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ABSTRACT

This report is about wave power generator. In the last decades, as a result of climate changes as well as energy self-sufficiency desires, renewable energy has grabbed the attentions of many across the world. The aim of this project is to design and manufacture wave power generator as a solution to compensate the increasing demands on energy. At this regard, electricity generation from motion of sea waves, project components and its materials will be discussed in details. Then related design equations will be solved using mathematics knowledge. This will be followed by explanations over manufacturing as well as assembling processes. The performance of the designed system will be tested experimentally and finally, the obtained values of efficiencies are $\eta_t = 32.8\,\%$ for the turbine efficiency and $\eta_P = 1.17\%$ for power efficiency. As a conclusion, this project can be useful for governments and public across the world, especially for islands such as Cyprus.

Key words: Renewable energy, wave energy, water column, turbine blades, turbine, generator.

LIST OF SYMBOLS

A	Cross-section-area (m^2).
b	Blade length(m).
c	Chord length (m).
C_d	Drag coefficient (non-dimensional number).
C_l	Lift coefficient (non-dimensional number).
C_T	Torque coefficient (%).
D	Diameter of the pipe (m).
F_a	Axial force acting on the airfoil blade (Newton).
Ft	Tangential force acting on airfoil blade (Newton).
g	Acceleration of gravity (m/s^2).
L/D	Pipe length to diameter ratio.
N	Number of blades.
n	Number of revolution.
P	Power (watt).
Δp	Pressure loss (Pa).
ΔP_T	Total pressure drop.
R_{av}	Average radius of the blades (m).
R_H	Hub radius (m).

R_T Tip radius of the rotor (m).

Re Reynolds number (non-dimensional number).

T Torque (Nm).

V Velocity of air (m/s).

V_A Axial velocity of air cross turbine (m/s).

V_t Tip linear velocity (m/s).

w Rotational speed of turbine (rad/s).

W_R Resultant relative velocity (m/s).

$\propto$ Angle of attack (°).

β Angle of incidence (°).

γ Angle between cord line and turbine tangential velocity (°).

Ω Rotational speed of rotor (rad/s).

λ Wave length (m).

ρ Density (kg/m^3).

μ Dynamic viscosity ($N.s/m^2$).

ε Surface roughness of the pipe (mm).

η_t Efficiency of turbine (%).

η_P Overall efficiency (%).

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CHAPTER I: INTRODUCTION

In this chapter an introduction to renewable energy will be presented and the importance of these technologies will be shown by answering why renewable energy is used, illustrating diverse sources of this energy, wave energy with its harvesting devices will be discussed briefly, and finally the project objectives and report organization will be mentioned.

1.1 Why Renewable Energy?

Population of the world is increasing dramatically, and it is expected to double with approximately 10 to 12 billion by the end of 21st century [1], accordingly the population demands on energy will grow as well. In order to meet these demands new sources of energy are required to be found as well as being replaced with conventional resources such as fossil fuel, which are on its way to deplete, and nuclear power.

The reduction of conventional resources is not the only problem. Besides, these sources impose hazardous and dangerous impacts on the environment for instance air pollution, ice melting, global warming and greenhouse effect.

Enacting new obligations as well as worldwide consensus over consolidation of renewable energy will have a major contribution in the solution of these complicated problems.

1.2 Renewable Energy Resources

Renewable energy has been diversified into a large number of resources in the last few years. It started with some basic technologies such as wind and flow energy, while in these days many sources and energy harvesting techniques are available.

1.2.1 Solar Energy:

By using various technologies, several forms of energy can be generated by absorbing and converting the solar radiation into another form of energy. For instance, electricity can be generated from solar radiation directly by using Photovoltaic devices (Solar Cells), as well as heat from solar water heating systems and solar collectors.

1.2.2 Wind Energy:

Wind energy is plentiful, therefore number of wind turbines has been enlarged dramatically in the last few years. According to the statistics, in the last 3 years, the number of wind turbines that are used to generate electricity have exceeded 20,000 turbine, where the number of those which used to pump water is over a million [1].

1.2.3 Wave Energy:

Plenty of ideas and designs were proposed for extracting and harvesting energy from sea and ocean waves. Several of these experimental designs were tested, yet the technology has not reached the commercial stage.

1.2.4 Hydroelectricity:

With a contribution of over 20% of the world electricity production, and capacity that can exceeds the capacity of conventional power station, hydroelectricity is one of the most important and considerable sources of renewable energy.

It is highly efficient, reliable, have relatively a long life time cycle and it can be controlled easily. Furthermore it is possible to add extra elements of storage into the electricity supply system to allow compensation for the varying capacity of other renewable sources and the variation of electricity demands.

There are several devices and applications for extracting energy from small and medium sized river and streams which have various flow rates with or without the use of dams.

1.3 Wave Energy in Details

Sea waves (distinct from internal waves which are caused by difference between hot and cold currents) are the transferred energy from wind to the sea/ocean. As the wind moves over the sea, an interaction occurs between the wind and the surface of water which leads to formation of waves. The generated energy differs into two kinds, first one is Kinetic Energy which is expressed by the motion and velocity of water particles, and second kind is the Potential Energy which is stored in the mass of the displaced particles away from its original mean level. The size (amplitude) and length of waves are related directly to the velocity and blow period of the wind.

The energy of waves is related to several parameter such as wind velocity, depth of sea/ocean, location (cape, bay …etc.) and storm areas, the nature of the shore (sandy or rocky shore), and it differs between open oceans and closed seas.

1.4 Project Objectives

In the project, detailed study about wave energy will be introduced. Calculations, comparison and advantages and limitations will be illustrated, and several methods of optimizing the old applications of OWC (oscillating Water Column) will be discussed.

This project is based on previous projects, devices and work done. Prototype will be built, tested and analyzed mathematically and technically by the suitable apparatuses (e.g. Wind Tunnel, Anemometer and Pressure Gauge), and software (SolidWorks).

The goal of this prototype is to achieve more than 1% for power efficiency and simultaneously with more than 40% turbine efficiency.

1.5 Organization of the Report

In chapter I renewable energy concepts are briefly introduced, various sources of this energy (Solar, Wind, Wave and Hydroelectricity) are mentioned and detailed explanation of wave energy is given. Later on, project objectives are also mentioned.

In chapter II a literature review will be introduced showing the history, distribution of waves in Cyprus, finally previous works done, advantages and disadvantages of each one.

In chapter III design and analysis of the prototype will be discussed in details with the components, material selection and manufacturing plan. In this chapter knowledge of mathematical for design calculation will be applied.

In chapter IV manufacturing, assembling and testing processes will be illustrated.

In chapter V experimental results will be obtained and final results will be discussed.

Last chapter is about future works and conclusion.

This report will include appendices (Logbooks, Gant chart, Technical drawings, Engineering standards and Manufacturing photos).

CHAPTER II: LITERATURE REVIEW

In this chapter old publication and researches will be surveyed, wave energy potential in Cyprus will be discussed and finally three devices will be illustrated.

2.1 Recent History of Wave Energy

Due to energy crisis in 1970, the interest in renewable energy increased all around the world, primarily Wave Energy, as a hidden source of electricity power in the sea/ocean. The ability to generate power from sea/ocean waves has grabbed the attention of people for centuries.

Despite, there were notions over hundred years old, it was only in 1970s that applicable plans started to unfold. Generally, these innovative wave energy diversion projects had trivial imperfections. There was a great probability that some of them might play an important role in energy contribution in the long run. In regions of the world where the wave climate is active and where classic energy sources are expensive, such as outlying islands, some of them might be already competitively.

Due to the large amount of wave energy resources available in the world, a large number of apparatus concepts invented, mathematically sculptured and experimentally examined with support from sponsors. Regrettably, deficient of money and time were determined to bring the various apparatus and the related technologies to ripeness.

However, a lower labor has been maintained by research teams, and a prototype of oscillating water column (OWC) has been prepared in Islay in Scotland. That small-scale apparatuses should have been considered as a source of energy for islands instead of diesel which supply the main energy source. Japan, Norway, UK and USA increased their research and development programs. Norway has an instant local need for wave energy since it gratifies an electricity nearly derived hydro-resources. It would like to distribute wave energy technology all around the world. Japan, moreover, in dire need more clean power provenance, but is surrounded by a humble wave climate [1].

A number of prototype projects had been examined at different sites around the world, but yet there had been modicum utilization of wave energy enormous potential. Through this century there was an expectation to see more prototype testing and development of some projects.

This section will explore the wave energy potential in Cyprus and talk in details about three mechanisms of generating energy from waves.

2.2 Wave Energy Potential in Cyprus

The acclimation and use of fabricated methodologies for the utilization of renewable energy naval resources is of the major cases today for the environmental science community. In this framework, the utilization of wave energy potential for coastal and island states looks to be one of the remarkable solutions from research and technological standpoint.

In the year 2005, wave energy resource for the Levantine Basin in Eastern Mediterranean was observed. Accurate data created by the wave model WAM was formed with accuracy of 1 arc minute (1.5-1.8 km), to emulate the wave states of the whole of Eastern Mediterranean sea [2].

The following Figure 2.1 shows the mean monthly values of wave energy potential for the year 2005 in Cyprus. Throughout the winter period (December to March) the values of wave power increased up to (5-6 KW/m). April and November can be described as fleeting months.

Generally, the wave energy potential is essentially influenced by the variation of the big wave height, a fact which is in accordance with the second order relation with it, and subaltern by the energy period which has a steady behavior because of domestic wave climatology.

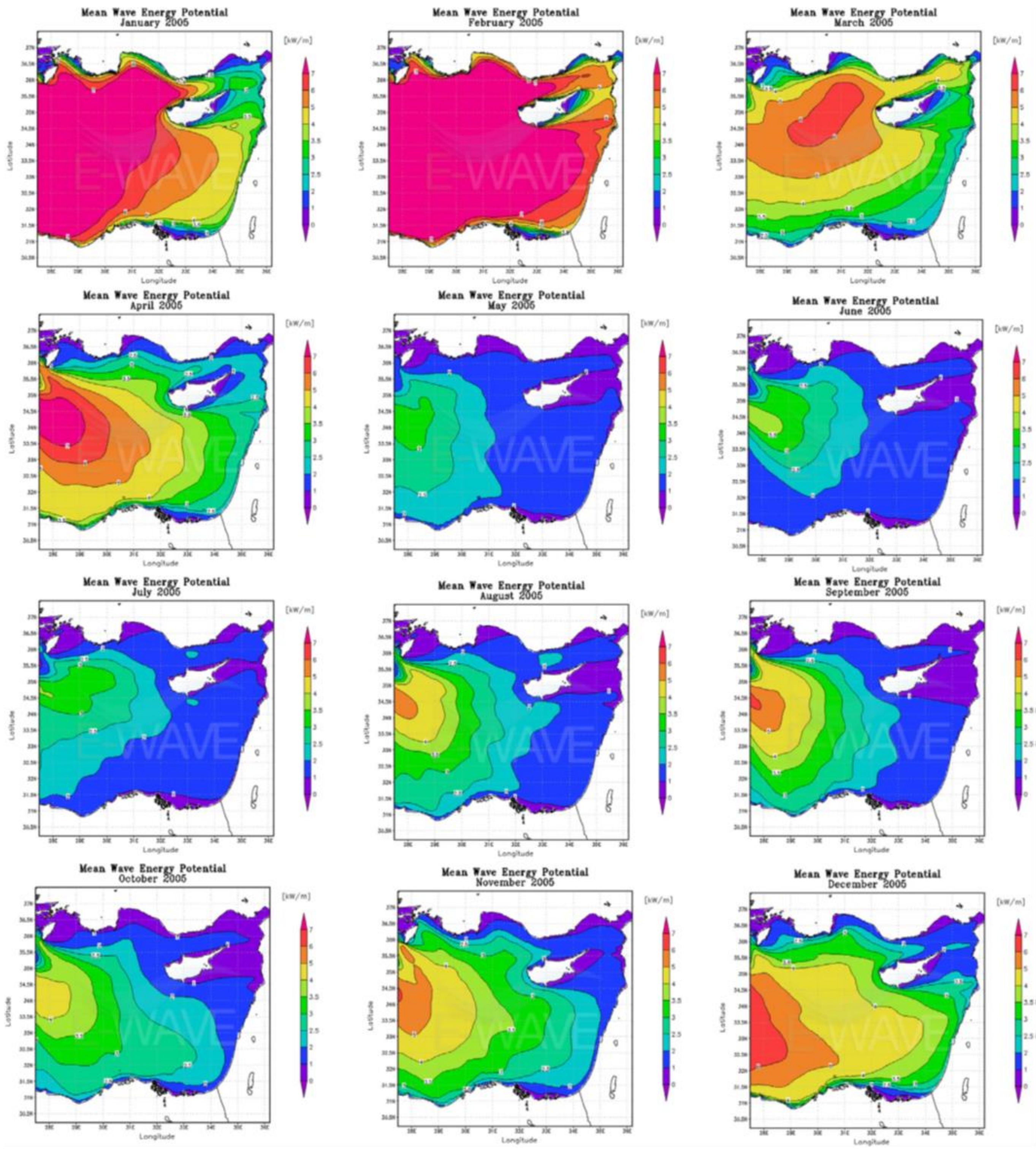

Figure 2.1 Monthly values of wave energy probability for the year 2005 in Cyprus [2].

2.3 Wave Energy Devices

There were many different types of wave energy converters around the world, in this section these devices will be classified according to Wave Energy Collector types (WEC). There are three main types of WEC which they are:

- Oscillating Water Column (OWC).
- Hinged Contour Device.
- Buoyant Moored Device.

2.3.1 Oscillating Water Column (OWC) (the Limpet)

The Limpet (Land Installed Marine Power Energy Transmitter) is an oscillating water column based on the beach wave (OWC), which was developed by Queen's University in Belfast and Wavegen of Inverness. It is based on the experience gained from the wave energy devices in the United Kingdom, and OWC on Eli [3].

Oscillating water column consists of partially submerged structure, which is opened to the sea water below it. This structure is attached to the column of air on top of the previous column of water. As waves affecting the device, they cause the water column rise and fall, which compresses and depressurizes air column above it. As a result, this compressed air will flow in and out of the atmosphere by a turbine. This energy can be extracted from the system and being used in order to generate electricity. Power is usually extracted from the reversed air flow by wells' turbine, which has the property of rotating in same directions regardless of the direction of air flow. As shown in Figure 2.2 below.

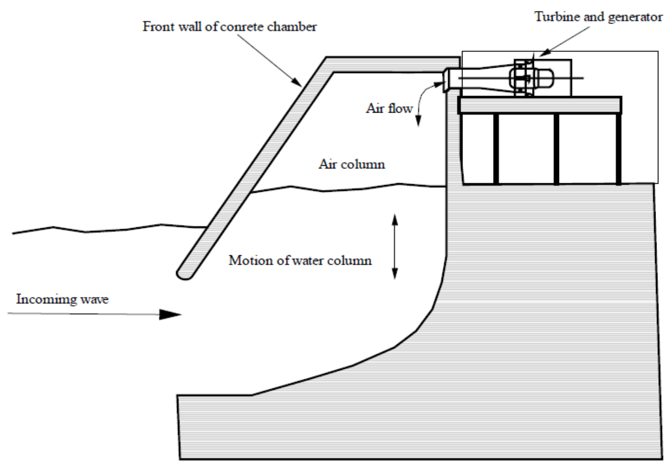

Figure 2.2 Outline of the LIMPET [4].

2.3.2 Pelamis Sea Snake

Pelamis development program has covered all parts of the design from the primary concept refinement through to accelerated cycle testing of individual components of reliability.

Pelamis Wave Power tested their first project at the European wave Energy, Scotland between 2004 and 2007. This was the first wave power machine in the world Which was designed at 750 kW.

The Pelamis as shown in Figure 2.3 absorbs the energy of waves and converts it into electricity. It operates in water depths more than 50m and is usually installed 2-10 km away from the beach. The machine is rated at 750 kW with a capacity factor of 25-40%, depending on the conditions at the work site. Usually one of these machines can provide sufficient power to meet the electricity demand of 500 homes [5].

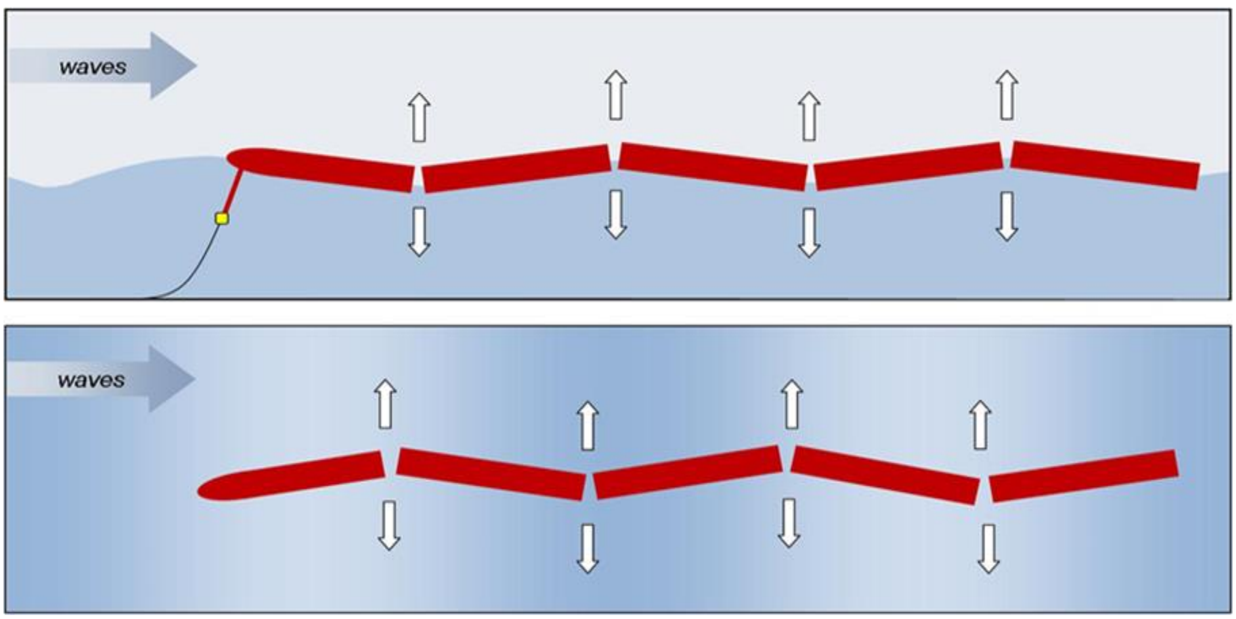

Figure 2.3 Pelamis Sea snake [6].

2.3.3 PowerBuoy

The PowerBuoy design process focuses on explanation of operational requirements at the beginning of the effort. A refined closed loop process optimizes different parts of the system. It's a small power station for generating electricity from wave power. It is a point absorber or float, currently in use at 10 sites around the world, especially in Australia and the United States.

It generates electricity using a hydroelectric turbine. PowerBuoys, can be connected to the electrical grid by power transference cables or can operate independently in a deep water. As shown in Figure 2.4.

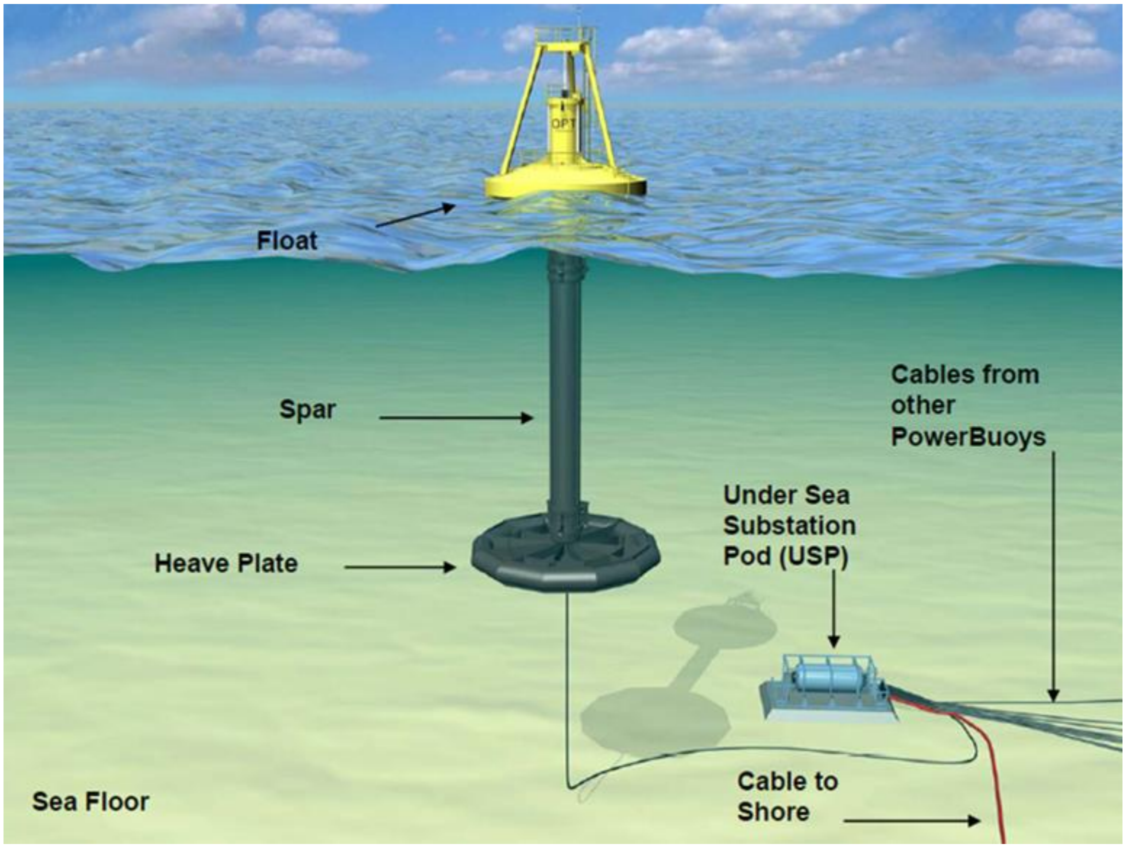

Figure 2.4 PowerBouy Power station [7].

2.4 Advantages and Disadvantages

All wave energy harvesting devices have common advantage which is generating energy in the regions which suffer from lack of other resources (e.g. cloudy weather which prevents usage of solar energy). Nevertheless, these devices share a common drawback that is the high initial costs and low efficiency. Moreover, the obtained power is not constant because of the variation of the wave's parameters (length, speed, amplitude, frequency…etc.) during the year from month to month.

Now, each device's advantages and disadvantages will be discussed in details:

2.4.1. Limpet

The first superiority of this device over others is the components are simple to be manufactured, assembled, maintained and replaced. It is located on the shore line which makes it easier to construct it and reach to it when being maintained. There is no direct contact with the sea water, which leads to longer life span of the device and its components.

Disadvantages are: the complex shape of the turbine blades (Wells Turbine). Another drawback is the symmetric shape of its blades which reduces the obtainable efficiency of the turbine.

2.4.2. Pelamis Sea Snake

The privilege of this device is that the machine is rated at 750 kW with a capacity factor of 25-40%, depending on the conditions at the work site.

On the other hand, the defect of this device is the need of a deep-water (more than 50 meters) so it is placed far from shore line (usually 2-10 Km from the beach); this leads to hard maintenance as well as difficulties in reaching to this device in emergencies. It also requires to be fixed at the bottom of the ocean by cables. This leads to higher costs and harmful impacts on the sea creatures.

2.4.3 PowerBouy

PowerBouy and Pelamis Sea Snake has almost same pros and cons. Nevertheless, PowerBouy has relatively small volume comparing to Pelamis which means higher efficiency in terms of area usage. For example a 300 sq. miles of area estimated to be capable of producing electricity to all California houses [8].

CHAPTER III: DESIGN & ANALYSIS

In this chapter the component of the project will be listed, suitable material will be selected according to the parameters of each part of the project, the related equation and calculation will be carried, and finally cost analysis of the project will be presented.

3.1 Prototype Components

Every system consists of several components, choosing the suitable components is crucial in any system and it should be chosen carefully in order to assure the proper operation of the system. The prototype of a sea wave device consists of several components. The design itself is simple and easy to be manufactured and analyzed. This project is made of five main components; water container, air duct, turbine, generator and sub-station or after generation components. In this section, the system's components will be discussed in details.

3.1.1 Container, Air Duct, Pipe, Wave Generating Device & Support

In the prototype, an open water tank is being used. Galvanized steel sheet is used in order to resist the high corrosion effect of the salty sea water. The container is being used in the prototype to contain the water that mimics the sea water and its waves.

Air duct is series of channels that are used to supply air to the propeller by sucking and blowing. The oscillating water in the bottom of the air duct will mimic the OWC, and as discussed before, the elevation of water column caused by waves will produce a differential pressure between the air in the duct and the outside air leading to the motion of the air inside the duct forward and backward which will rotates the propeller. The air duct has a decreasing cross-sectional area which concentrates the air current leading to higher air speed and pressure differential. The materials of air ducts varies depending on its usage and application but the most known materials are: Galvanized steel, aluminum, polyurethane, fiberglass and other materials.

The pipe is used to fix the generator inside it, also as an exit and inlet for air flux.

Wave generation mechanism is used to simulate sea waves in the prototype.

And finally the support is used to carry the whole prototype on itself and stabilize the prototype as shown in the following Figure 3.1.

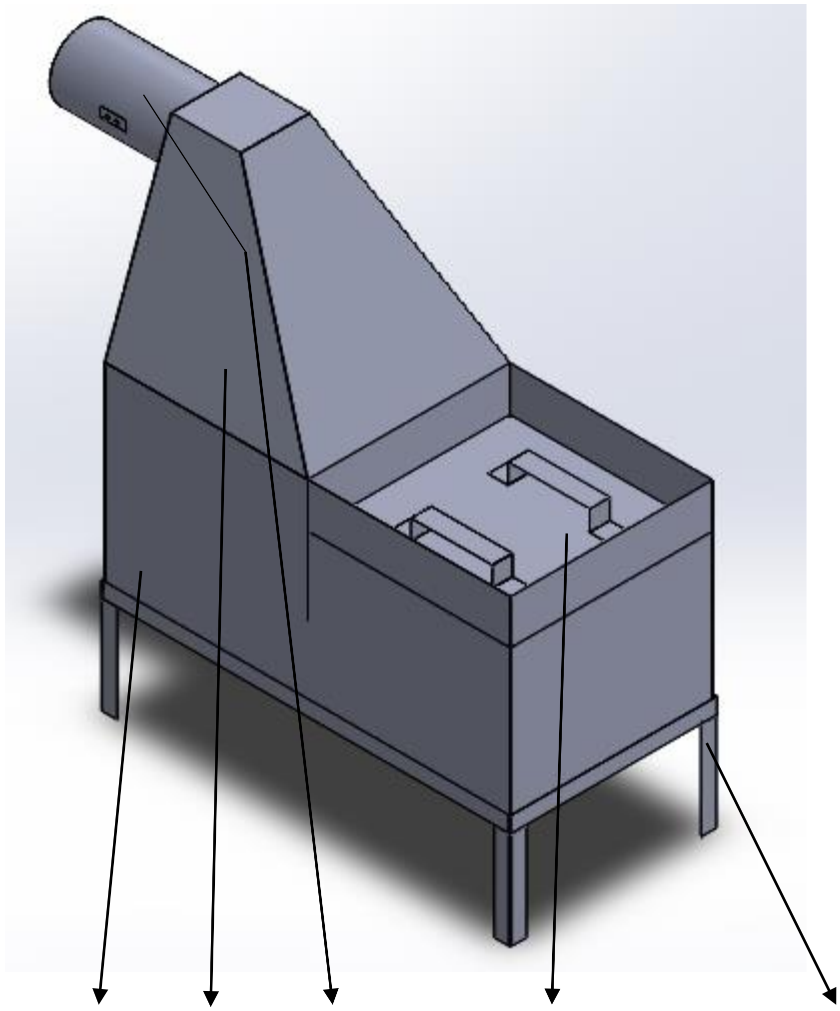

Figure 3.1 Container, Air Duct, Pipe, Wave Generating Device & Support.

3.1.3 Turbine

A turbine is a mechanical device that harvests and extracts energy from the flow of fluid or gases and converts this energy into rotation (useful mechanical work). The turbine is consists of a rotor part which is a drum and blades. The variable pitch, configuration and angle of the blades allows to convert flow energy into rotation. The blades angle and pitch are defined according to several parameters such: flow velocity, density of the fluid/gas, turbine desired RPM and several other factors.

In the application of sea waves and OWC, special type of turbines with special configurations are used, this type is known as "Wells Turbine". Wells turbine is a symmetric turbine as shown in Figure 3.2, i.e. its foils have a symmetric profile. This property assures that despite the flow direction weather it is forward or backward, the turbine will rotates in the same direction.

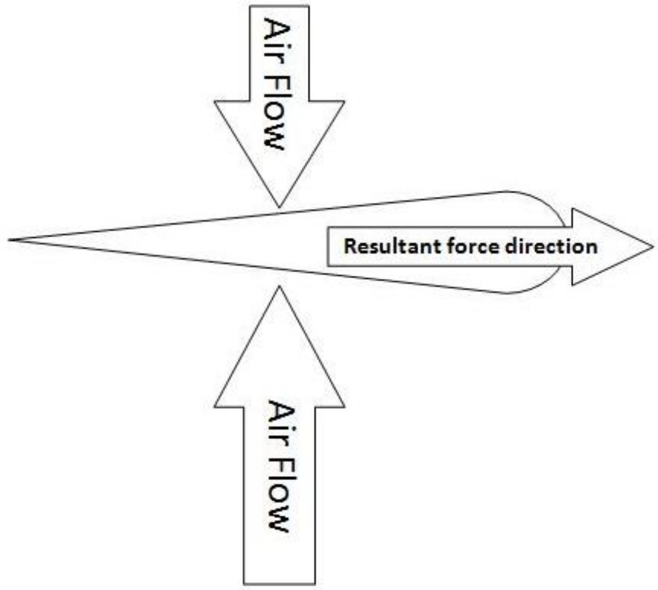

Figure 3.2 Schematic of resultant force on wells turbine [9].

3.1.4 Generator

Generator or dynamo is an electrical device that converts the mechanical work (rotation of the rotating parts) into electrical current through the use of electromagnetic induction. Generator is a general term for the devices that generate AC and DC current, where dynamo is more specified for the generators of DC current. The following Figure 3.3 shows the design of prototype's turbine and generator.

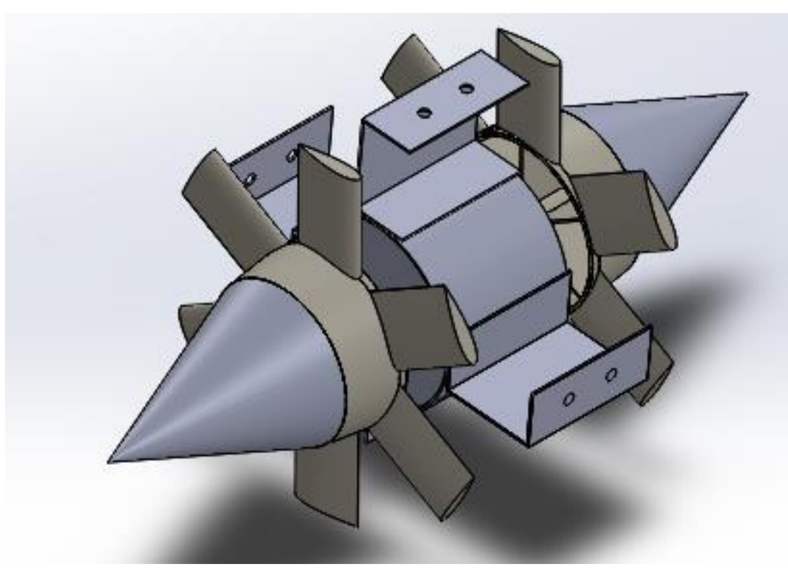

Figure 3.3 Turbine & Generator.

3.2 Material Selection and manufacturing methods

Different types of materials are used in manufacturing the prototype, each part is made from different material than others. The material should be selected to fit the specifications and the properties of each part of the prototype.

3.2.1 Galvanized Steel

Galvanized steel sheets as shown in the Figure 3.4 are available everywhere with different thicknesses and they are easy to deal with it in all manufacturing processes. The container, wave generator mechanism, air duct and the pipe (where the turbine is mounted) are all made from galvanized steel in order to resist corrosion. The standard dimensions of the used sheets were: 2000x1000x1 mm x 2 sheets.

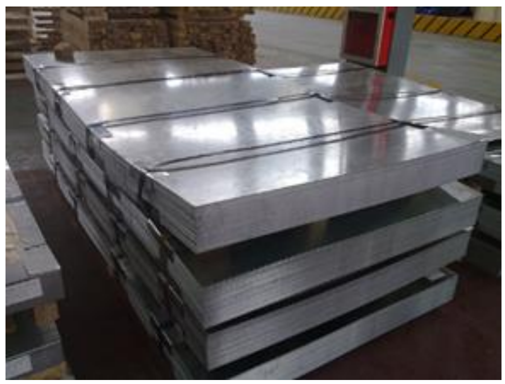

Figure 3.4 Galvanized steel sheets [10].

3.2.2 Angle Iron

The prototype support is made from angle iron 40x40x4 mm as shown in Figure 3.5.

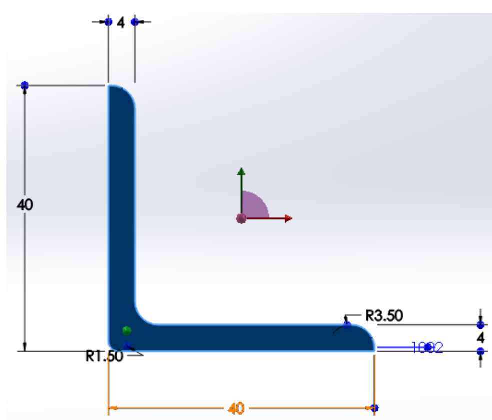

Figure 3.5 Steel bar L profile.

3.2.3 ABS-FDM Plastic

ABS (Acrylonitrile Butadiene Styrene) the turbine blades are made from ABS-FDM material, which is a very light material (density equal to 104 kg per cubic meter).

3.2.4 Polystyrene

Polystyrene is a light weight material that is easy to be formed and shaped to any desired shape. This material is used in front of each pulley of the turbine to direct the air toward the blades and reduce pressure drop and improve the aerodynamics properties.

3.2.5 Manufacturing Methods

In order to manufacture our design, components are manufactured in the workshop using conventional (Cutting, drilling, welding, grinding, joining) and modern manufacturing techniques (3D Printer).

3.3 Calculations

This section is about prototype studying and calculations by using the relative equations, starting from studying wave profile, then air flow, pressure drop, and finally turbine design.

3.3.1 Wave Velocity and Airflow

When the elevations of waves are parallel to the spreading direction, the wave could be longitudinal, it could be transverse when the elevations perpendicular to the spreading direction. These elevations have periodically time-varying displacement in which the direction is perpendicular or parallel, therefore the acceleration and velocity are also periodically time-varying in same directions as shown in Figure 3.6.

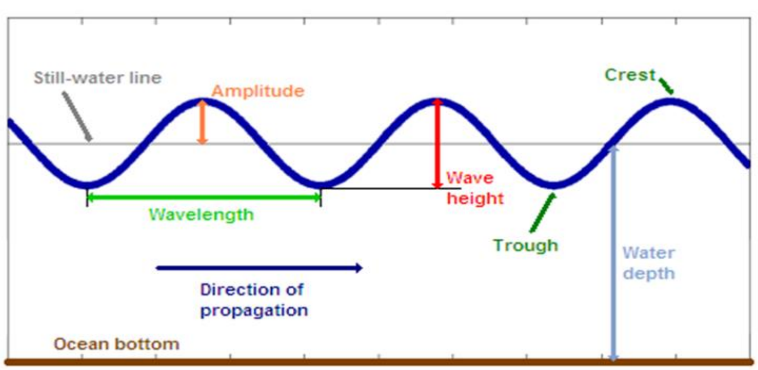

Figure 3.6 Wave profile [11].

According to variation of the wave height, some amount of air will be pressed into the duct. The area of the duct is not constant. It decreases in the area in order to increase the speed of air till it reaches the sufficient velocity to rotate the turbine.

On water surface the velocity of air is equal to the velocity of wave:

For deep water: $d > \frac{\lambda}{2}$ $$v = \sqrt{\frac{g.\lambda}{2.\pi}} \quad (3.1)$$

For shallow water: $d < \frac{\lambda}{20}$ $$v = \sqrt{g.d} \quad (3.2)$$

Where: v is the velocity of air (m/s), g acceleration of gravity (m/s²), and **λ** wave length (m).

According to continuity equation (3.3) the velocity of the air at the outlet of the duct can be obtained by considering the velocity of waves on water surface and the inlet cross-sectional area of the duct and cross-sectional area of the outlet of the duct:

$$A_1.v_1 = A_2.v_2 \quad (3.3)$$

A_1 is cross-sectional area of the inlet of the duct (m²), A_2 is cross-sectional area of the outlet of the duct (m²), v_1 is the velocity of the air at the inlet of duct (m/s), and v_2 is the velocity of the air at the outlet of the duct (m/s).

From equation (3.3) the velocity of air at the inlet of the pipe where the turbine is located can be obtained.

Reynolds equation (3.4) is used to determine the nature of flow:

$$Re = \frac{\rho.v.d}{\mu} \quad (3.4)$$

Re is Reynolds number (non-dimensional number), ρ is the density of air (kg/m³), v is the velocity of air (m/s), d is the diameter of the pipe (m), and μ is the dynamic viscosity of air (N.s/m²).

Pressure drop in the duct can be calculated from equation (3.5):

$$\Delta p = \rho . g . \Delta h \quad (3.5)$$

Pressure drop in the pipe can be determined from equation (3.6):

$$\Delta p = f_D \frac{L}{D} \frac{\rho v^2}{2} \quad (3.6)$$

Δp is the pressure loss due to friction (Pa), *L/D* is the ratio of the length to diameter of the pipe, *ρ* is the density of the fluid (kg/m3), *v* is the mean flow velocity (m/s), *Δh* is the height difference (m), and f_D is Darcy Friction Factor; a (dimensionless) coefficient of laminar, or turbulent flow.

For laminar flow (Re < 2100): $f_D = 64/\mathrm{Re}$ (3.7)

For the completely turbulent region: $\frac{1}{\sqrt{f_D}} = -2\log[\frac{\varepsilon}{3.7D} + \frac{2.51}{Re\sqrt{f_D}}]$ (3.8)

ε is the surface roughness of the pipe (mm).

The pressure drop at the turbine can be calculated from Bernoulli equation that can be seen below:

$$\Delta p = \frac{1}{2}\rho \,.\, ({v_2}^2 - {v_1}^2) \quad (3.9)$$

3.2.2 Turbine Calculations

The torque on the blade can be written as:

$$T = \frac{1}{2}\rho . \Omega^2 . N . c . (C_l . sin\beta - C_d . cos\beta) . (R_T - R_H) . R_{av} \quad (3.10)$$

T is the torque (Nm), *Ω* is the rotational speed of turbine (rad/s), *ρ* is the density of the fluid (kg/m3), *β* is the angle of incidence:

$$\beta = tan^{-1}(\frac{v_t}{v_A}) \quad (3.11)$$

$$\propto = \beta - \gamma \quad (3.12)$$

∝ Is the angle of attack (see Figure 3.7), *γ* angel between cord line and turbine tangential velocity:

Tip linear velocity: $V_t = \Omega . R_T$ (3.13)

The axial velocity of air cross turbine (see Figure 3.8): $V_A = V . \frac{R_T^2}{(R_T^2 - R_H^2)}$ (3.14)

Resultant relative velocity: $W_R^2 = V_t^2 + V_A^2$ (3.15)

N is the number of blades, *c* is chord length (m), C_l is lift coefficient, C_d is drag coefficient C_l & C_d values are taken from Table 1, R_T is the tip radius of the rotor, R_H is the hub radius, and R_{av} is the average radius of the blades:

$$R_{av} = R_H + \frac{R_T - R_H}{2} \quad (3.16)$$

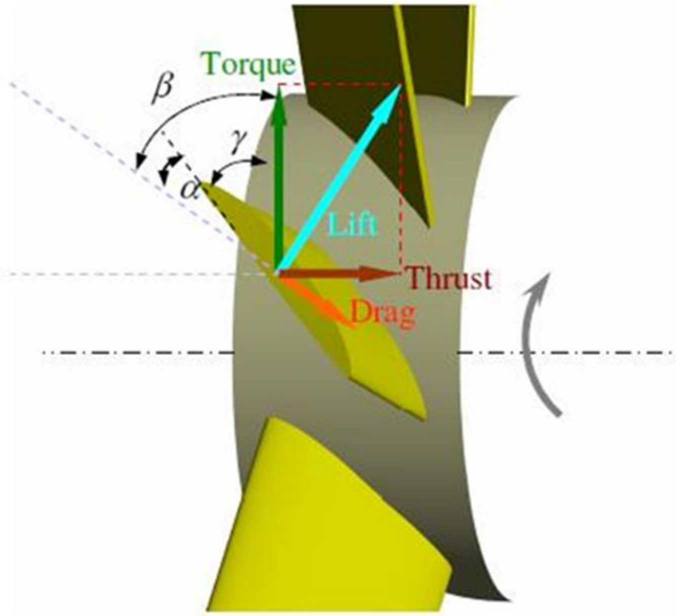

Figure 3.7 illustration the forces on turbine blade [12].

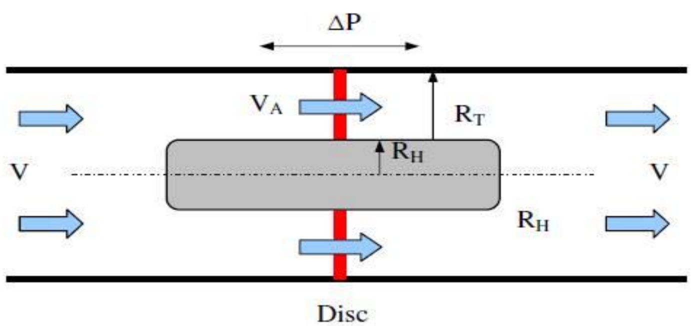

Figure 3.8 illustration for axial velocity and other parameters [12].

Table 1 Calculated and Experimental Aerodynamic Coefficients [13].

α deg	C_l				C_d				C_m			
	calc	exp	error $\times10^4$	% error	calc	exp	error $\times10^4$	% error	calc	exp	error $\times10^4$	% error
0	0.1558	0.1469	89	6	0.0062	0.0070	-8	-11	-0.0446	-0.0443	-3	1
1.02	0.2755	0.2716	39	1	0.0062	0.0072	-10	-14	-0.0475	-0.0491	16	-3
5.13	0.7542	0.7609	-67	-1	0.0069	0.0070	-1	-1	-0.0586	-0.0609	23	-4
9.22	1.0575	1.0385	190	2	0.0416	0.0214	202	95	-0.0574	-0.0495	-79	16
14.24	1.3932	1.1104	2828	25	0.0675	0.0900	-225	-25	-0.0496	-0.0513	17	-3
20.15	1.2507	0.9113	3394	37	0.1784	0.1851	-67	-4	-0.0607	-0.0903	396	-33

Maximum potential torque on the blades:

$$T_{max} = \frac{1}{2}\rho . A_T . V_A^2 . R_T \quad (3.17)$$

A_T is section area of the pipe where the turbine has been fixed.

Then Torque efficiency C_T calculated from the following formula:

$$C_T = \frac{T}{T_{max}} \quad (3.18)$$

Lift force (L) (as shown in Figure 3.4), which is the force that perpendicular to the airflow direction can be calculated from the following equation:

$$L = \frac{1}{2}\rho . C_l . W_R^2 . c . b . N \quad (3.19)$$

Where b is blade length.

Drag force (D), which is the force that parallel to the airflow direction can be calculated from the following equation:

$$D = \frac{1}{2}\rho . C_d . W_R^2 . c . b . N \quad (3.20)$$

The axial force F_a which is acting on the airfoil blade can be determined from the following equation:

$$F_a = L . cos\beta + D . sin\beta \quad (3.21)$$

The tangential force F_t which is acting on airfoil blade can be determined from the following relation:

$$F_t = L . sin\beta - D . cos\beta \quad (3.22)$$

The relation between torque and power produced from the spinning of turbine can be written as:

$$P = T . \Omega = T . 2\,\pi . \mathrm{n}/60 \quad (3.23)$$

P is the power produced (watt), n is the number of revolutions.

The efficiency of turbine η_t can be calculated from the relation

$$\eta_t = \frac{Power\ out}{Power\ in} = \frac{T.\Omega}{\Delta P_T . \pi\ (\mathrm{R_T}^2 - \mathrm{R_H}^2) . V_a} \quad (3.24)$$

Where: ΔP_T is total pressure drop.

Overall efficiency η_P can be calculated from the relation

$$\eta_P = \frac{V.I}{T.\Omega} \quad (3.25)$$

V is output voltage (volt), *I* output current produced (A).

3.4 Theoretical Results

The aim of this project is to achieve more than 1% of power efficiency, and more than 40% of turbine efficiency.

Assumptions:

According to similar projects produced before:

$\lambda = 0.2\,m,$ $n = 200$; $\eta_t = 50\%,$ and $\eta_P = 3\%.$

Solution:

Plugging λ into equation (3.1):

$v_1 = 0.599\,m/s.$

Cross-sectional area of inlet of the duct $A_1 = 0.25\,m^2$

Cross-sectional area of inlet of the pipe $A_2 = 0.0227\,m^2$

By plugging previous values into equation (3.3):

The velocity of the air at the inlet of the pipe: $v_2 = 6.156\,m/s.$

To determine if the air flow is turbulent or laminar, Reynolds number was calculating by plugging the following values:

(At air temperature T=20°C, density of air was taken$\rho = 1.2041\,\frac{Kg}{m^3},$ $v_2 = 6.156\,m/s,$ $\mu = 1.846\ x\ 10^{-5}\ \frac{N.s}{m^2},g = 9.81\ \frac{m}{s^2}$) into equation (3.4):

$Re = 68262\ >\ 4000$ so the flow is turbulent.

Friction factor inside the pipe calculated from equation (3.8) by taking several iterations for the both sides of the equation:

$f_D = 0.022$. Where: ε = 0.15 m for GL.steel, D = 0.17 m.

Pressure drop in the pipe is calculated by plugging the results into equation (3.6):

$\Delta p\ = 0.517\ Pa.$

Pressure drop in the duct due to level elevation was found from equation (3.5):

$\Delta p = 7.38\ Pa.$

$R_T = 0.08\ m$, $R_H = 0.0375\ m$, plugging into equation (3.16) average radius of the blades is calculated:

$\mathrm{R_{av}} = 0.0588\ m.$

From equation (3.13) tip linear velocity is calculated:

$V_t = 1.6752\ mls.$

From equation (3.14) axial velocity of air cross turbine:

$V_A = 7.89\ mls.$

From equation (3.15) resultant relative velocity is calculated:

$W_R = 8.07\ m/s.$

Angle of incidence was calculated from equation (3.11):

$\beta = 11.73\ °,$

$\gamma = 0°$ That gives from equation (3.12) angle of attack:

$\propto = 11.73°.$

From the Table 3 at $\propto = 11.49°$ by applying linear interpolation:

$C_l = 1.266$, $C_d = 0.055$.

$c = 0.032\ m$, $N = 12$.

The torque in turbine blades is calculated from equation (3.10):

$T = 0.0496\ N.m.$

From equation (3.17) maximum obtainable torque can be calculated:

$T_{max} = 0.068\ N.m.$

The coefficient of torque is obtained from equation (3.18):

$C_T = 72.9$ %.

To find lift and drag forces; Lift force from equation (3.19) is:

$L == 0.692\ N.$

And drag force from equation (3.20) is:

$D = 0.0311\ N.$

From previous values, tangential and axial forces is calculated as follows; axial force from equation (3.21):

$F_a = 0.0684\ N.$

And tangential force from equation (3.22):

$F_t = 0.1104\ N.$

In order to calculate output power from equation (3.23):

$P\ = 0.9423\ Watt.$

From equation (3.24):

$\eta_t =\ 50$ %; $\Delta P_T = 15.23\ Pa$

Pressure drop at the turbine blades is found from equation (3.9):

$\Delta p\ = 7.33\ Pa$; $v_{Exit} = 5.07\ mls.$

Overall efficiency $\eta_P =\ 3\%$ when closed circuit constructed using 120 Ohm resistor, plugging into equation (3.25):

$\eta_P = \frac{V.I}{T.\Omega} = 3$ %; $\quad V.I = \eta_P.T.\Omega = 0.03x0.9423 = 0.0283\ Watt.$

The following Table 2 show the theoretical results.

Table 2 Theoritical Results

Item	Theoretical Result	Unit
$\boldsymbol{\lambda}$	0.2	m
n	200	
$\boldsymbol{\Omega}$	20.94	rad/s
$\boldsymbol{v_1}$	0.599	m/s
$\boldsymbol{v_2}$	6.156	m/s
$\boldsymbol{v_{Exit}}$	5.07	m/s
$\boldsymbol{\Delta P_T}$	15.23	Pa
$\boldsymbol{V_A}$	7.89	m/s
$\boldsymbol{V_t}$	1.6752	m/s
$\boldsymbol{W_R}$	8.07	m/s
β	11.73	°
$\boldsymbol{\gamma}$	0	°
∝	11.73	°
$\boldsymbol{C_l}$	1.266	
$\boldsymbol{C_d}$	0.055	
c	0.032	m
N	12	
$\boldsymbol{T}$	0.0496	N.m
$\boldsymbol{T_{max}}$	0.068	N.m
$\boldsymbol{C_T}$	72.9%	
$\boldsymbol{L}$	0.692	N
$\boldsymbol{D}$	0.0311	N
$\boldsymbol{F_a}$	0.0648	N
$\boldsymbol{F_t}$	0.1104	N
$\boldsymbol{P}$	0.9423	W
η_t	50%	
η_P	3%	

3.5 Cost Analysis and Suppliers List

In this section required materials availability, cost of ordered materials and suppliers list will be introduced.

3.5.1 Required Parts List

The following Table 2 shows the required materials and whether they were available in Turkey or TRNC or no.

Table 3 Required Materials Availability.

Required parts list		
Part	**Material**	**AV/NA in Turkey and TRNC**
Generator	-	AV
Turbine blades	ABS-FDM Plastic	NA
Turbine Pulley	PVC	AV
Cone	Polystyrene	AV
air duct	GL.steel	AV
Container	GL.steel	AV
Support	angular steel bar	AV
Assembly material	Adhesive	AV
	Steel bolts	AV
	Nuts	AV
	Rivet	AV
	welding Electrodes E-7018	AV
	Epoxy paste	AV
	silicon	AV
	paint	AV

3.5.2 Costs of Ordered Materials

The following Table 3 illustrates the costs of ordered materials.

Table 4 Ordered Materials.

Costs of ordered material			
Material	**Qty**	**Price**	**total cost**
Generator	1	245	TRL 245.00
Turbine blades	12	14	TRL 168.00
Turbine pulley	2	20	TRL 40.00
Polystyrene board	1	10	TRL 10.00
Adhesive	1	7.5	TRL 7.50
GL.Sheet metal	2	100	TRL 200.00
Paint	1	10	TRL 10.00
Silicon	1	25	TRL 25.00
Transportation	-	150	TRL 150.00
TOTAL			**TRL 855.50**

3.5.3 Suppliers List

The following Table 4 shows the suppliers and their addresses.

Table 5 Supplier List.

<table>
<tr><th colspan="3">Suppliers list</th></tr>
<tr><th>Material</th><th>Supplier</th><th>Address</th></tr>
<tr><td>Generator</td><td>PEDAL SPORTIVE</td><td>Istanbul, Turkey</td></tr>
<tr><td>Turbine blades</td><td>LAB 3D Print -Cyprus</td><td>Nicosia, Cyprus</td></tr>
<tr><td>Turbine pulley</td><td>TURKOGLU ELEKTRONIK</td><td rowspan="6">Gazimagusa, TRNC</td></tr>
<tr><td>Polystyrene board</td><td>YAPI KIRTASIYE</td></tr>
<tr><td>Adhesive</td><td></td></tr>
<tr><td>GL.Sheet metal</td><td>RAHMI SARI TURBO GUNESLIK</td></tr>
<tr><td>Paint</td><td rowspan="2">YUSUF PARALIK.CO.LTD.</td></tr>
<tr><td>Silicon</td></tr>
</table>

CHAPTER IV: MANUFACTURIN, ASSEMBLY & TESTING

This chapter will explain how the manufacturing process was conducted; also details of assembly step by step and testing of final product will be reported.

4.1 Manufacturing

To manufacture the prototype, components were manufactured in the workshop using conventional (Cutting, drilling, welding, grinding, joining) and modern manufacturing techniques (3D Printer).

4.1.1 Container & Air Duct

The following steps were taken in order to manufacture the container and air duct:

1- Cutting the galvanized sheet (check Figures E1-3 in Appendix-E) to the following segments:

a- (1500x1000x1 mm) 1 piece. (See APPENDIX-C-DWG.NO.00-02-01)

b- (500x500x1 mm) 2 pieces. (See APPENDIX-C-DWG.NO.00-02-02)

c- (951x500x1 mm) 1 piece. (See APPENDIX-C-DWG.NO.00-02-03)

d- (1072x500x1 mm) 1 piece. (See APPENDIX-C-DWG.NO.00-02-04)

e- (858x500x1 mm) 1 piece. (See APPENDIX-C-DWG.NO.00-02-05)

The following Figure 4.1 shows cutting processes by using sheet metal guillotine (Shearing-machine).

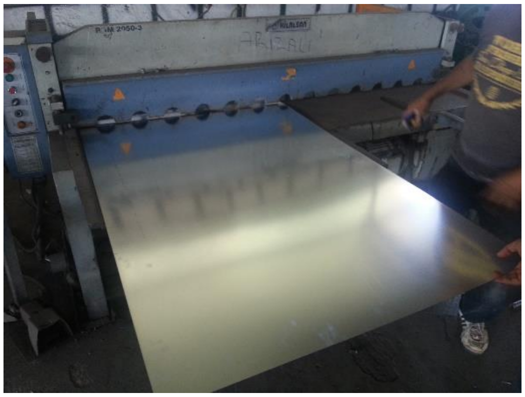

Figure 4.1 Cutting sheets metal by (Shearing-Machine).

2- Bending process was applied on segments (a, d and e) according to the design drawing as it is shown in 2 Figure E-3 and in the following Figure 4.

Figure 4.2 Bending process.

3- Manual Metal Arc Welding process was applied in order to join all the parts to each other to form the desire design (see APPENDIX-C-DWG.NO.00-02) as shown in Figures E5-7 in Appendix-E and in the following Figure 4.3.

Figure 4.3 MMAW Process.

4- Surface finishing by using grinding machine shown in Figure 4.4.

Figure 4.4 Surface finishing.

5- Epoxy paste was applied over all welded surfaces shown in Figure 4.5 to protect it from corrosion effects.

Figure 4.5 Applying Epoxy paste over welded part.

6- Painting the welded parts by Epoxy coating paint as shown in Figures E8-10 and the following Figure 4.6.

Figure 4.6 Painting process.

4.1.2 Pipe & Wave Generating Device

Pipe, where the turbine fixed inside it, was manufactured from galvanized steel sheet which had been cut (554x300x1 mm). Then, rolled by using manual rolling machine to the diameter 170 mm and 300 mm length (see APPENDIX-C-DWG.NO.00-02.06), then the edges of the sheets were welded to each other by spot welding process.

Wave generating device was manufactured from galvanized sheet metal that has been cut into desired dimension (500x500x1 mm). Then, two handles were made from galvanized sheet meats also welded to the previous sheet by spot welding process as shown in Figure 4.7.

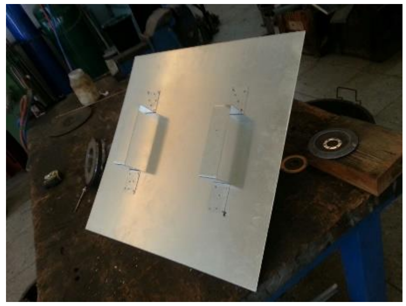

Figure 4.7 Wave generating device.

4.1.3 Prototype Support

Support has been manufactured from standard angle iron 40*40*4 mm to the following segments:

A-) 1010 mm 2 pieces, B-) 510 mm 2 Pieces, C-) 240 mm 4 Pieces.

Figure 4.8 shows cutting process by using portable grinding machine.

Figure 4.8 Cutting support's parts.

Then, the cut parts have been welded to each other according to the related drawing (as shown in APPENDIX-C- DWG.N0.00-01) by MMAW Process as shown in Figure 4.9.

Figure 4.9 Support manufacturing process.

4.1.4 Turbine Blades

The designed turbine has 12 blades. These blades (as shown in figure 4.10) were designed by SolidWorks based on NACA 0021 shape (see Appendix-D-Table D.1) and then manufactured by 3Dprinter.

Figure 4.10 Turbine blade.

4.1.5 Generator

Generator was made by modifying AC fan motor into AC generator (see Figures E11-13 in Appendix-E) as the following steps:

1- Disassembly of the motor as shown in Figure 4.11.

Figure 4.11 Disassemble fan motor.

2- Drilling six holes on the external surface of the rotor as shown in Figure 4.12.

Figure 4.12 Drilling holes on external surface of the rotor.

3- Fixing a magnate at each hole using epoxy glue as shown in Figure 4.13.

Figure 4.13 Fixing magnate on rotor.

4- Reassembly of the motor and testing it as shown in Figure 4.14.

Figure 4.14 Reassembly the motor.

By this process the motor was converted to generator by creating magnetic field between the coils of the stator. As the rotor is being rotated, the magnetic field will be changed and alternated on coils, causing electrons movement and electrical current generation.

Blades were glued on 2 plastic pulleys (6 blades on each pulley by Cyanoacrylate adhesive).

Generator support that holds the generator inside the pipe was made from galvanized steel sheet segments by cutting and rolling to the outer diameter of the generator. Two U shaped segments were spot welded on the support in order to hold it in place and modifying.

Cones were made from cubic polystyrene parts and shaped to conical shapes.

4.2 Assembly

The assembly process was accomplished by joining all the parts of the system together as shown in Figure 4.15.

Figure 4.15 Prototype after assembly.

First of all, the pulleys with turbine blades were assembled to the generator shaft by nuts as shown in Figure 4.16.

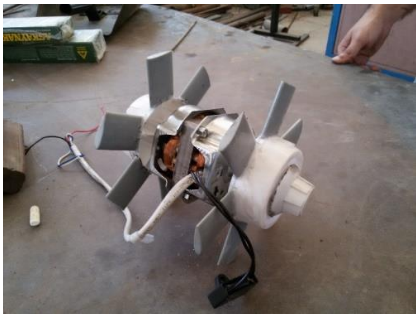

Figure 4.16 Turbine & Generator assembly.

Secondly, the assembled turbine-generator set had been joined with its supports and cones inside the pipe by screws and nuts. Then, the air pipe has been assembled on the topside of the air duct as shown in Figure 4.17 by using rivets.

Figure 4.17 Pipe & Air duct assembly.

Elsewhere, the tank and air collector were mounted on the supports as shown in the figure. Finally, the AVO meter was connected to the generator output plug as shown in Figure 4.18.

Figure 4.18 Final assembly.

Testing of Final Product

After manufacturing process is done, and all components were assembled together, the container is filled with water. The water was pressed and released by wave generating mechanism as shown in Figures E15-19 in Appendix-E. Water level raised and dropped inside the collector according to wave's movement, this alternative elevation difference leaded to frequent positive and negative pressure difference between the space inside the collector and the outer atmosphere. This frequent change leaded the air to move in the pipe forward and backwards. As the air moved it stroked the turbine blades surfaces divided into two components, drag force and lift force. Drag force results into deflection of the blades in the direction of air flow, where lift force causes rotation of the turbine.

The turbine spinning which connected to generator resulted in generating electrical power.

Air velocity before and after the turbine was measured by using Pitot-tube connected to a manometer. Voltage and current of generated electricity were measured using AVO-meter as shown in Figure 4.19.

Figure 4.19 Testing the project.

CHAPTER V: RESULTS AND DISCUSSIONS

In this chapter experimental results will be obtained and plugged into related equations, finally the final results will be discussed.

5.1 Experimental Results

By testing the prototype at constant water wave amplitude, the output of generator was 2.0 volts (open circuit). Then, air velocity at the exit of the pipe and before entering turbine blades were measured, as following, by using manometer that was connected to Pitot tube;

$v_{Exit} = 4.1\ m/s.$

$v_{Before\ turbine} = v_2 = 5.79\ m/s.$

Cross-sectional area of inlet of the duct $A_1 = 0.25\ m^2$

Cross-sectional area of inlet of the pipe $A_2 = 0.0227\ m^2$

By plugging previous values into equation (3.3):

The velocity of the air at the inlet of duct: $v_1 = 0.526\ m/s.$

Plugging v_1 into equation (3.1):

The wave length calculated as $\lambda = 0.177\ m.$

To determine if the air flow is turbulent or laminar, Reynolds number was calculating by plugging the following values:

(At air temperature T=20°C, density of air was taken $\rho = 1.2041\ Kg/m^3$, $v_2 = 5.79\ m/s$, $\mu = 1.846\ x\ 10^{-5}\ N.s/m^2$, $g = 9.81\ m/s^2$) into equation (3.4):

$Re = 64230 > 4000$ so the flow is turbulent.

Friction factor inside the pipe calculated from equation (3.8) by taking several iterations for the both sides of the equation:

$f_D = 0.0229$. Where: ε = 0.15 m for GL.steel, D = 0.17 m.

Pressure drop in the pipe is calculated by plugging the results into equation (3.6):

$\Delta p = 0.48\, Pa.$

Pressure drop in the duct due to level elevation was found from equation (3.5):

$\Delta p = 7.38\, Pa.$

Pressure drop at the turbine blades is found from equation (3.9):

$\Delta p = 10.06\, Pa.$

The overall pressure drop is calculated by summing all pressure drop values:

$\Delta P_T = 17.92\, Pa.$

Rotational speed Ω was measured by calculating number of rotation n and stopwatch

$n = 180\, rpm$ and $\Omega = 18.85\, rad/s.$

$R_T = 0.08\, m$, $R_H = 0.0375\, m$, plugging into equation (3.16) average radius of the blades is calculated:

$\mathrm{R_{av}} = 0.0588\, m.$

From equation (3.13) tip linear velocity is calculated:

$V_t = 1.508\, mls.$

From equation (3.14) axial velocity of air cross turbine:

$V_A = 7.42\, mls.$

From equation (3.15) resultant relative velocity is calculated:

$W_R = 7.57\, m/s.$

Angle of incidence was calculated from equation (3.11):

$\beta == 11.49\,°$,

$\gamma = 0°$ That gives from equation (3.12) angle of attack:

$\propto = 11.49°.$

From the Table 3 at $\propto = 11.49°$ by applying linear interpolation:

$C_l = 1.164$, $C_d = 0.056$.

$c = 0.032\ m$, $N = 12$.

The torque in turbine blades is calculated from equation (3.10):

$T \ == 0.0363\ N.m.$

From equation (3.17) maximum obtainable torque can be calculated:

$T_{max} = 0.0602\ N.m.$

The coefficient of torque is obtained from equation (3.18):

$C_T = 0.603 = 60.3$ %.

To find lift and drag forces; Lift force from equation (3.19) is:

$L = 0.655\ N.$

And drag force from equation (3.20) is:

$D = 0.0315\ N.$

From previous values, tangential and axial forces is calculated as follows; axial force from equation (3.21):

$F_a = 0.0648\ N.$

And tangential force from equation (3.22):

$F_t = 0.0996\ N.$

In order to calculate output power from equation (3.23):

$P \ = 0.684\ Watt.$

From equation (3.24):

$\eta_t = 32.8$ %.

To measure overall efficiency, a closed circuit is constructed using 120 Ohm resistor, the output voltage of the turbine $V = 0.1$ volt and the current $I = 0.08$ A, plugging into equation (3.25):

$\eta_P = \ 1.17$ %.

The following Table 5 show the experimental results and theoretical results.

Table 6 Experimental & Theoretical Results.

Item	Theoretical Result	Experimental Results	Unit
$\boldsymbol{\lambda}$	0.2	0.177	m
n	200	180	
$\boldsymbol{\Omega}$	20.94	18.85	rad/s
$\boldsymbol{v_1}$	0.599	0.526	m/s
$\boldsymbol{v_2}$	6.156	5.79	m/s
$\boldsymbol{v_{Exit}}$	5.07	4.1	m/s
$\boldsymbol{\Delta P_T}$	15.23	17.92	Pa
$\boldsymbol{V_A}$	7.89	7.42	m/s
$\boldsymbol{V_t}$	1.6752	1.508	m/s
$\boldsymbol{W_R}$	8.07	7.57	m/s
$\boldsymbol{\beta}$	11.73	11.49	°
$\boldsymbol{\gamma}$	0	0	°
$\propto$	11.73	11.49	°
$\boldsymbol{C_l}$	1.266	1.164	
$\boldsymbol{C_d}$	0.055	0.056	
$\boldsymbol{T}$	0.0496	0.0363	N.m
$\boldsymbol{T_{max}}$	0.068	0.0602	N.m
$\boldsymbol{C_T}$	72.9%	60.3	
$\boldsymbol{L}$	0.692	0.655	N
$\boldsymbol{D}$	0.0311	0.0315	N
$\boldsymbol{F_a}$	0.0648	0.0648	N
$\boldsymbol{F_t}$	0.1104	0.0996	N
$\boldsymbol{P}$	0.9423	0.684	W
η_t	50%	32.8	
η_P	3%	1.17%	

5.2 Discussion of Results

All results are related mainly to wave's parameters (wave length λ, wave height, amplitude and frequency) as wave height increases the wave kinetic energy will increases which is directly proportional to the velocity at the water surfacev_1 as a result air velocity in the duct v_2 and in the pipe v_A will increases leading to higher rotational velocity Ω and higher torque $T$and so power generation P increased accordingly.

The angle of attack $\propto$ affect directly on the torque. Increasing air velocity across the turbine will increase angle of attack and this will increase the torque.

Generator efficiency $\eta_P = 1.17\%$ was relatively low because it was modify using fan motor by the means of sample materials and manufacturing techniques, nevertheless, the goal which was $\eta_P > 1\%$ is accomplished. On the other hand efficiency (coefficient) of torque $C_T = 60.3\%$ and was acceptable. Finally efficiency of turbine $\eta_t = 32.8\%$ was below the aimed amount which was $\eta_t > 40\%$ because the the calculation were made at wave length $\lambda = 20\ cm$, yet the experimental wave length was $\lambda = 17.7\ cm$ and that explains this slight difference.

Table 7 Testing results

Efficiency	**Power** η_P	**Torque** C_T	**Turbine** η_t
Aimed Amount	> 1%	-	> 40%
Achieved Amount	1.17%	60.3%	32.8%

The obtained results illustrate that with the means of more advanced technologies of manufacturing, the efficiencies could be enhanced to achieve higher gain in power and make this project justified economically.

5.3 Technical Difficulties

Many difficulties were faced during the process of manufacturing, assembling and testing; in manufacturing the chosen sheets were thin which imposed difficulties in welding process, these problem could be overcame by increasing the thickness of sheet metal but that would increase the cost of that project. Also it was hard to obtain materials in TRNC for examples the generator was not available in the market and the university's 3D printer was out of raw materials (powder and resin binder). Measurement devices couldn't be found in the university and the experimental parameters were measured by the old methods.

CHAPTER VI: FUTURE WORKS & CONCLUSION

The future works and developments of the project will be discussed in this chapter as well a final conclusion.

6.1 Future Works

First of all the turbine blades can have variable pitches depending on flow direction in order to obtain the maximum possible efficiency. Second, air speed can be controlled using extra controlled check valve which opens when the air pass over the designed speed to decrease the speed of air. Third, the generator can be optimized in order to increase the efficiency. Finally, a guide pates can be placed in front of turbine blades to guide the air toward the blades and obtain the maximum efficiency by minimizing the drag force and increasing the lift force generated by the turbine blades.

6.2 Conclusion

This report has summarized engineering problem of energy and introduced brief information about this problem. Then, wave energy was introduced as a solution for this problem, many previous projects were illustrated and comparison has been made between advantages and disadvantages of each one. Later, project components were proposed, materials were selected, design related equations were solved using mathematic knowledge and cost analysis with detailed list of suppliers were introduced. Moreover, manufacturing steps were explained in detail, assembling process has been illustrated, testing was conducted and experimental results were reported. Finally, these experimental results were plugged into related equations and calculations were made. As a conclusion, wave power energy can be used as a subsidiary power source generation. Although the efficiency is low and accordingly not feasible but with more advanced and precise manufacturing technologies it can become feasible and economically justified.

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APPENDICES

APPENDIX-A: Logbooks.

APPENDIX-B: Gantt Chart.

APPENDIX-C: Drawings.

APPENDIX-D: Engineering Standards Used.

APPENDIX-E: Manufacturing Photos.

APPENDIX-F: Poster, Website & Final CD.

APPENDIX-A: LOG BOOKS

Logbook: Mhd Imad Eddin Khchifati 138484

Dates	Details
21/10/2014	Firstly, I received our capstone project from our advisor Lec. Cafer Kızılörs with my team members. Our advisor explained briefly about the project
23/10/2014	Group meeting was held. I started working on Gantt chart.
25/10/2014	I started researching about sea waves various systems.
28/10/2014	My team members and I suggested several designs and ideas with our advisor
31/10/2014	Group meeting was held and duties were distributed where I took the responsibility to write the introduction chapter
03/11/2014	My team members and I visited our advisor for extra information and explanation. Preliminary design was suggested.
07/11/2014	My team members and I started drawings and calculations.
14/11/2014	We met our advisor and asked for his help in designing turbine.
15/11/2014	I started writing the introduction chapter
24/11/2014	I sent the introduction chapter to our advisor for checking and we visited him for his notes and comments.
05/12/2014	I started writing the components part of the design chapter
09/12/2014	My team members and I started writing calculations part.
13/12/2014	I drew air collector system using SolidWorks software
17/12/2014	I sent my final works to my other team members and we worked on organization of the report
29/12/2014	I visited our advisor with my team members for report's finished parts checking
01/01/2015	Group meeting was held. We worked on repairing our report.
05/01/2015	I visited our advisor with my team members for report's checking
09/01/2015	We have submitted the final report to the supervisor Assit.Prof. Neriman Ozada

16/01/2015	I had a meeting with my group mates to search for materials and components
23/01/2015	Another meeting was organized to distribute duties for searching duties
02/02/2015	My group mates and I had meeting to share our search results.
10/02/2015	We decided which suppliers to visit and started in Famagusta industrial areas.
13/02/2015	Another visit to suppliers in Famagusta was organized.
18/02/2015	We visited several suppliers in Nicosia
16/03/2015	We had a meeting with our adviser to share information
24/03/2015	I have visited GENC store to check for materials.
04/04/2015	I had meeting with my group mates
14/04/2015	I helped Awad in Turbine testing
24/04/2015	We had a meeting with our adviser to check our search results share opinions
25/04/2015	With my group mates, we have modified the design
01/05/2015	We have ordered the sheet metal and I started working on the support
20/05/2015	We have assembled the parts which we were working on
22/05/2015	I have sealed the corners of assembly with silicone sealant
27/05/2015	My group mates and I started experimenting and taking data
28/05/2015	We had a meeting to start calculations of our project
03/06/2015	We started working on the report
12/06/2015	We had a meeting with our adviser to show him our work and take feedbacks
15/06/2015	My group mates and I had meeting to finalize the report
17/06/2015	We showed our final work to our adviser

Logbook: Abdullah Terkaoui 138565

Dates	Details
21/10/2014	Firstly, I received our capstone project from our advisor Lec. Cafer Kızılörs with my team members. Our advisor explained briefly about the project
23/10/2014	Group meeting was held
26/10/2014	I started researching about sea waves various systems.
28/10/2014	Me and my team members suggested several designs and ideas with our advisor
31/10/2014	Group meeting was held and duties were distributed where I took the responsibility to write the historical view about wave generation and wave energy probability in Cyprus in chapter II
03/11/2014	I and my team members visited our advisor for extra information and explanation. Preliminary design was suggested.
07/11/2014	Me and my team members started drawings and calculations.
14/11/2014	We met our advisor and asked for his help in designing turbine.
24/11/2014	Me and my team members visited our advisor and asked him for his notes and comments on Chapter I
1/12/2014	I started writing my duties in chapter II
07/12/2014	I started writing the material selected part of the chapter III
09/12/2014	Me and my team members started writing calculations part
11/12/2014	I drew steel barrel and its support with wave generation mechanism by using SolidWorks software
15/12/2014	I sent my final works to my partners and we worked on organization of the report
29/12/2014	I visited our advisor with my team members for report's finished parts checking
01/01/2015	Group meeting was held. We worked on repairing our report.
05/01/2015	I visited our advisor with my team partners for report's checking
06/01/2014	I prepared my logbook

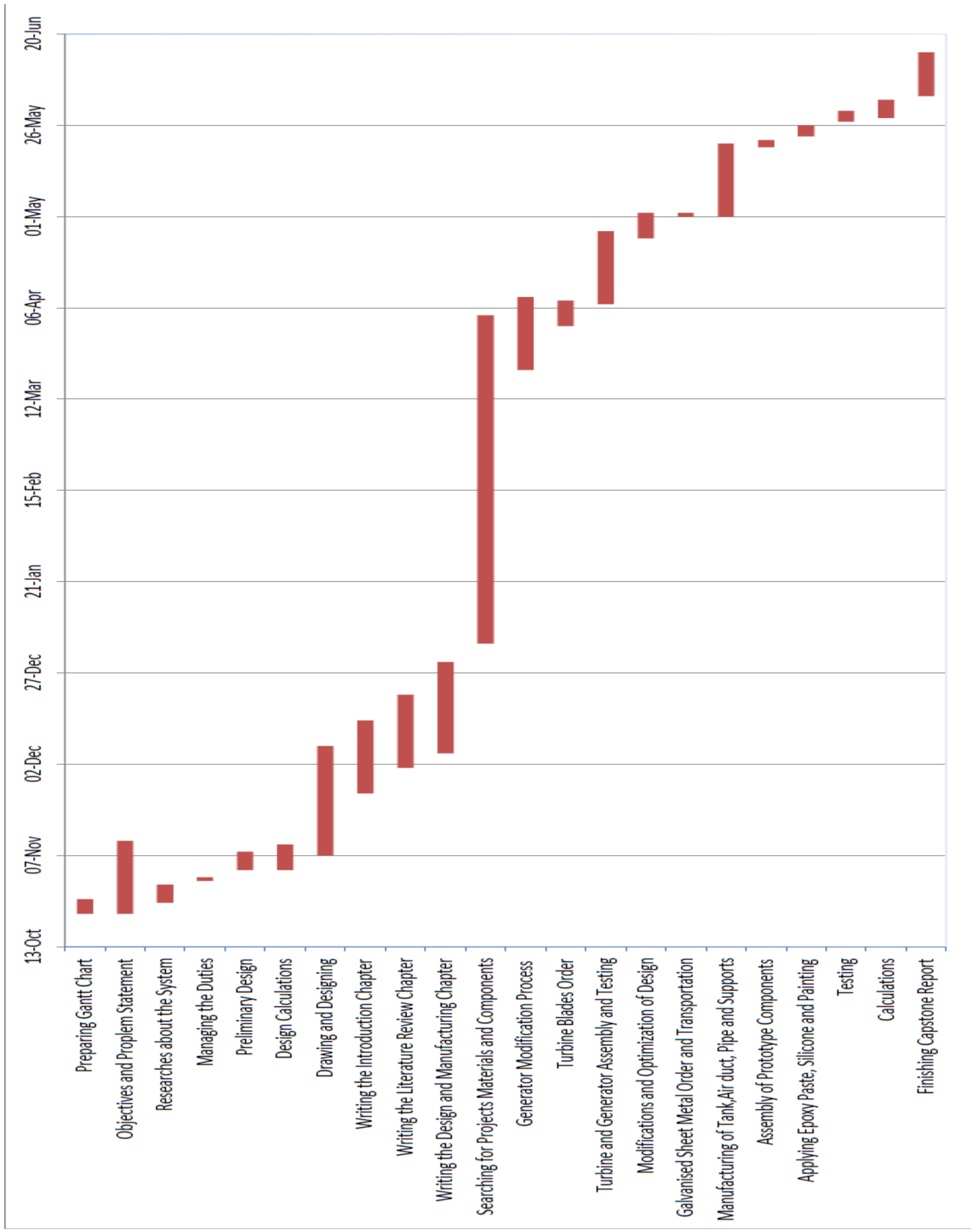
09/01/2015	We have submitted the final report to the supervisor Assit.Prof. Neriman Ozada
16/01/2015	I had a meeting with my group mates to search for materials and components
23/01/2015	Another meeting was organized to distribute duties for searching duties
02/02/2015	My group mates and I had meeting to share our search results.
10/02/2015	We decided which suppliers to visit and started in Famagusta industrial areas.
13/02/2015	Another visit to suppliers in Famagusta was organized.
18/02/2015	We visited several suppliers in Nicosia
16/03/2015	We had a meeting with our adviser to share information
24/03/2015	I have visited several electronics stores to check for a generator.
04/04/2015	I had meeting with my group mates
07/04/2015	I worked on generator modifications
24/04/2015	We had a meeting with our adviser to check our search results share opinions
25/04/2015	With my group mates, we have modified the design
04/05/2015	I started working on the air collector and turbine support
20/05/2015	We have assembled the parts which we were working on
22/05/2015	I have applied epoxy paste to welded areas of assembly
27/05/2015	My group mates and I started experimenting and taking data
28/05/2015	We had a meeting to start calculations of our project
03/06/2015	We started working on the report
12/06/2015	We had a meeting with our adviser to show him our work and take feedbacks
15/06/2015	My group mates and I had meeting to finalize the report
17/06/2015	We showed our final work to our adviser

Logbook: Awad Alterkaoui   138566

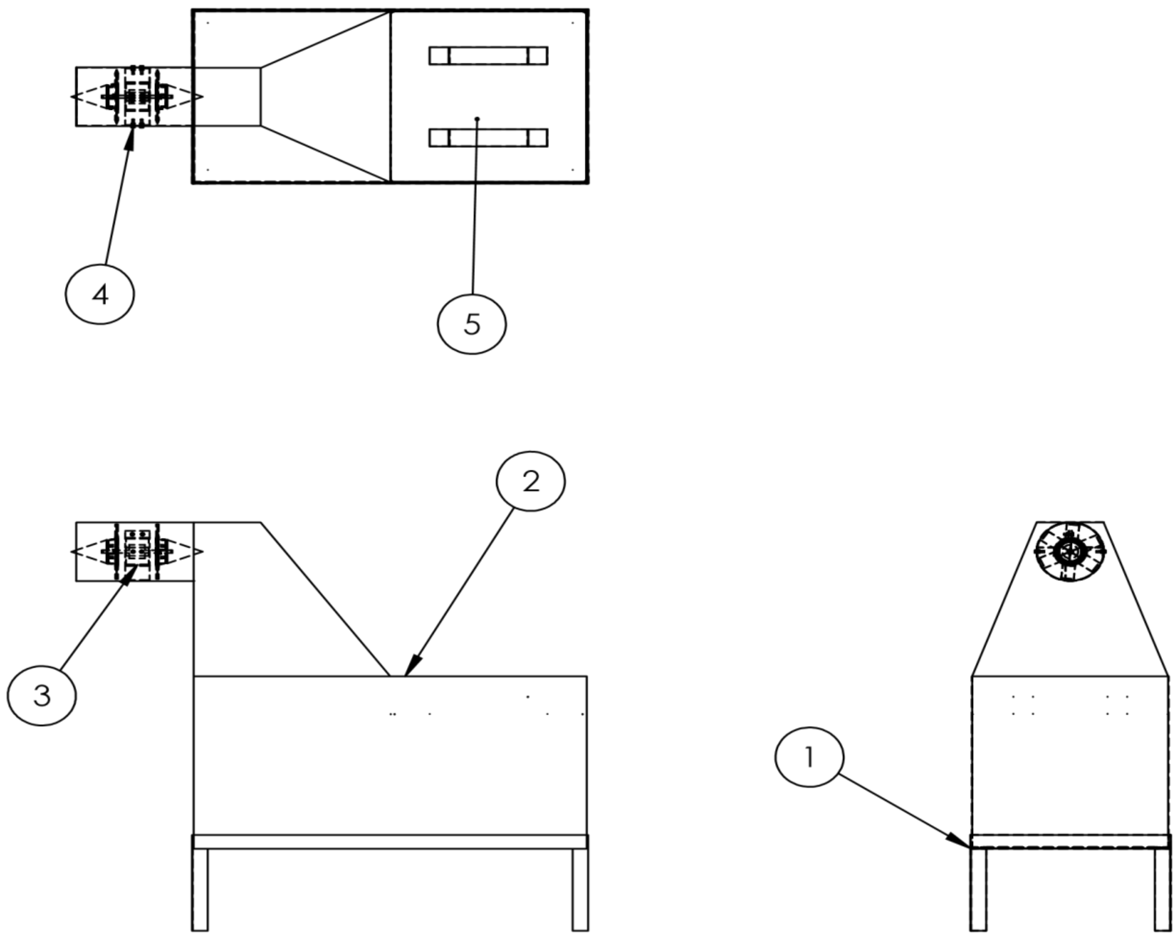
Dates	Details
21/10/2014	Firstly, I received our capstone project from our advisor Lec. Cafer Kızılörs with my team members. Our advisor explained briefly about the project
23/10/2014	Group meeting was held
25/10/2014	I started researching about sea waves various systems.
28/10/2014	Abdullah, Imad and me suggested several designs and ideas with our advisor
31/10/2014	Group meeting was held and duties were distributed where I took the responsibility to write the wave energy devices and their development in chapter II
03/11/2014	My team partners and me visited our advisor for extra information and explanation. Preliminary design was suggested.
07/11/2014	Me and my team members started drawings and calculations.
14/11/2014	We met our advisor and asked for his help in designing turbine.
24/11/2014	Me and my team members visited our advisor and asked him for his notes and comments for chapter I.
02/12/2014	I started writing my duties in chapter II
05/12/2014	I started writing the manufacturing and assembling part of the design chapter
09/12/2014	Me and my team members started writing calculations part.
12/12/2014	I drew the turbine blades, blades fixer, a the dome by using SolidWorks software
17/12/2014	I sent my final works to my partners and we worked on organization of the report
29/12/2014	I visited our advisor with my team members for report's finished parts checking
01/01/2015	Group meeting was held. We worked on repairing our report.
05/01/2015	Me and my partners visited our advisor for report's checking
07/12/2014	I prepared my logbook
09/01/2015	We have submitted the final report to the supervisor Assit.Prof. Neriman Ozada

16/01/2015	I had a meeting with my group mates to search for materials and components
23/01/2015	Another meeting was organized to distribute duties for searching duties
02/02/2015	My group mates and I had meeting to share our search results.
10/02/2015	We decided which suppliers to visit and started in Famagusta industrial areas.
13/02/2015	Another visit to suppliers in Famagusta was organized.
18/02/2015	We visited several suppliers in Nicosia
16/03/2015	We had a meeting with our adviser to share information
01/04/2015	I have ordered turbine blades from Nicosia
04/04/2015	I had meeting with my group mates
07/04/2015	I went to Nicosia to collect the turbine blades from the supplier
08/04/2015	I worked on Turbine assembly
24/04/2015	We had a meeting with our adviser to check our search results share opinions
25/04/2015	With my group mates, we have modified the design
01/05/2015	I started working on the container and pipe
20/05/2015	We have assembled the parts which we were working on
22/05/2015	I painted the welded areas
27/05/2015	My group mates and I started experimenting and taking data
28/05/2015	We had a meeting to start calculations of our project
03/06/2015	We started working on the report
12/06/2015	We had a meeting with our adviser to show him our work and take feedbacks
15/06/2015	My group mates and I had meeting to finalize the report
17/06/2015	We showed our final work to our adviser

APPENDIX-B: GANTT CHART

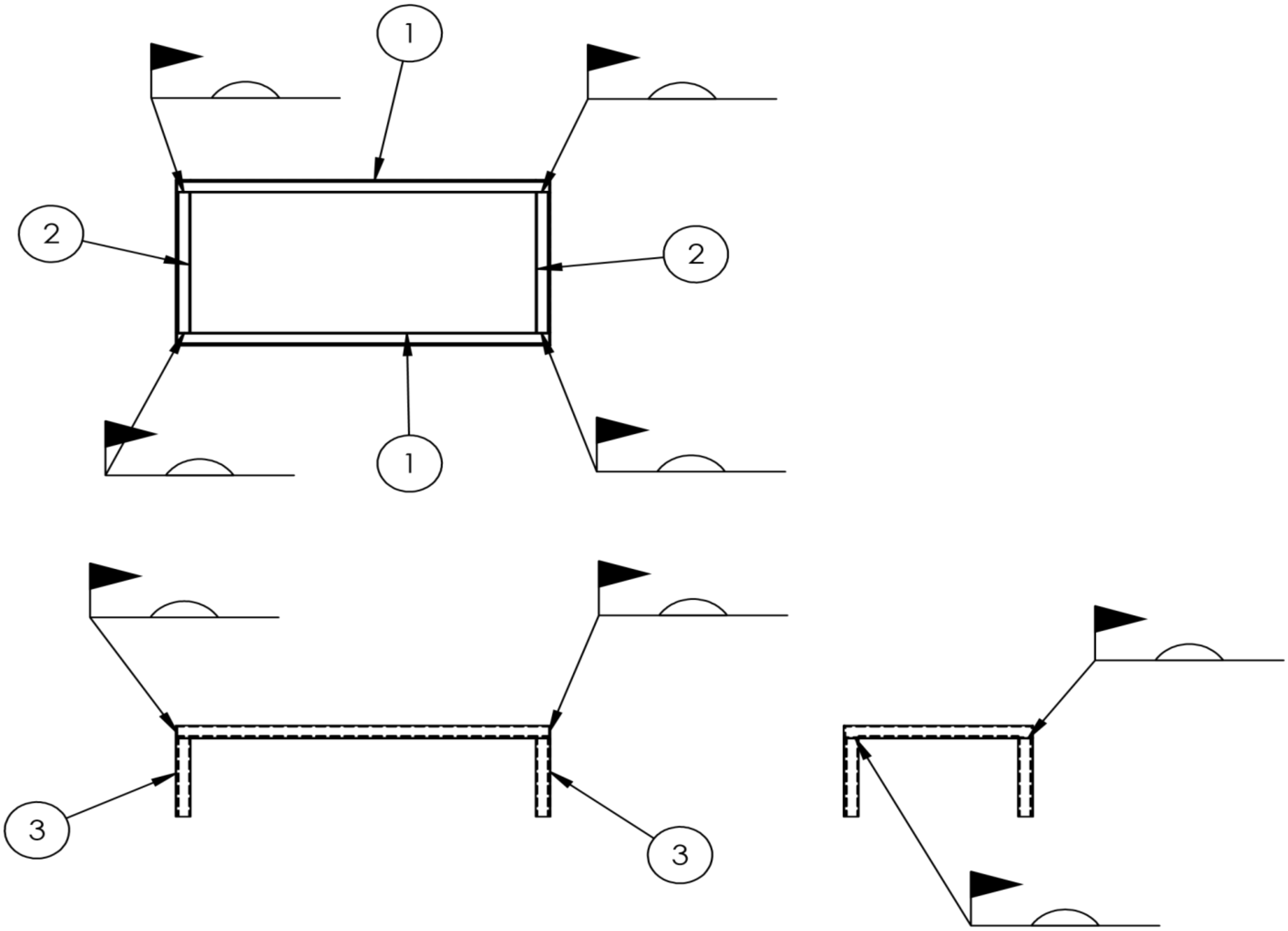


APPENDIX-C: DRAWINGS



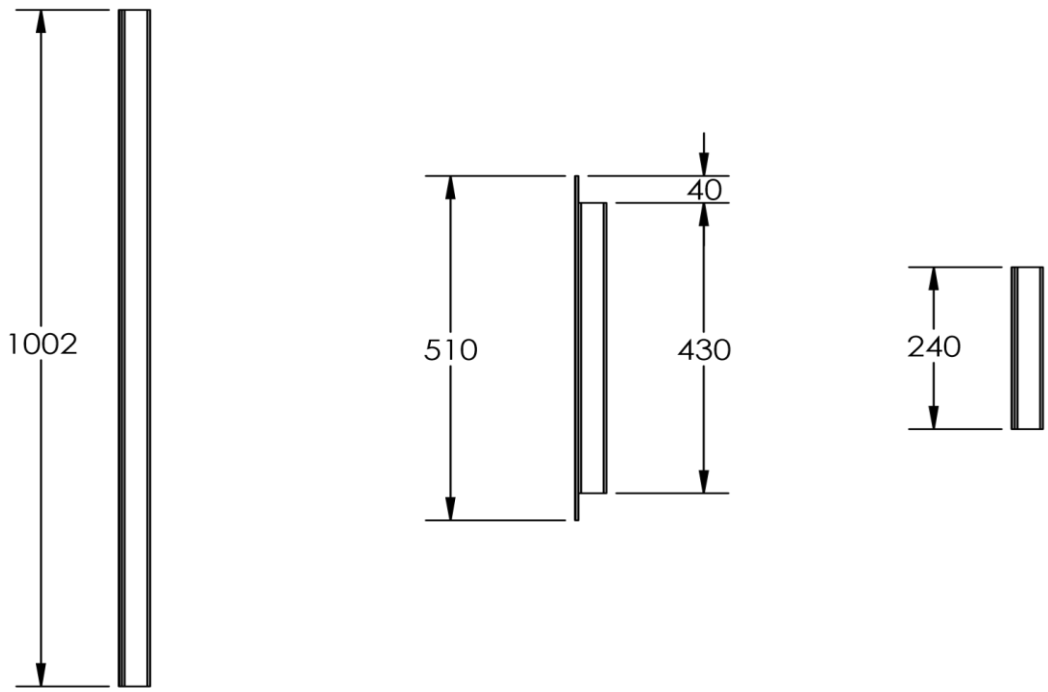
ITEM NO.	PART NAME	DESCRIPTION	QTY.
5	WAVE GENERATING DEVICE	GL. STEEL SHEET WITH 1mm THICK	1
4	STEEL BOLT	M5/ 8.8 /ANSI/ASME B18.2.3.5M	4
3	GENERATOR & TURBINE ASSEMBLY		1
2	CONTAINER & AIR COLLECTOR ASSEMBLY	GL. STEEL SHEET WITH 1MM THICK	1
1	SUPPORT ASSEMBLY	ANGLE IRON 40*40*4mm	1

	NAME	DATE	EMU
DRAWN BY	A. A	31/04/2015	
CHECKED	C. K		
SCALE 1:20	WAVE GENERATOR ASSEMBLY		DWG. NO. 00



ITEM NO.	PART NAME	DESCRIPTION	QTY.
3	SUPPORT PT 3	40*40*4mm ANGLE IRON BAR	4
2	SUPPORT PT 2	40*40*4mm ANGLE IRON BAR	2
1	SUPPORT PT 1	40*40*4mm ANGLE IRON BAR	2

	NAME	DATE	EMU
DRAWN BY	I. K	25/04/2015	
CHECKED	C. K		
SCALE 1:20	SUPPORT ASSEMBLY		DWG. NO.00- 01



PART 1

ANGULAR IRON BAR 40*40*4mm

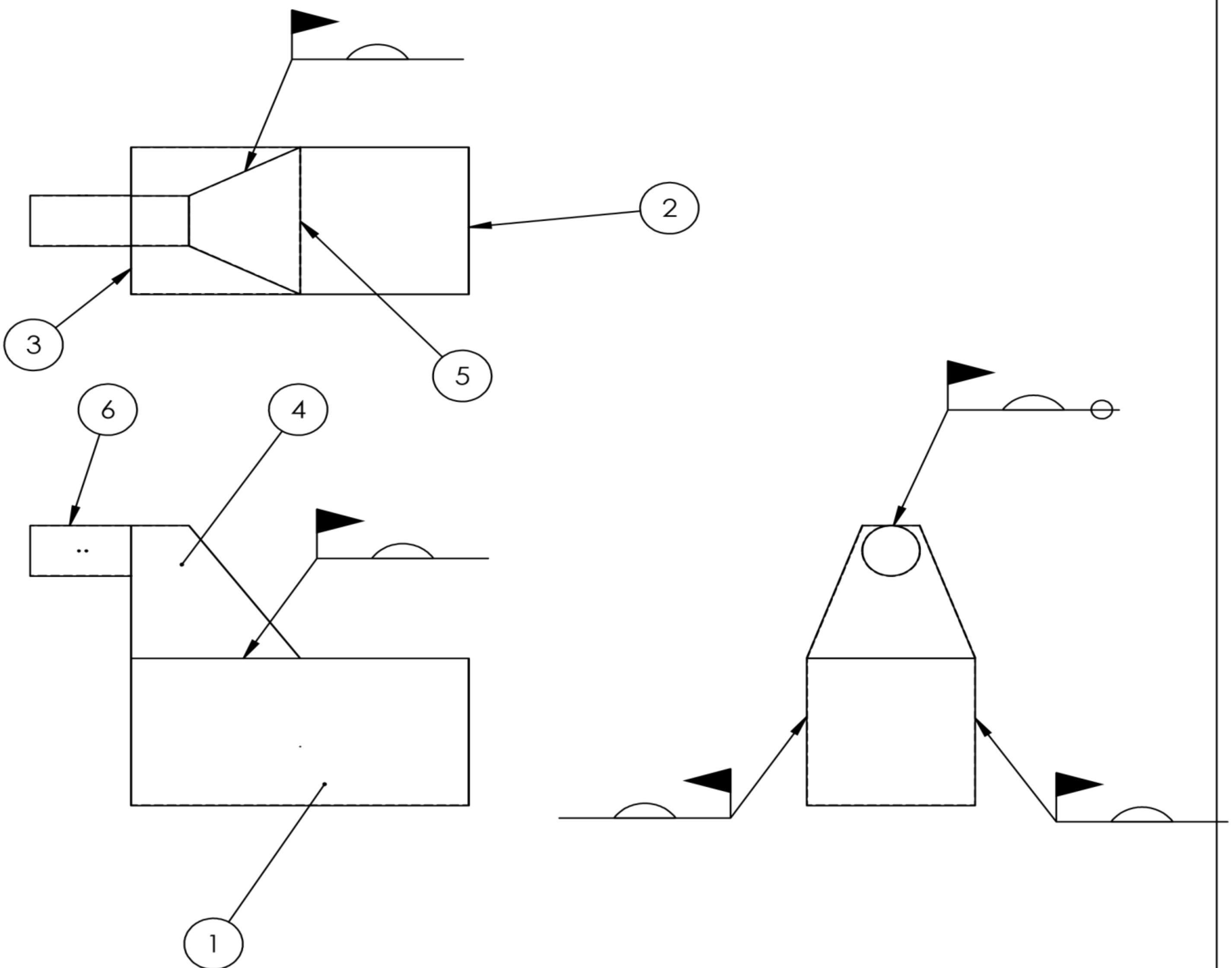
PART 2

ANGULAR IRON BAR 40*40*4mm

PART 3

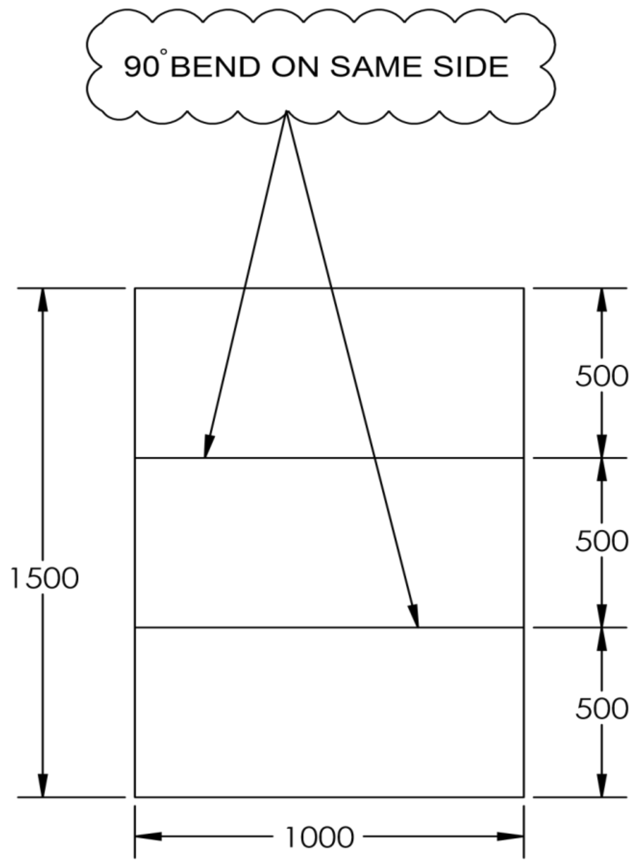
ANGULAR IRON BAR 40*40*4mm

	NAME	DATE	EMU
DRAWN BY	I. K	31/04/2015	
CHECKED	C. K		
SCALE 1:10	SUPPORT PARTS (1, 2, 3)		DWG. NO. 00 - 1- (1, 2 , 3)



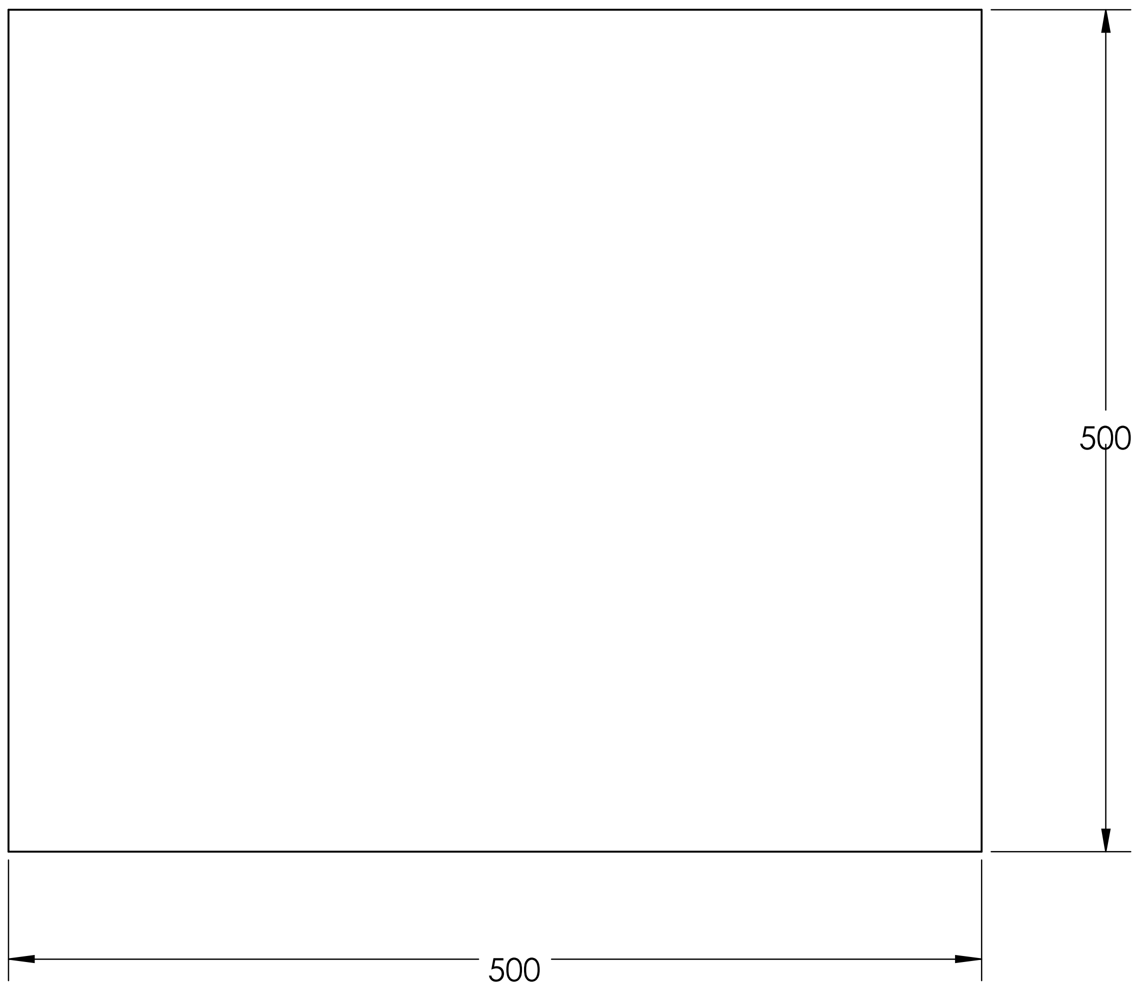
ITEM NO.	PART NAME	DESCRIPTION	QTY.
6	PIPE	GL. STEEL SHEET WITH 1mm THICK	1
5	Air Duct WALL PT 2	GL. STEEL SHEET WITH 1mm THICK	1
4	Air Duct WALL PT 1	GL. STEEL SHEET WITH 1mm THICK	1
3	CONTAINER WALL PT 2	GL. STEEL SHEET WITH 1mm THICK	1
2	CONTAINER WALL PT 1	GL. STEEL SHEET WITH 1mm THICK	1
1	CONTAINER BASE	GL. STEEL SHEET WITH 1mm THICK	1

	NAME	DATE	
DRAWN BY	A. T	26/04/2015	EMU
CHECKED	C.K		
SCALE 1:20	CONTAINER & AIR DUCT ASSEMBLY		DWG. NO.00- 02



GL. STEEL SHEET WITH 1mm THICK

	NAME	DATE	
DRAWN BY	A. T	26/04/2015	EMU
CHECKED	C.K		
SCALE 1:20	CONTAINER BASE		DWG. NO. 00-02 -01



GL. STEEL SHEET WITH 1mm THICK

	NAME	DATE	EMU
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CHECKED	C.K		
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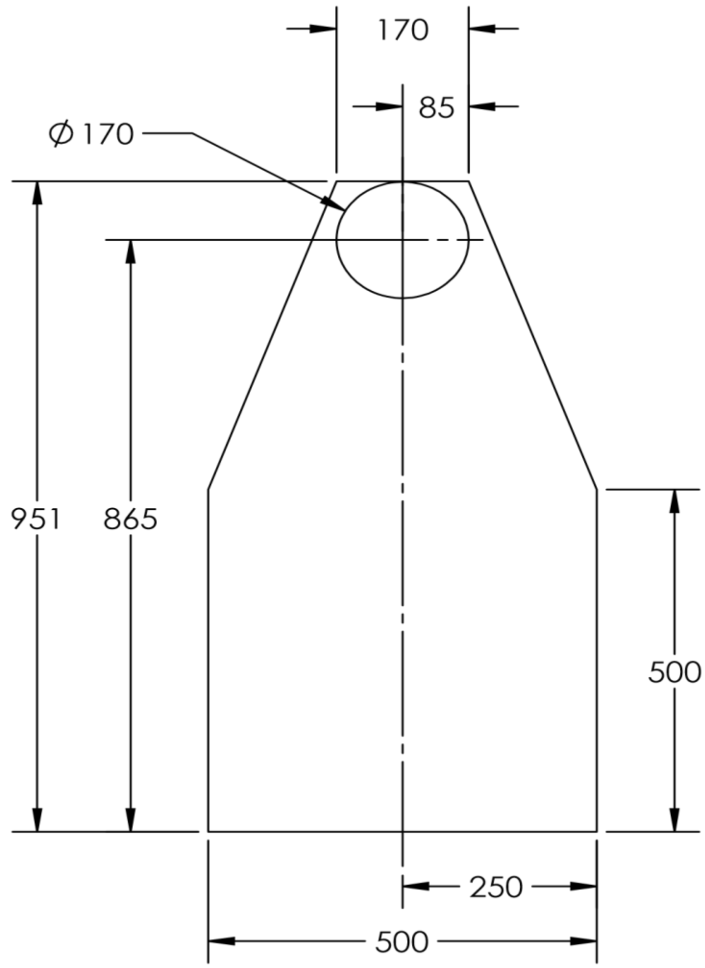
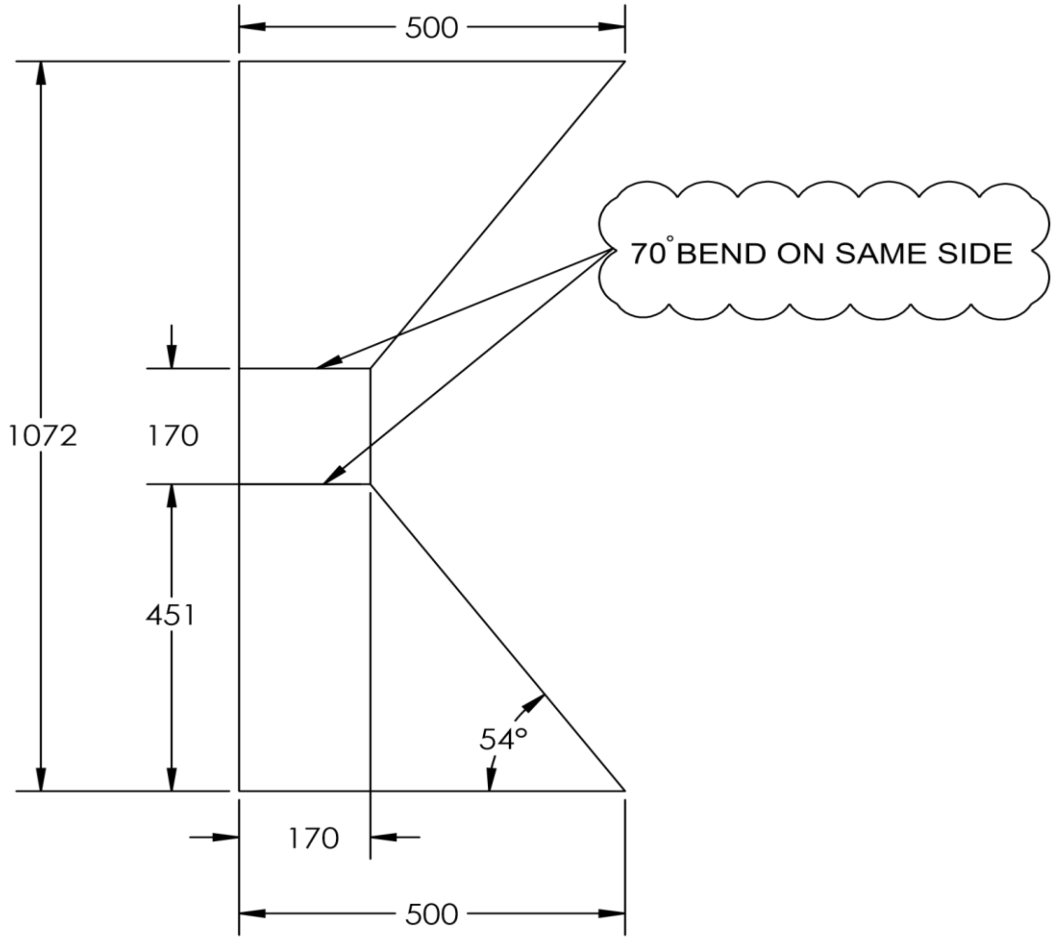


GL. STEEL SHEET WITH 1mm THICK

	NAME	DATE	EMU
DRAWN BY	A. T	26/04/2015	
CHECKED	C.K		
SCALE 1:10	CONTAINER WALL PT 2		DWG. NO. 00-02 -03



GL. STEEL SHEET WITH 1mm THICK

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CHECKED	C. K		
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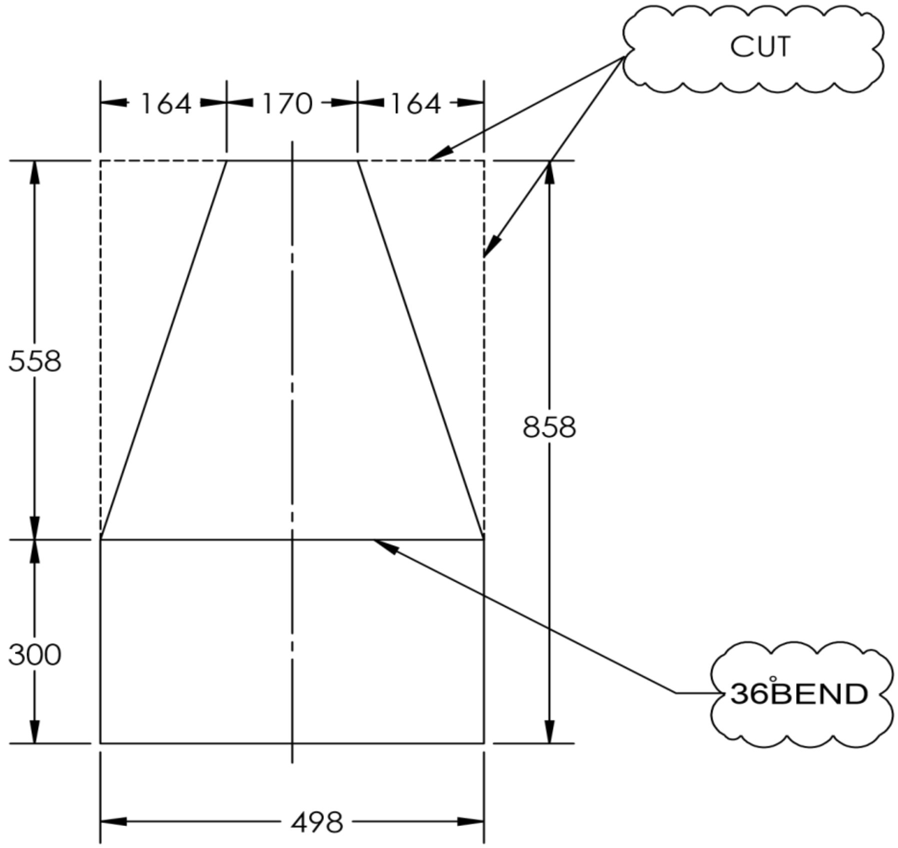

GL. STEEL SHEET WITH 1mm THICK

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CHECKED	C.K		
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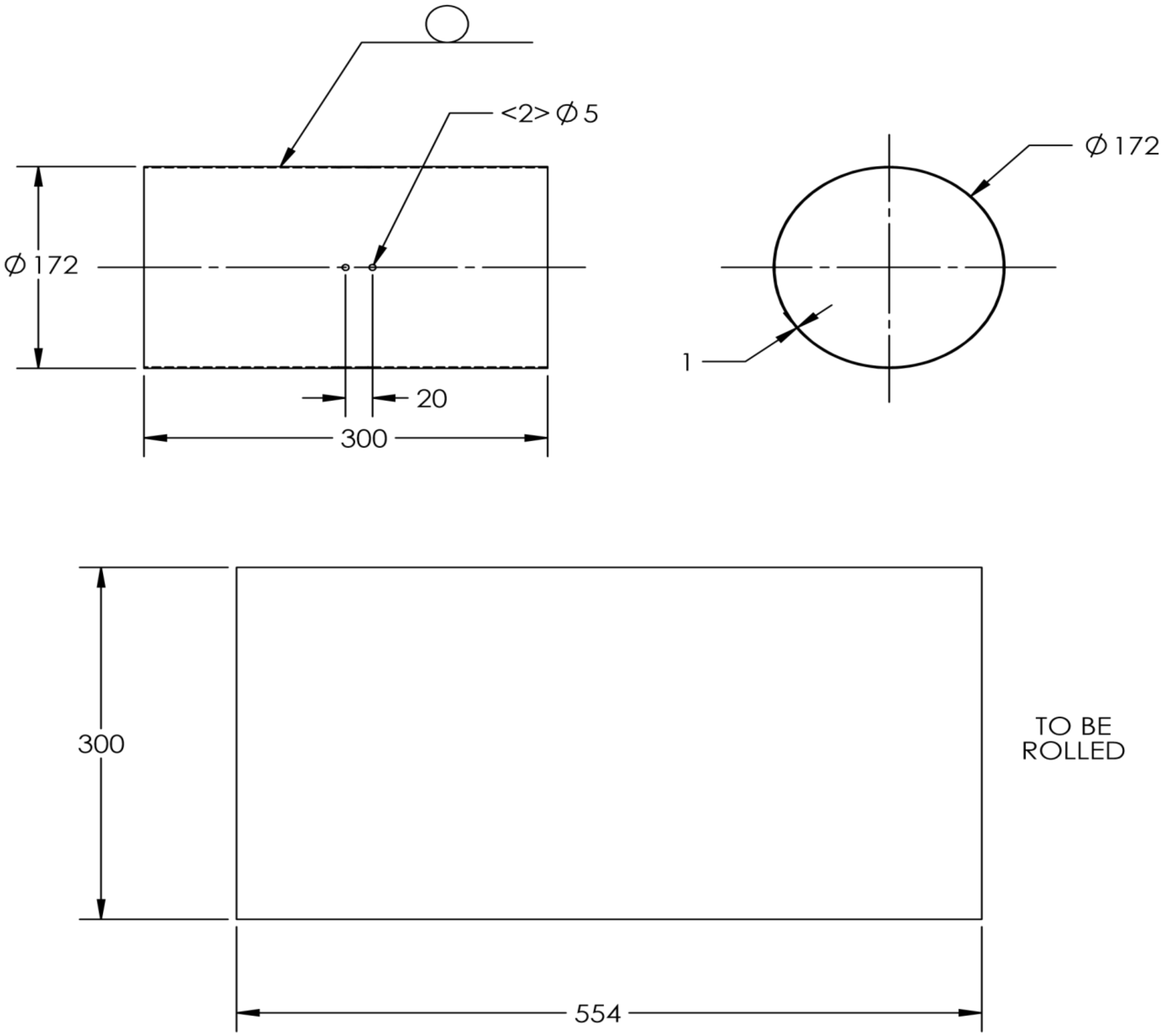

GL. STEEL SHEET WITH 1mm THICK

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CHECKED	C.K		
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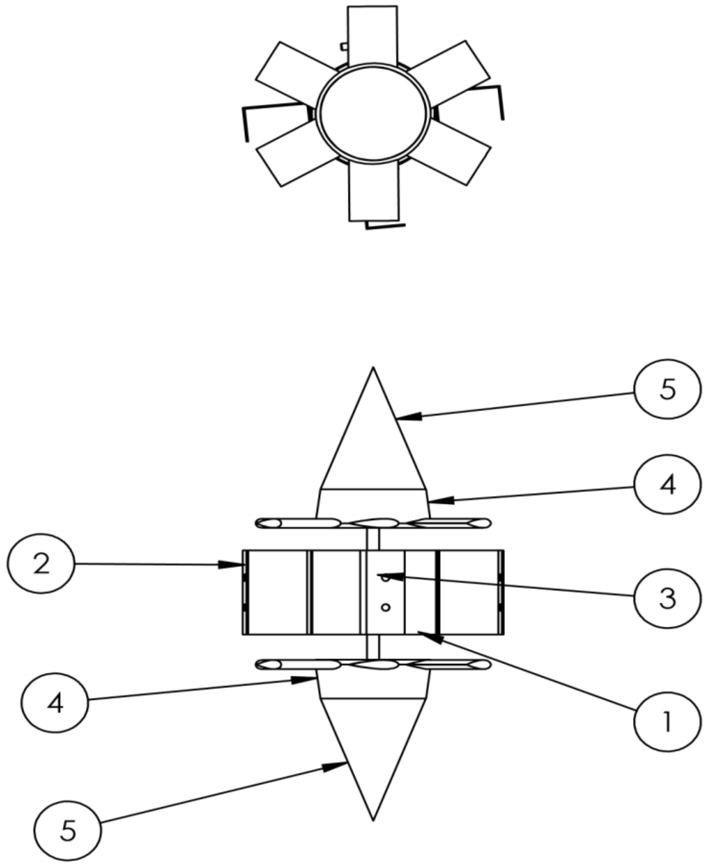

5	CONE	POLYSTIREN	2
4	TURBINE	ABS-FDM Plastic	4
3	STEEL BOLT	M5/ 8.8 / ANSI/ASME B18.2.3.5M	4
2	GENERATOR SUPPORT	GL. STEEL SHEET WITH 1MM THICK	1
1	GENERATOR	FAN MOTOR	1
ITEM NO.	PART NAME	DESCRIPTION	QTY.

	NAME	DATE	
DRAWN BY	A. A	29/04/2015	EMU
CHECKED	C. K		
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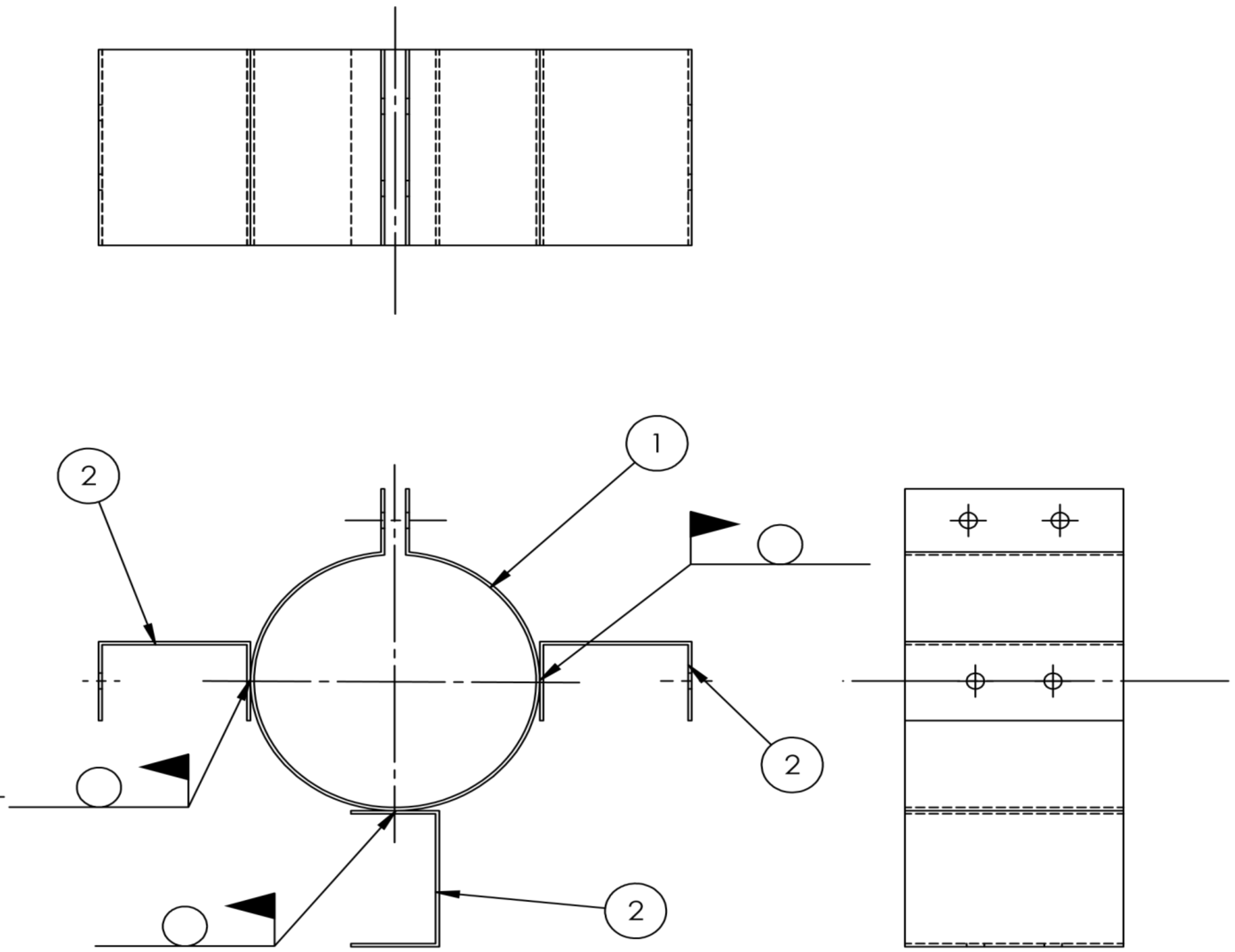
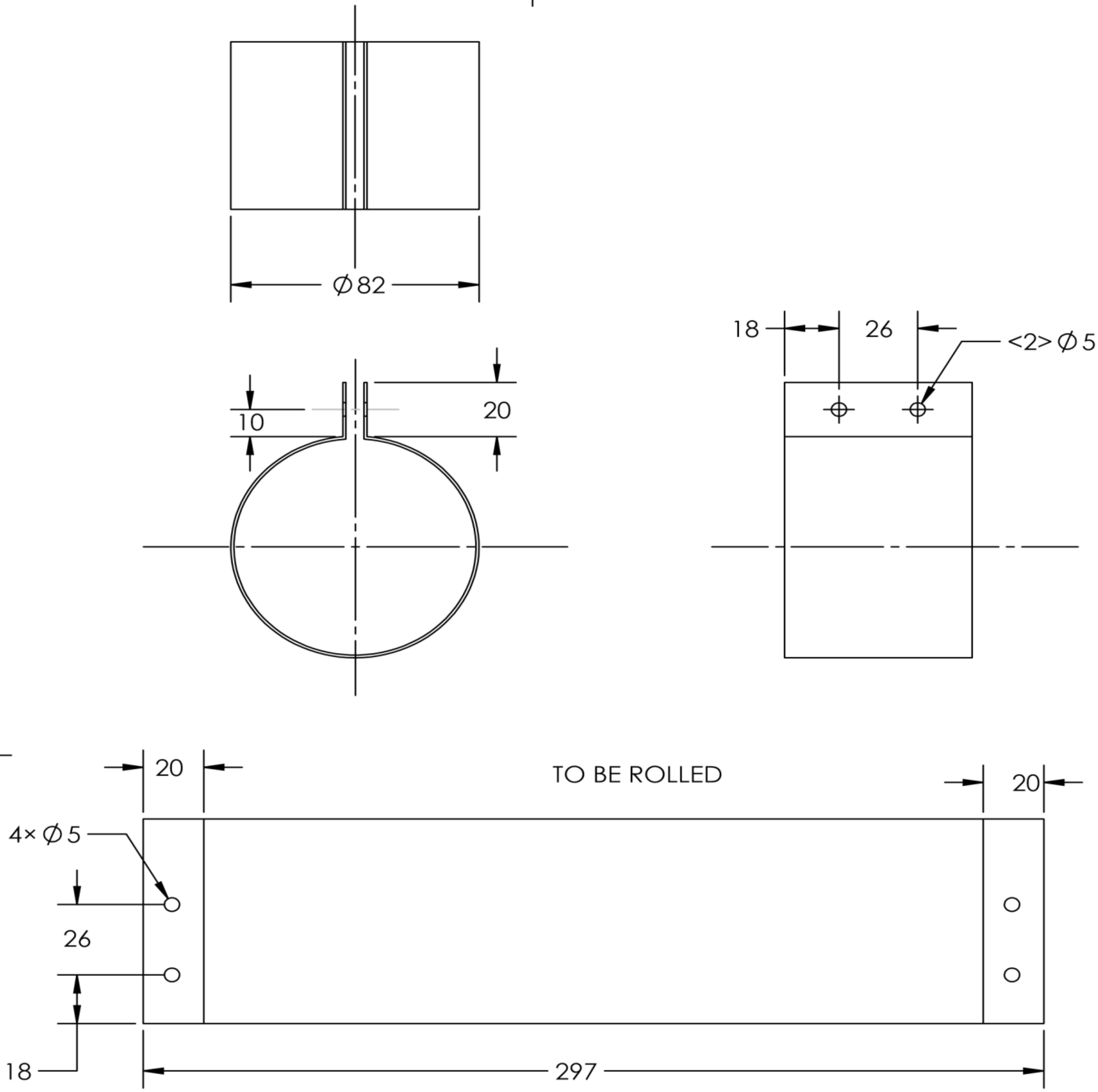


ITEM NO.	PART NAME	DESCRIPTION	QTY.
2	GENERATOR SUPPORT LEG	GL.STEEL SHEET 1mm THICK	3
1	GENERATOR SUPPORT PT 1	GL.STEEL SHEET 1mm THICK	1

	NAME	DATE	
DRAWN BY	A. A	31/04/2015	EMU
CHECKED	C. K		
SCALE 1:2	GENERATOR SUPPORT		DWG. NO. 00-03-02



GL.STEEL SHEET 1mm THICK

	NAME	DATE	EMU
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CHECKED	C. K		
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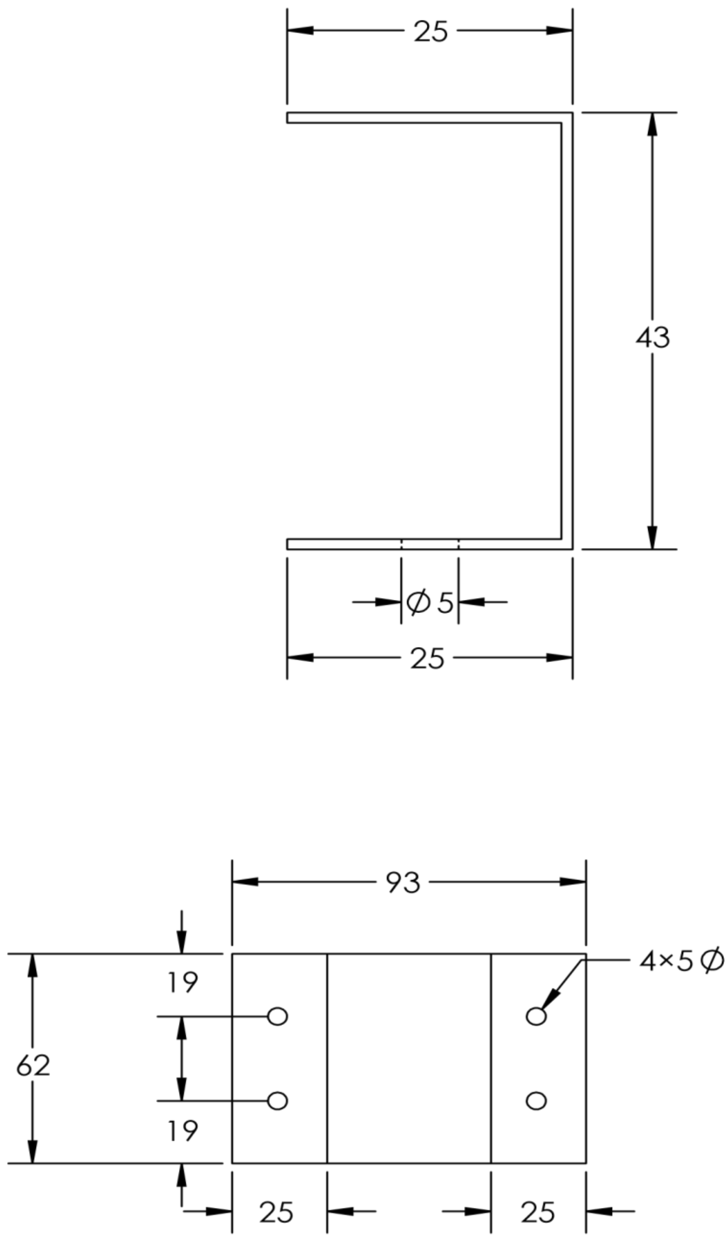
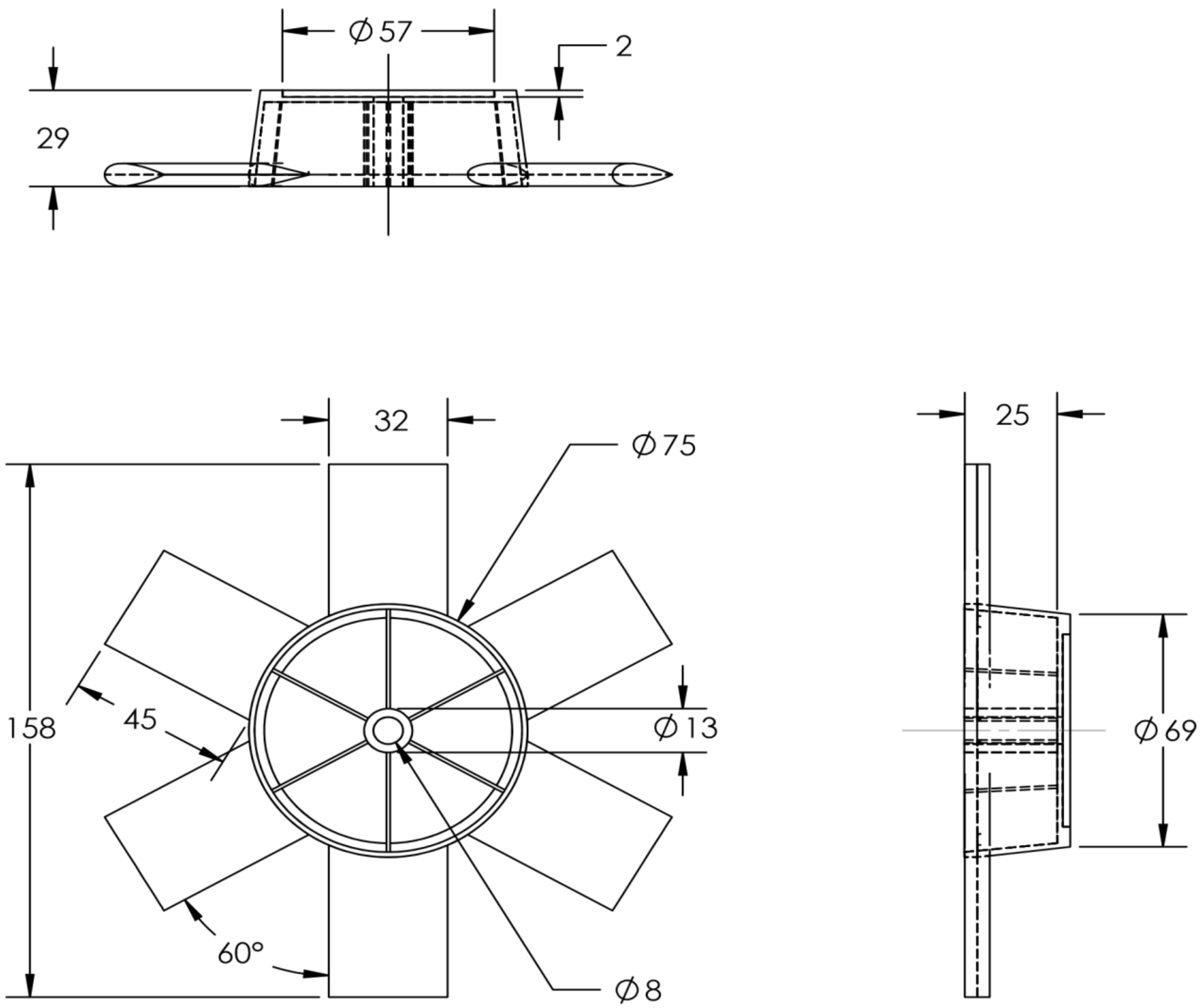


SCALE 1:1

	NAME	DATE	EMU
DRAWN BY	A. A	31/04/2015	
CHECKED	C. K		
SCALE 3:2	SUPPORT LEG		DWG. NO. 00-03-02-02



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CHECKED	C. K		
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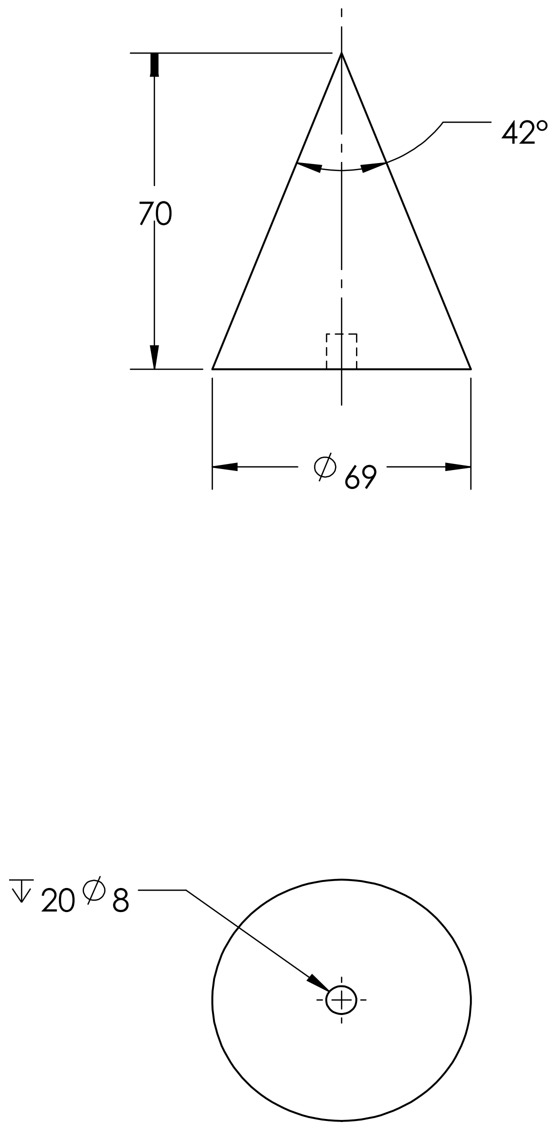

	NAME	DATE	
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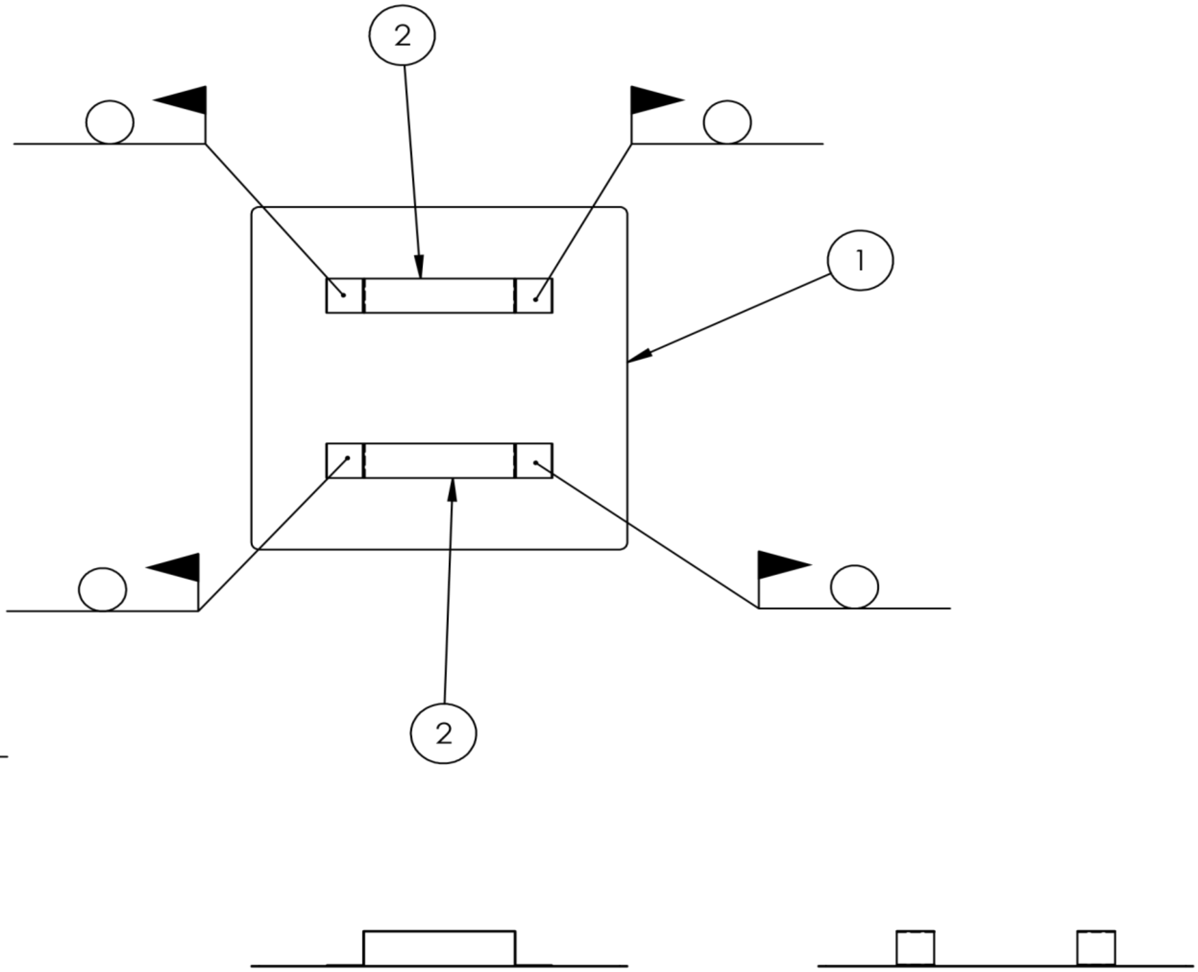
CHECKED	C. K		
SCALE 1: 2	CONE		DWG. NO. 00-03-05



ITEM NO.	PART NAME	DESCRIPTION	QTY.
2	HANDEL	GL. STEEL SHEET WITH 1mm THICK	2
1	COVER PLATE	GL. STEEL SHEET WITH 1mm THICK	1

	NAME	DATE	EMU
DRAWN BY	I. K	27/04/2015	
CHECKED	C. K		
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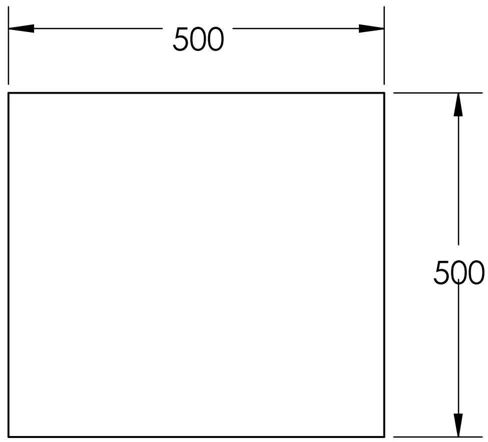

GL. STEEL SHEET WITH 1mm THICK

	NAME	DATE	EMU
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CHECKED	C. K		
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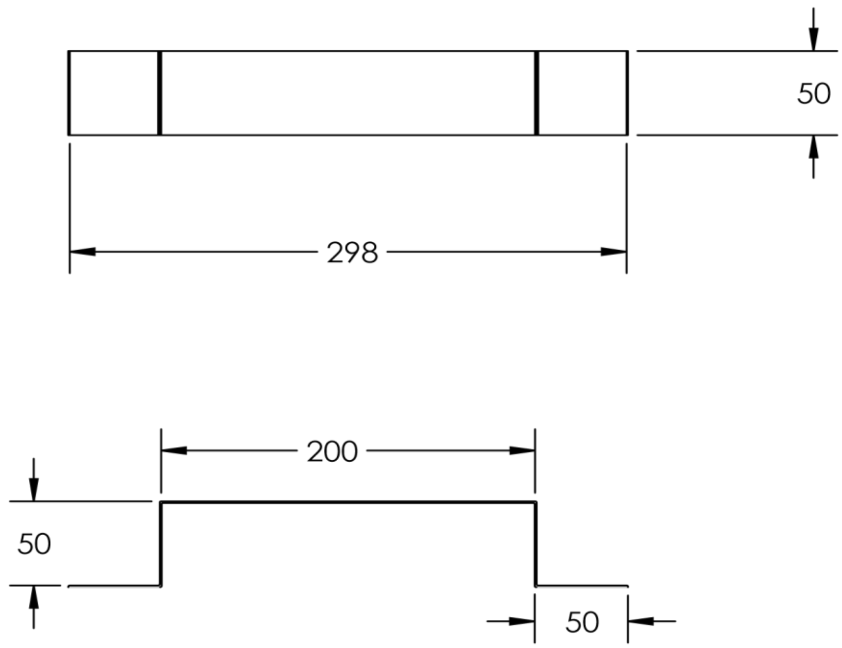


GL. STEEL SHEET WITH 1mm THICK

	NAME	DATE	
DRAWN BY	I. K	27/04/2015	EMU
CHECKED	C. K		
SCALE 1:4	HANDEL		DWG. NO. 00-05-02

APPENDIX-D: ENGINEERING STANDARDS USED

Table D.1: Airfoil Coordinate data according to NACA 0021

Airfoil coordinates data	
NACA 0021	
1.0000	0.00221
0.9500	0.01412
0.9000	0.02534
0.8000	0.04591
0.7000	0.06412
0.6000	0.07986
0.5000	0.09265
0.4000	0.10156
0.3000	0.10504
0.2500	0.10397
0.2000	0.10040
0.1500	0.09354
0.1000	0.08195
0.0750	0.07350
0.0500	0.06221
0.0250	0.04576
0.0125	0.03315
0.0000	0.00000
0.0125	-0.03315
0.0250	-0.04576
0.0500	-0.06221
0.0750	-0.07350
0.1000	-0.08195
0.1500	-0.09354
0.2000	-0.10040
o0.2500	-0.10397
0.3000	-0.10504
0.4000	-0.10156
0.5000	-0.09265
0.6000	-0.07986
0.7000	-0.06412
0.8000	-0.04591
0.9000	-0.02534
0.9500	-0.01412
1.0000	-0.00221

APPENDIX-E: MANUFACTURING PHOTOS

Figure E- 1 Manufacturing container wall pt1.

Figure E- 2 Manufacturing container wall pt3.

Figure E- 3 Manufacturing air duct wall pt1.

Figure E- 4 Manufacturing container base.

Figure E- 5 Tank and air duct assembly.

Figure E- 6 MMAW process.

Figure E- 7 Manufacturing hole for the pipe.

Figure E- 8 Applying epoxy paste.

Figure E- 9 Preparing for painting process.

Figure E- 10 Painting process.

Figure E- 11 Modifying generator shaft 1.

Figure E- 12 Modifying generator shaft 2.

Figure E- 13 Turbine and generator assembly.

Figure E- 14 Manufacturing prototype support.

Figure E- 15 Final assembly.

Figure E- 16 Testing the prototype.

Figure E- 17 Checking the results.

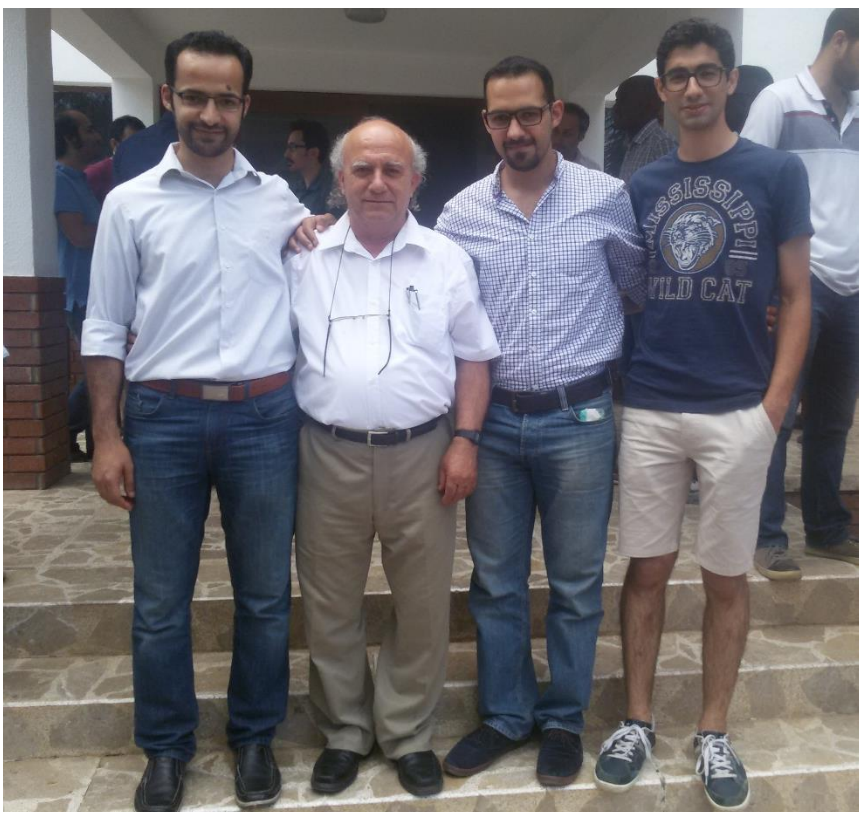


Figure E- 18 Group 08 A.I.A mates & Supervisor.

APPENDIX-F: POSTER, WEBSITE & FINAL CD

(W . P . G)

Abstract

In the last decades, as a result of climate changes as well as energy self-sufficiency desires, renewable energy has grabbed the attentions of many across the world. The aim of this project is to design and manufacture wave power generator as a solution to compensate the increasing demands on energy. At this regard, electricity generation from motion of sea waves, project components and its materials will be discussed in details. Then related design equations will be solved using mathematics knowledge. This will be followed by explanations over manufacturing as well as assembling processes. The performance of the designed system will be tested experimentally and finally, the results of the experiment will be plugged into related equations and calculations will be done

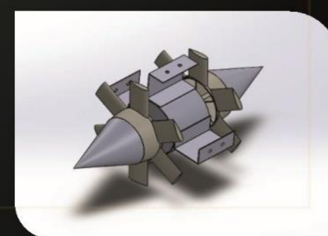
Aim

This project is based on previous projects, devices and work done. Prototype will be built, tested and analyzed mathematically and technically by the suitable apparatuses (e.g. Wind Tunnel, Anemometer and Pressure Gauge), and software (SolidWorks).
The goal of this prototype is to achieve more than 1% for power efficiency and simultaneously with more than 40% turbine efficiency.

Conclusion

This project can be useful for governments and public across the world, especially for islands such as Cyprus. This property can be beneficial in order to have better environment to live in.

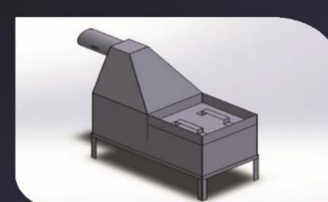
Turbine & Generator Assembly



Project Specification at λ

Wave Length	λ=0.18 m
Rotational Speed	n=180 rpm
Torque	T =0.0363 N.m
Torque Coefficient	% C_T=60.3
Output Power	P =0.684 Watt
Turbine Efficiency	η_T=32.8 %
Power Efficiency	η_P=1.17%

Wave Power Generator



Project Component

1	Water Tank 0.25 m3
2	Air Duct
3	Pipe D =0.17m
4	Turbine
5	Generator
6	Support
7	Wave Generating Device

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