to be perfect to ensure the design can be assemble without any hitch. Shown below is the final drawing that has been approved:

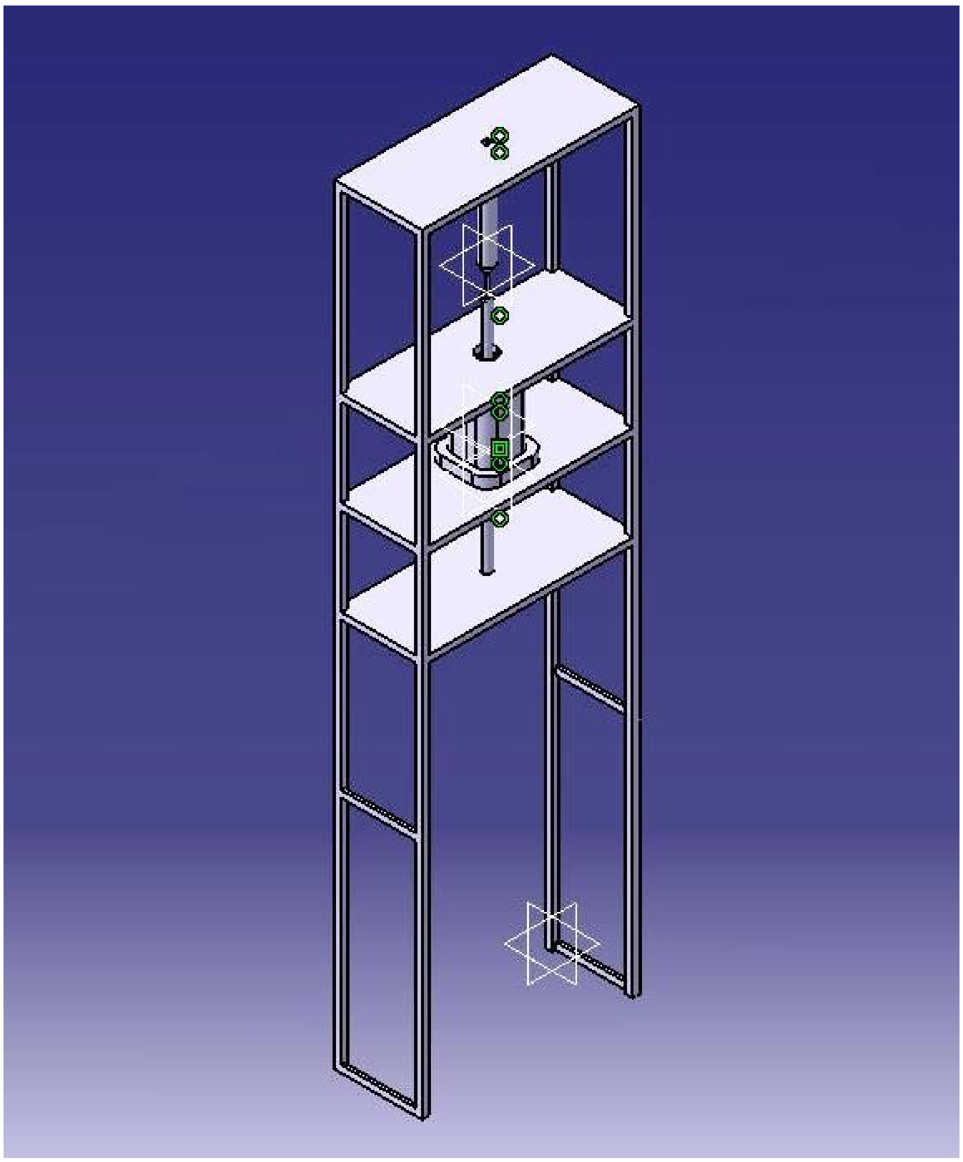


Figure 13: Wave Induced Generator 3D Drawing

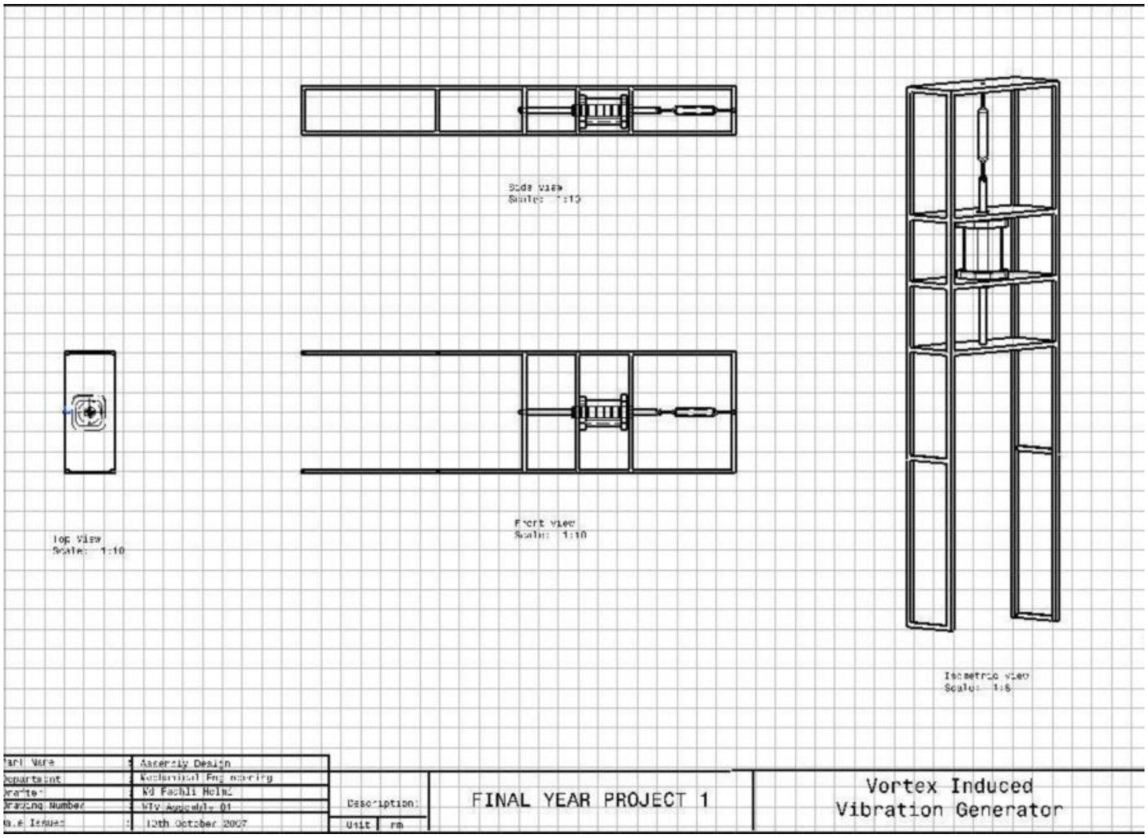


Figure 14: Wave Induced Generator 2D Drawing

** The overall parts of the drawing can be view at the Appendix Page.

3.5 Material Research

From the conceptual design we come out with the list of material that needs to be considered for the successfulness of the project. The materials that need to be research and study are:

3.5.1 Spring Material

The spring plays an important role in the project where the magnet core will be hanging there. The spring needs to have sufficient stiffness, K to handle the weight of the magnet core (6.2 Kilogram) and also need to have frequency about 6 Hertz. The range amplitude required for the spring is about 70 to 100 millimeter. Figure 12 below show the picture of the Spring:

Figure 15 : Spring

3.5.2 Magnet Coil Plate Material

As requested by the supervisor, the plate of the Magnet Coil needs to be change from metal to other material. The current plate of the Magnet Coil produce so much cogging effect between the Magnet Core and the Magnet Coil thus reduces the efficiency of the generator. After doing some researched, three materials (paper, wood and polystyrene) have been proposed to the supervisor as the substitute for the current plate. Figure 16 below show the picture of Steel Plate and Paper Plate:

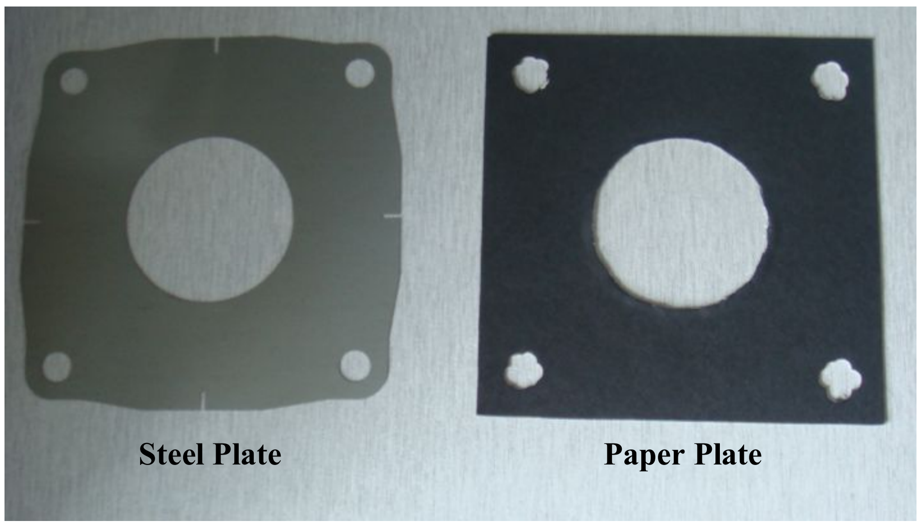
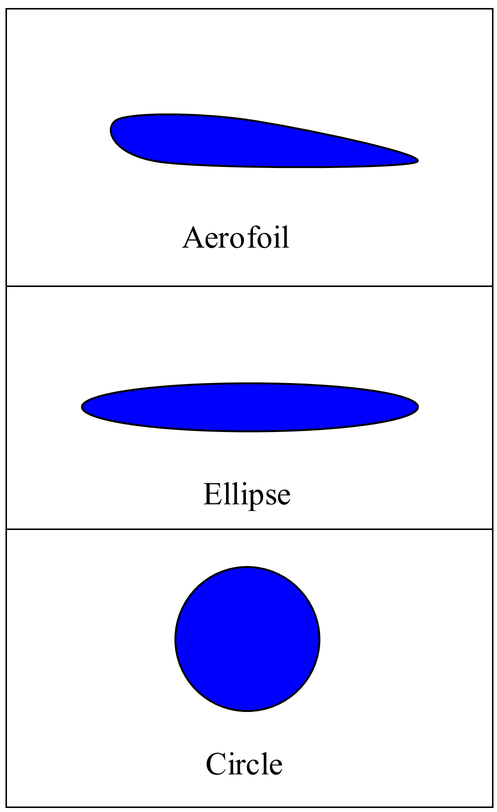


Figure 16 : Plate material

3.5.3 Wave Induced Vibration Wing Element

In order to have large amplification from the Wave Induced Vibration (WIV) forces, the material and the design shape of the WIV Wing was crucial. The shape of the wing will determine the amount of amplitude generated.

The shapes proposed to be use as a Wing Element are:



3.6 Project Fabrication

Fabrication of the project has been started at the end of last semester, during that period all the material needed was ordered by the technician. 30% of the fabrication process has been completed last semester and the fabrication continues this semester as all the material and parts are already arrived. Until this period, almost 98% of the fabrication has been completed and it will continue to meet the due date as planned in the Gantt Chart.

Figure 17 : WIV Generator During Fabrication

The fabrication of the project was done at Block N – CNG Lab. Stated below is the Built Of Material (BOM) of the project:

No.	**Description**	**Purpose**	**Quantity (Units)**
1	Iron Bar	Material for the frame	8
2	L-Plate	Plate to join the frame	40
3	M5 Bolts & Nut	Tighten the frame	80
4	Perspex	Frame cover	2 pieces
5	Journal Bearing	Reduce Friction	1
6	Baby Spring	Enhance magnet movement	2
7	Grinder	Cutting the Iron Bar	1
8	Saw	Cutting the Perspex	1
9	Portable Drill	Drilling Hole on the Perspex	1
10	3 Inch PVC Pipe	WIV-Wing	1
11	Bicycle Rim Spoke	WIV-Wing	12
12	Polar Modeling Material	WIV-Wing	1
13	Tie Twist	WIV-Wing	1
14	Magnet Bar	VIV-Main Part	1
15	Coil	VIV-Main Part	1
16	Multimeter	Data Tracking	1
17	Oscilloscope	Data Tracking	1
18	Video Camcorder	Data Tracking	1

Table 1 : Project Built Of Material (BOM)

CHAPTER 4

RESULT AND DISCUSSION

4.1 Data Gathering and Analysis

4.1.1 Aerofoil Analysis

Aerofoil wing shape has been selected to be the first design for the Wave-Induced Vibration Generator. Due to that, some analysis and simulation using FLUENT software was done to determine the best angle of attack used by this project.

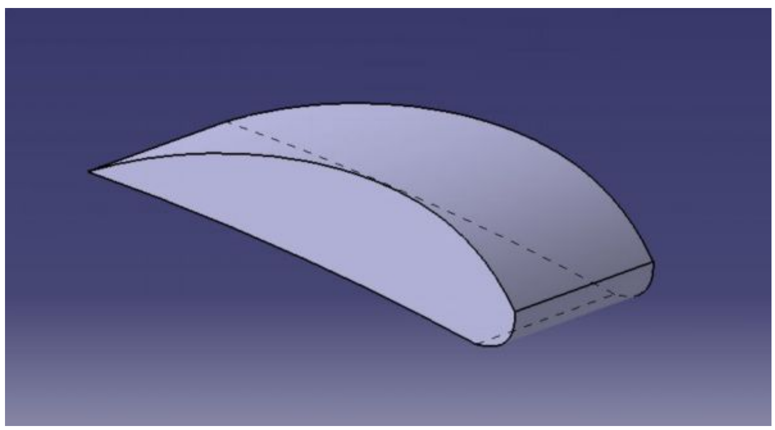
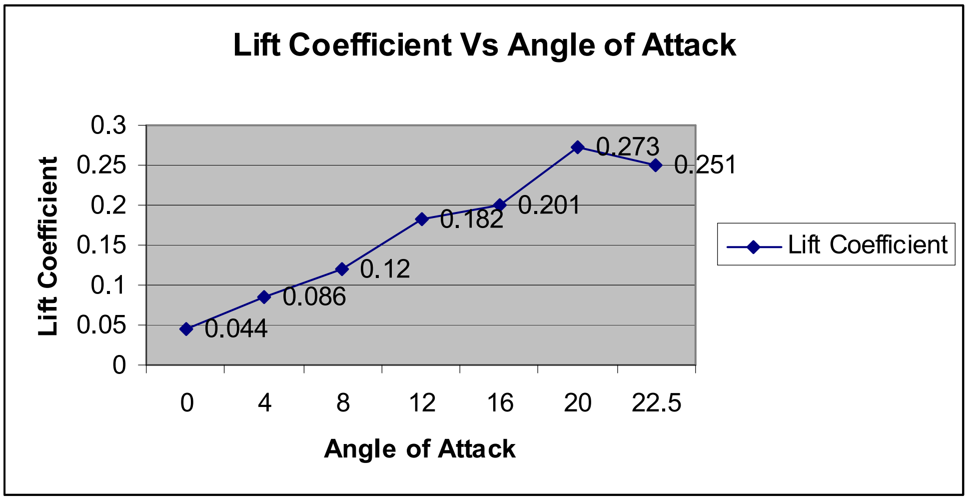


Figure 18: Aerofoil Wing Shape

Shown below is the overall result of the analysis:

Angle Of Attack (degree)	Lift Coefficient
0	0.0440
4	0.0860
8	0.1200
12	0.1820
16	0.2010
20	0.2730
22.5	0.2510

Table 2 : Angle Of Attack Effect on Aerofoil Lift Coefficient



Graph 1 : Aerofoil Lift Coefficient Vs Angle of Attack

From Table 2 and Graph 1, we can see that the lift coefficient of an aerofoil is directly related to the angle of attack. Increasing angle of attack is associated with increasing lift coefficient up to the maximum lift coefficient.

As the angle of attack on the wing of an aerofoil increases, separation of the airflow from the upper surface of the wing becomes more pronounced, leading to a reduction in the rate of increase of the lift coefficient. At the critical angle of attack the wing, this in this analysis at **22.5 degree**, the lift coefficient of the aerofoil starts decreasing or we can call as *stalled phenomena*. From this analysis, the best way to get the maximum lift coefficient is by using the angle of attack at **20 degree**.

** The analysis data can be viewed at Appendix page

4.1.2 Ellipse Analysis

Ellipse wing shape has been selected to be the second design for the Wave-Induced Vibration Generator. The simulation on lift forces was done using ANSYS software at different angle of attack.

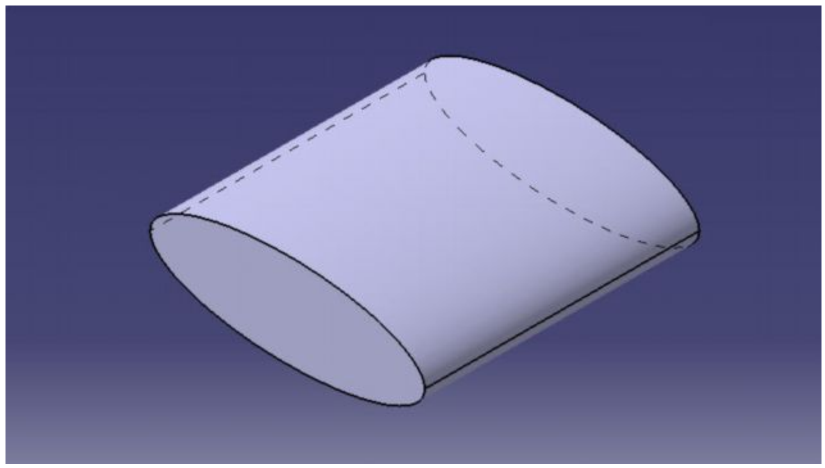
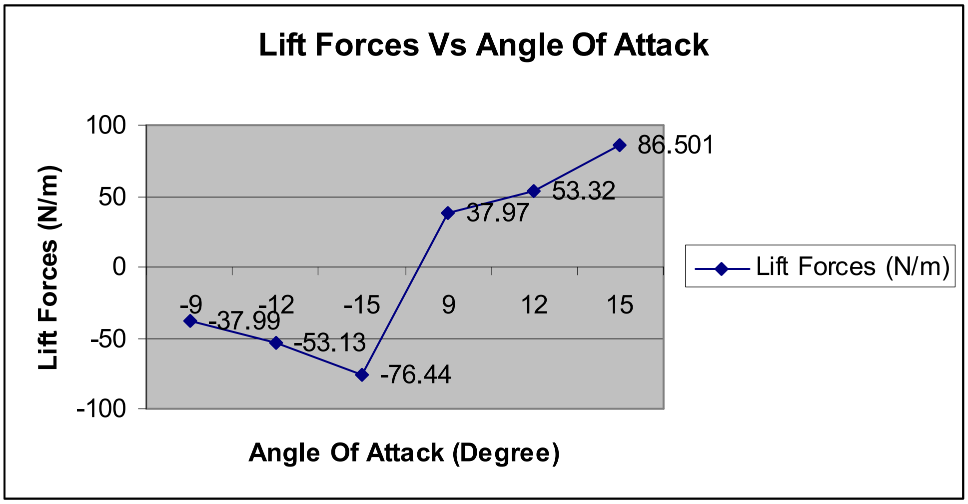


Figure 19: Ellipse Wing Shape

Shown below is the result of the lift forces generated:

Angle Of Attack (degree)	Lift Forces (N/m)
-9	- 37.99
-12	- 53.13
-15	- 76.44
3	11.71
9	37.97
12	53.32
15	86.501

Table 3 : Angle Of Attack Effect on Ellipse Lift Forces



Graph 2 : Ellipse Lift Forces Vs Angle of Attack

From Table 3 and Graph 1, we can see that the lift force of an ellipse wing is directly related to the angle of attack. Increasing angle of attack is associated with increasing lift forces.

As the angle of attack on the wing of an ellipse increases, pressure different between upper and lower streamline also changes. At the angle of attack either at negative degree value or positive degree value, the ellipse wing created almost the same amount of lift forces. This is due to the symmetrical shape of the ellipse wing. From this analysis, the best angle of attack for this ellipse wing is **either at -15 degree or at 15 degree angle**.

** The analysis data can be viewed at Appendix page

4.1.3 Preliminary Testing

As planned, the first experiment for the project will be held just after the mid-semester break or during Week 7 in this semester. The project needs to use the Water Tank that was located at Civil Department Fluid Mechanics Lab. During this lab experiment, the author will try to run the project and gather any possible data achieved. With the help of student from Electrical and Electronic Department, the author will try to use the oscilloscope to plot the data and then transfer it into a computer to be interprets. Shown below is the project that has been set up at the Water Tank.

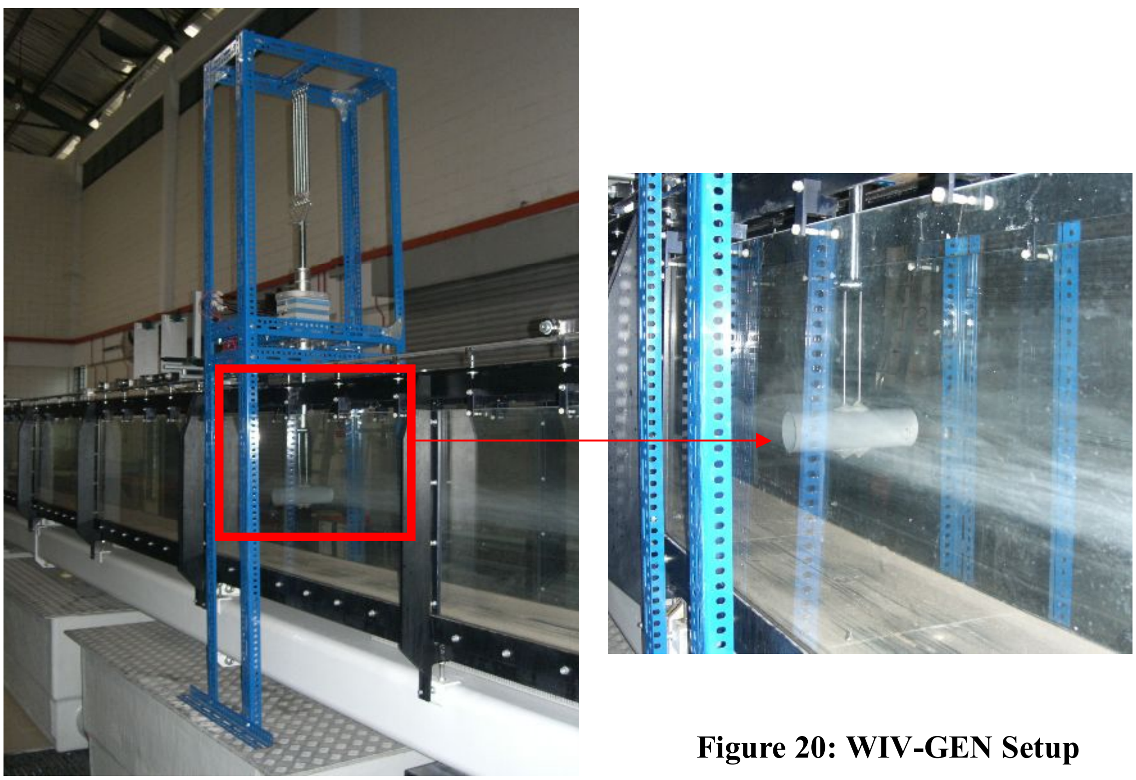
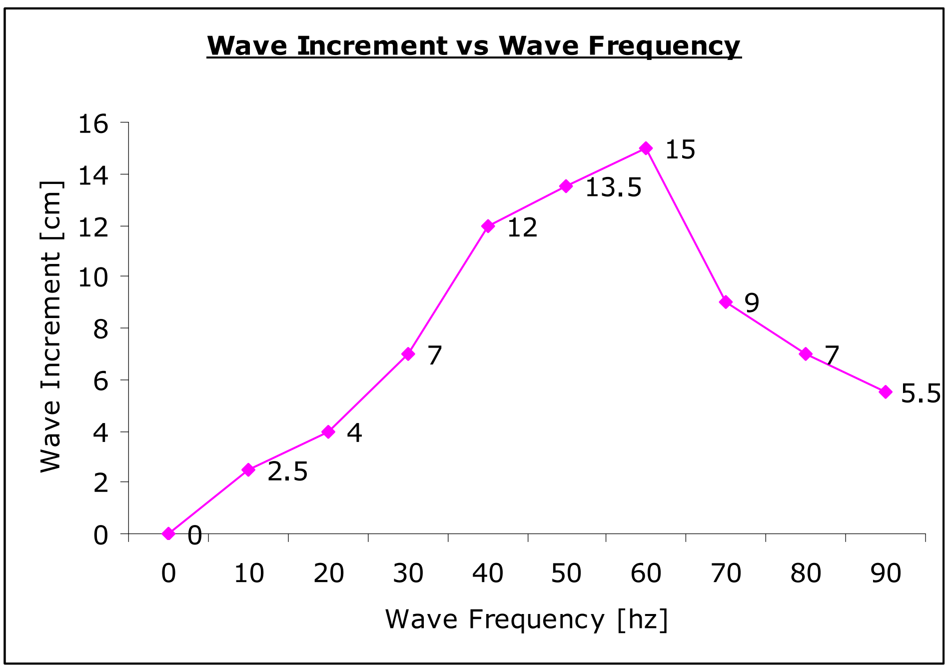


Figure 20: WIV-GEN Setup

Stated below are some data on the wave that collected during the preliminary testing.

Wave Frequency [hz]	Wave Increment [cm]
0	0.0
10	2.5
20	4.0
30	7.0
40	12.0
50	13.5
60	15.0
70	9.0
80	7.0
90	5.5

Table 4 : Wave Increment for certain Wave Frequency



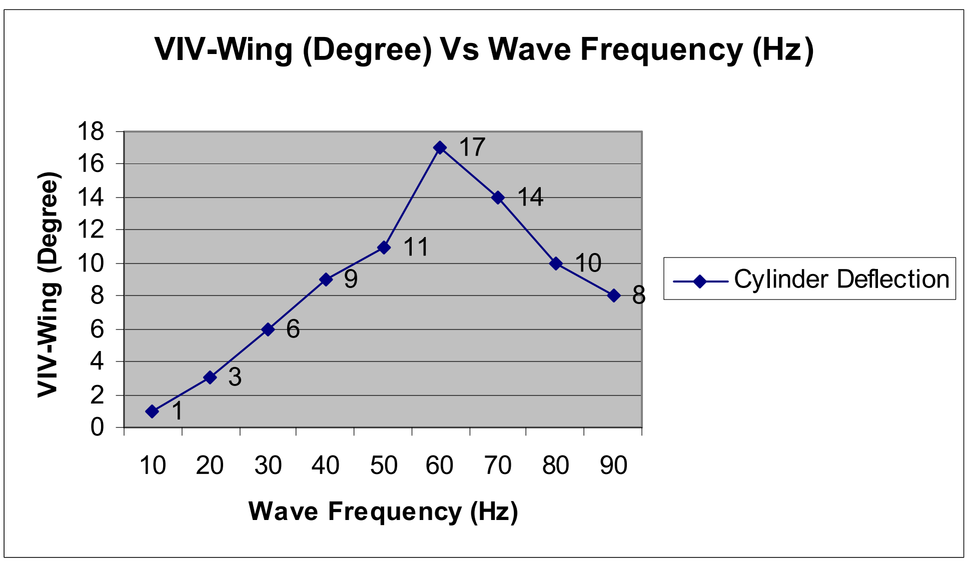
Graph 3 : Wave Increment vs Wave Frequency

From Graph 1: Wave Increment Vs Wave Frequency, the wave height increased when wave frequency increased. The increment of the wave height increase until it reaches 60 Hz and after that the wave height starts to decrease again. At frequency more than 60 Hz, the wave height was short and the movement of the wave was fast compare to the wave at low frequency.

During the preliminary testing, due to insufficient force from the Vortex Induced Vibration, no result or no electricity was collected. It is because the Wave Tank does not have sufficient velocity of current needed by the project. But there was some movement at the VIV-Wing itself and the data was collected was shown below:

Wave Frequency (Hz)	VIV-Wing Deflection (Degree)
10	1
20	3
30	6
40	9
50	11
60	17
70	14
80	10
90	8

Table 5: Wing Deflection based on Wave Frequency



Graph 4: Wing Deflection Vs Wave Frequency

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

Wave Induced Vibration Generator is a new source of renewable energy that uses the velocity of the sea current. This project differs than conventional Wave Generator where the wing was submerged underneath the sea where it uses the sea current flow that more stable than the normal wave height. The project translates and captures the energy from the Wave-Induced Element and converts it into electricity. The linear vertical motion generated by Wave Induced Vibration (WIV) is used as the force to translate magnet pack linearly within a stator coil to generate electricity. The concept behind the Wave Induced Vibration is all about the shape of the wing that generates induced forces.

After analysis has been done, the aerofoil shape is choose to be the best design that can generate the lift forces to power the linear generator and the circular shape will be alternative design to power the linear generator using the Vortex Induced Vibration forces. Although no electricity generated from the linear generator due to limitation of the Wave Tank, the author believe the design will work if the project is supplied with sufficient flow velocity.

5.2 RECOMMENDATION

5.2.1 Possible location to set up the project in the future.

Normal Tidal Energy Generator requires about 5 meter head to work with high efficiency. This kind of tidal can harm the marine life and also destroying the coral underneath the sea. In other hand, current energy converters such as water mills/turbines require at least 4 knots to be efficient. But Wave Induced Vibration Generator is one of the new technologies that give high and efficient energy without destroying the environment. It gives high energy density and also mechanically simple or in other word the total cost to built it is rather low compare to conventional generator.

The author personally suggests that Wave Induced Vibration Generator project can be set up around Malaysia's sea due to its high efficiency. The location in the open sea is the best place to set up the project as it uses the current velocity to generate the forces. Picture below show the possible location to set up the project.

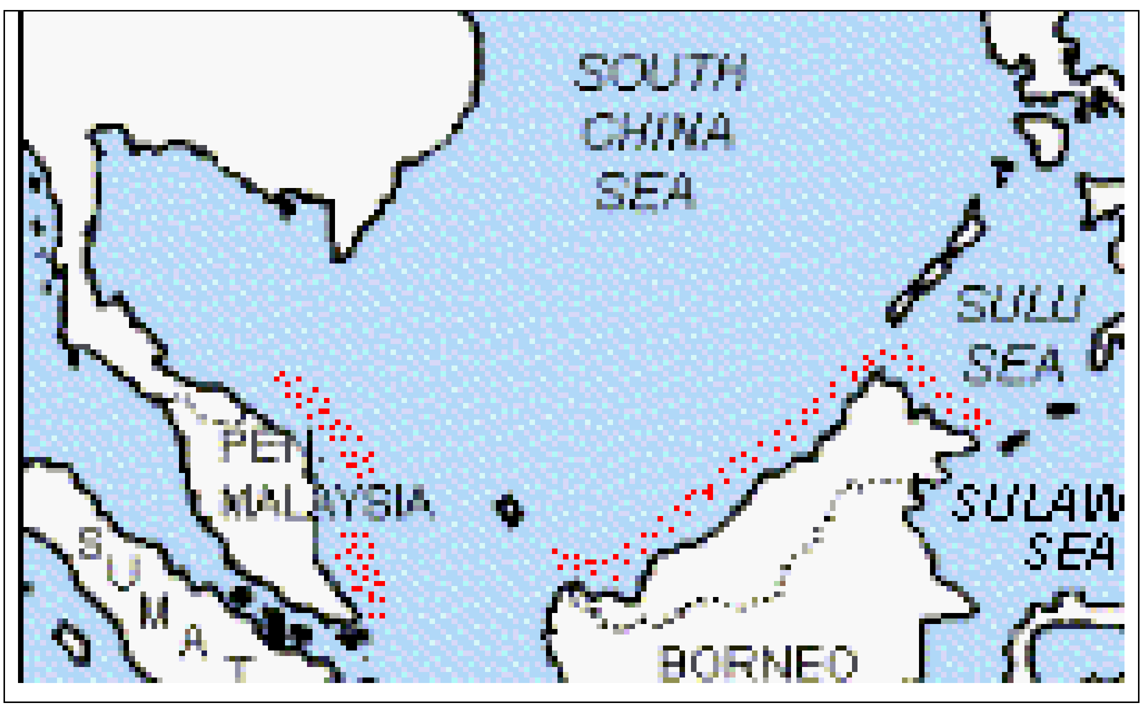


Figure 21: Possible Location of WIV-Gen (Red Dot)

5.2.2 Alternative setup location

This project does not rely on 100% wave generation but it relies on the velocity of the fluids that goes through the wing to generate forces to power a linear generator. So it means that it can be used in any fluids including normal air. For example when a car moving at a high velocity, the fluid velocity passed the car also will be high and the author think we can take advantages from this situation. Imagine if the small scale wave induced generator was located at the back spoiler of the car, the fluid velocity generated will supply the forces to the wing to power the linear generator. From there, the amount electricity generated can be transferred to be used back on the car. It is a new renewable energy~!!.

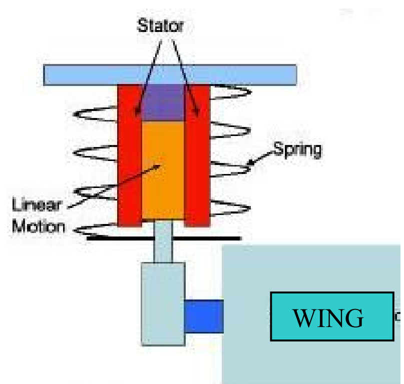


Figure 34: WIV-Gen at the car spoiler

CHAPTER 7

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APPENDICES LIST