Design and Fabrication of Airborne Wind Turbine Using Analytical & Fea Technique

Apurva Potdar, Mohammed Ahmedullah Khan, Mohamed Khalid, Mohammed Rifhan, Sandeep Joshi, Sampath S S, Veerakumar M, Chitrai Pon Selvan

ABSTRACT: Wind is the amplest source of energy after Solar. Considering the rise in demand for alternatives to conventional generation of electricity using fuel, wind energy is an attractive sustainable solution. This project focuses on the design and fabrication of an airborne wind turbine, which is a new generation of wind turbine systems that consists of a turbine elevated at high altitude using helium balloon tied with tethers to restrict movement. The current work focuses to overcome the limitations of ground-based windmills by reducing production costs, location constraints and altitude limit. The prototype built is modelled using CREO software and it is simulated using ANSYS Work Bench to enhance the structural stability and obtaining design parameters. The system has a maximum capacity to generate up to 700 W, which is enough to supply half a high electricity consumption household.

KEYWORD: Airborne, sustainability, helium, tethers, FEA.

INTRODUCTION:

The technology of wind energy is in existence and in use since centuries. Sailors have used the principle of aerodynamic lift since an early time [1]. Around 200 BC, Vertical Axis Wind Turbines (VAWT) were found at the Persian-Afghan border followed by the discovery of horizontal axis turbines in the Mediterranean and Netherlands around 1300 to 1875 AD [2]. A notable leap in the wind energy development was when the US government took interest in the research and development of this field, after the oil crisis of 1973 [2]. In an attempt to generate eco-friendlier and sustainable electricity, unlike the conventional method of using fossil fuels, there has been a serious amount of consideration and interest shown on the wind energy development in the last thirty years [2]. Looking at the latest global wind statistics, the wind energy has developed at a steady rate in the last 8 years, especially in Asia and Europe [3]. The concept of "Airborne" wind energy systems has come up in the last few years. These systems mainly consist of extraction of wind energy without a stationary tower to support the system. A major classification among these are the helium filled buoyant systems and the kite design systems. The former uses a helium filled balloon to lift the turbine and generator assembly into the atmosphere. The kite designs have the generator on the ground and rotational power is generated due to the tensile force acting on the tethers, this design beneficial as the generator weight does not have to be lifted for power generation. Figure 1 shows the amount of power generated using wind energy in various regions. Maximum amount of 32000 MW is produced in 2015 in Asia.

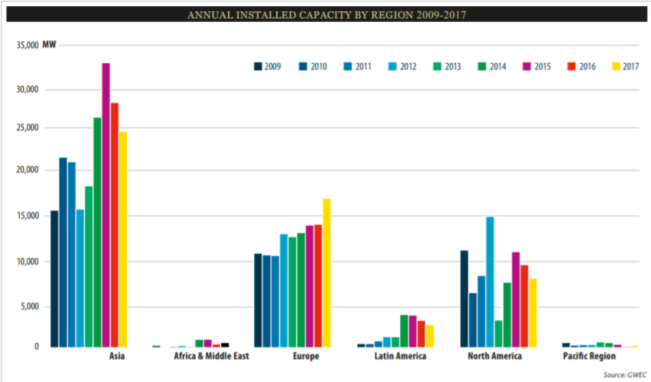

Fig.1 Annual Installed Capacity by Region [3].

Ground based systems have limitations such as instability of wind and high cost of installation. The airborne wind systems provide advantage over conventional wind turbines such that they can reach higher controllable altitudes and wind at such high altitudes is more stable and has potential to generate more power. Also, airborne wind turbine systems have lower cost of installation [4]. The speed of wind plays an important role in the amount of power generated. At about height of 10 meters the wind speed obtained is 6 m/s. The higher we go more speed is achieved due to less obstruction and there is less turbulence. Due to availability of artificial fibres like Nylon, Rayon, Dacron which are 30 to 100 times stronger than steel and have densities 2-5 times less, it is possible to tether this system to the ground [4]. The scope of this work is limited to the design and fabrication of a wind turbine using two generators of 350 W which can be lifted by a helium balloon. It is sufficient to supply half the power required to run a household. Taking into consideration of the fact that helium is expensive, the project has been constrained to work within the weight limit of 8 kg. The maximum altitude that this system is to be studied under is within a limit of 10 to 15 m above ground, taking into consideration that, to access higher altitude wind, a stable system is required. Regardless of the height limit of this project, literature and

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related material has been studied. The current methods of generating power using wind energy have a high investment and are inefficient. The motivation behind this project is to eliminate the problems of a traditional wind turbine and make an airborne wind turbine that is relatively inexpensive and can generate more or equivalent amount of power without using up much space like a wind turbine farm that needs a large area to be functional. Moving forward our fossil fuel resources will be extinguished and there will be a need for a new sustainable and renewable method of power generation. In UAE the main source of renewable energy is solar energy. The aim of this project is to support the design and fabrication of an airborne wind turbine so that solar and wind energy together can completely replace traditional means of power generation.

RELATED STUDY:

Moritz Diehl [5] is mainly focused on basic concepts on airborne wind turbine. It introduces the main basic fundamental ideas on different types of airborne wind turbine systems like the idea of crosswind kite power- i.e. when tethered wings fly fast in the crosswind direction then, theoretically very high-power densities is obtained of around 40 kW/m^2 of total area of the wing. The work talks about different ways to generate power that are classified in this paper according to Moritz Diehl -like On Board Generation, i.e the apparent wind at the wing is driven by a small airborne wind turbine. The paper also discusses about the Ground based generation on how fast moving tethered wings do not use high volts of electrical transmission, via tethers the strong tether tension is directly unrolling from a drum and it drives an electric generator and, in this way, both the drum and generator are placed on the ground. Airborne wind energy for vehicle propulsion is also classified in the paper and that how strong tethered tension is used directly to drive a vehicle on the ground. This paper also describes about the fundamental physical limits of airborne wind energy, cosine losses due to gravity and the power limit of airborne wind energy. The paper concludes by comparing all the types of power generation and its limitations. **Nykolai Bilaniuk** [6] talks the technological requirements for an airborne wind turbine that uses tethered wind generator technology which can be feasible as well as economically achievable. The current work explains wind power related terms like “Efficiency”, “BETZ Limit”, “Capacity factor” etc and by giving a brief understanding about terrestrial wind towers. The paper proceeds by asking questions on requirements for an airborne wind energy system like the advantages of airborne technology, generator location, tether arrangements, sources of lift, and the consideration of environmental hazards and answering them, that make the reader understand as to what is actually been talked and how it reflects in the performance of the entire system. Through this work, one can find some data analysis with respect to wind speed and altitude etc. This research concludes by saying that though there is only one type of wind turbine (axial flow) is dominating the market, the airborne wind systems have their own advantages and disadvantages over terrestrial wind systems and that their major advantage is their efficiency with autonomous survivability under various climatic conditions except when it gets really extreme. **Bas Lansdorp and Prof. Dr. W.J. J Ockels** [9] proposed the wing concept which is used to lift the body and it is attached by the tether that is used to drive the generator. The authors explained several concepts that benefit the high-altitude wind energy. First concept was the ladder mill which makes use of endless tethers with wings attached on it. Second concept was the pump mill that uses single tether with a number of wings distributed evenly over it. When the authors compared both the concept, it was found that ladder mill has better weather mobility than pumping mill but on ground station pumping mill is simpler than the ladder mill. Finally based on numerical comparison, amount of material required for ladder mill is doubled than the pumping mill.

Alexander Bolonkin [11] proposed the ground-based wind energy extraction system which talks about the limitations of current design such as wind stability, high cost of installation and small output of a single unit. The author describes how the wind is clean and unlimited source of energy and how it is utilized for renewable vitality for many decades. This paper concludes by explaining the problems of launching, starting, guidance and control, stability of the device at high altitudes. **Lorenzo Fagiano and Trevor Marks** [10] talk about basic airborne wind turbine energy that aims to produce wind vitality at high altitudes by providing wing linked to the ground by using tethers. This paper aims to fill partially the details of the complete design of small prototype by studying airborne wind turbine, including power supply mechanics, actuators, low level control system, wings and lines, sensors and human-machine interface. The authors focused on the main design of small prototype which allows system to perform number of test aspects, including aerodynamic and wind design, line and wing fatigue. They concluded that the basic maneuvers can be used to operate the prototype and it can be consistently. **A. Fazlizan et al.** [7] talks about an innovative device called the ODGV (Omni-directional-guide-vane) which is placed around a VAWT. Its design was made to increase the performance in terms of its power output, rotational speed and self-starting behaviour as well as to minimize the safety. In order to improve the performance of VAWT, a wind tunnel test as well as a CFD (Computational fluid dynamics) simulation was performed. As part of the initial testing in case of wind tunnel experiment the ODGV was exposed to the wind coming from various directions i.e. 0^0, 30^0 and 60^0. The next level was conducted by using a 5-bladed (FX 63-137 airfoil) H-rotor was used. CFD simulation was done using a single bladed NACA 0015 airfoil VAWT and by using water as a working fluid in order to enhance the ability to get relatively low frequency measurements at appropriate blade Reynolds number. The results obtained for wind tunnel testing showed that at 6 m/s, the rotational speed achieved was 182% a free running condition and the power output obtained at maximum torque was 3.48 times higher for the ODGV integrated VAWT as compared to the VAWT without ODGV. CFD simulation results showed that the torque output obtained for the

NACA 0015 airfoil, single bladed VAWT was increased by 58% and 39% at tip speed ratios 2.5 and 5.1 respectively. The research work concludes by telling the importance of OGDV in urban areas and also in places where the wind speed is low since the tests proved that the ODGV integrated wind turbine can start producing energy at low wind speeds. **P.Jaen sola et al.** [8] starts by giving an introduction to the airborne wind turbine systems but it mainly focuses on the buoyant airborne wind turbines, eg: Altaeros turbine and its drive train system and also the different ways in which we can reduce its mass. For this purpose, a 100 kW airborne wind turbine has been analyzed in order to obtain the lightest arrangement. The initial study was made by considering a permanent magnet generator with or without gear box wherein for the gear box assembly, the ratio is variable and that the generator masses are based on electromagnetic design and scaling. The second part of the study focused on using composite materials for the supporting structures of the generator. A data analysis on gearbox ratio VS drive train mass shoes that as the gearbox is added, the drive train mass reduces (although the gearbox mass is increased, the reduction in generator mass is higher). Based on a comparison for generator supporting mass structure, for the gearless type, the steel structure weighed 105 kg whereas the composite structure weighed only 22 kg. It indicates 80% reduction in generator mass and 20% drop in the drive train mass. The paper concludes through a demonstration saying that by making use of the mosaic pattern 4-unit disc model for the composite structure, all the structural requirements like air-gap defection limit can be achieved. **I. S. HWANG et al. [12]** discussed about Helium balloon wind turbine and parafoil wind turbine. According to their study about the Cycloidal helium balloon wind turbine, the balloon is filled with helium gas and electric generator is mounted below the balloon with tethers, cables and a set of winches attached to the ground is used to hold the whole system. As per their data, for diameter 15.1m and Height 500m &1500m, the average speed it can produce is 12.8m/s and 15m/s. The amount of power generation will be 58.9KW and 71.6KW respectively. In parafoil wind turbine, their construction of the system is similar to balloon wind turbine only difference is that the helium balloon is replaced with parafoil. As per the parafoil data table, rotor generators lifting force to lift the whole system at required altitude than once it reaches to required altitude it changes its mode of conversion and starts storing whatever power the turbine is producing. Their studies also show that for height 1500m, the average power it can produce is 64KW. It also talks about how parafoil energy consumption increases up to 200KW in critical condition when turbine gets less input from the wind than rotor has to do all the work. Based on the comparison made, balloon wind turbine output is 10% higher than parafoil wind turbine but parafoil wind turbines lift force is much higher at high wind speed condition since, in this type of turbine the larger the rotor size that much times the energy it can produce. The paper concludes by saying that balloon wind turbine is more stable and easy to control. While, parafoil rotor can be designed in such a way that it can produce much more speed at higher altitudes. **Prithi Seshadni and Dharmalingam** [11] suggested the helium balloon windmill design where air rotor frame work depends on Magnus effect and helium gas balloon is elevated at certain heights to generate power. This paper described the usage of helium gas, generation of power, helium balloon design, working and construction, analysis using computational fluid dynamics (CFD) and compared it with horizontal turbine. The authors concluded that the helium gas filling is easily installed and it can control high altitude winds by utilizing the fastened wind turbine which can open up twist asset compared to customary turbines.

METHODOLOGY:

The methodology of design and fabrication of the turbine is shown in figure 2.

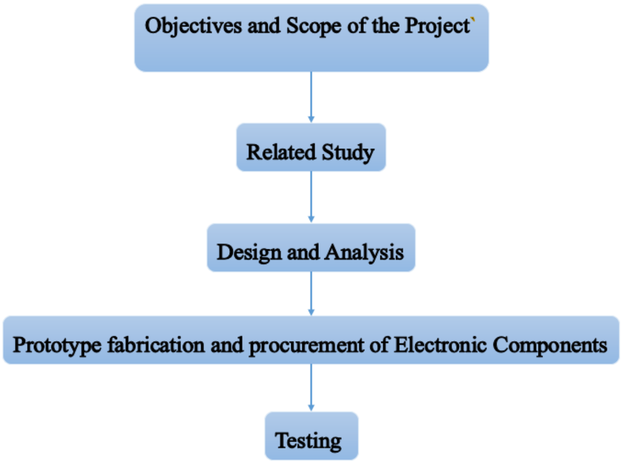

Fig. 2 Methodology

The project was carried out with a predefined systematic procedure that was the backbone of our project till the end. Initially the objectives and scope of the project was discussed and evaluated. All related material was read through and challenges were discussed. Designing was done using the software's. Auto CAD has been used for drafting, Creo v5 for modelling and Ansys Workbench has been used for analysis purpose. Stresses and deformations were observed. Static Structural and Modal analysis were the main platforms taken into consideration. Every part of the system has been designed and fabricated from scratch and each electronic and structural component selected individually. Testing of each component and the entire assembly has been done on ground level. Simultaneous documentation has been done.

PROPOSED DESIGN:

The initial design was proposed as shown in Fig.3 consisting a basic wind system that can be lifted by a helium balloon.

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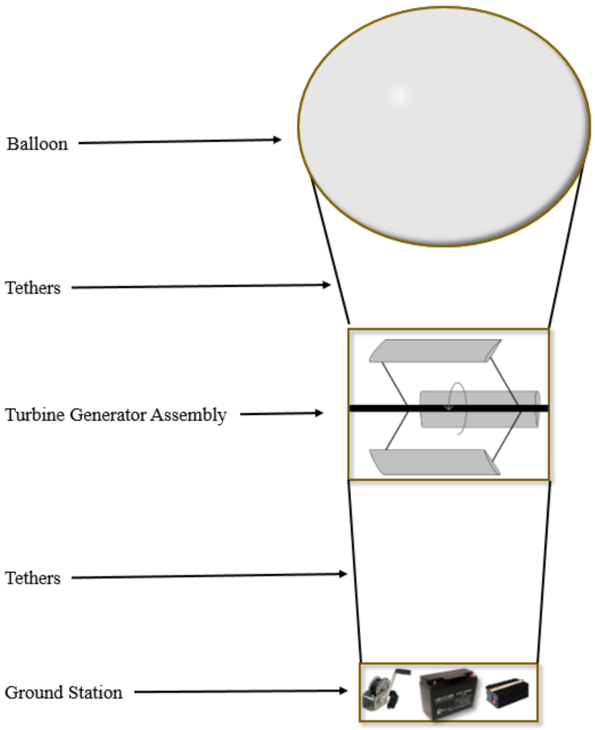

Fig. 3 Design Proposal

Considering the cost of helium, design scale for the turbine generator assembly was decided to be kept of a moderate size. Restrictions to weight were taken into consideration.

CIRCUIT BLOCK DIAGRAM LAYOUT:

Figure 4 shows the layout of the system in which the power is transferred. The power generated from the generator (generated due to the rotation of the turbine) is transferred to the batteries via charge controller, which controls the flow of current and also displays digitally the voltage and current. For the DC generator, it is necessary to convert the power to AC, if AC applications are to be used.

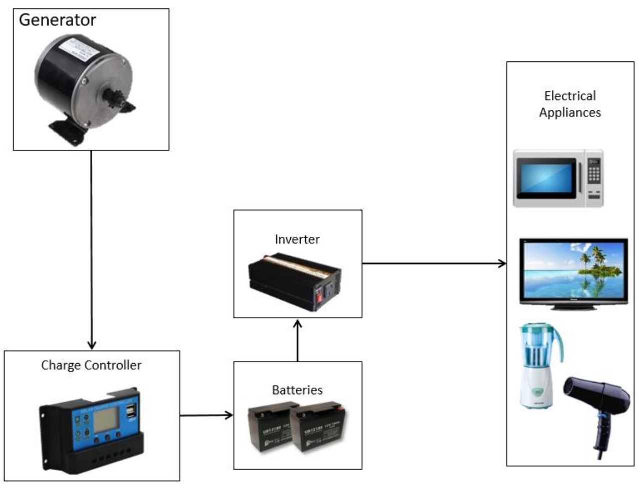

Fig. 4 Stand-alone wind system circuit layout

TOOLS USED:

A number of tools have been used in this project; some important measuring devices include the tachometer (Fig. 5) to measure the rpm, anemometer (Fig. 6) to check the wind speed, multimeter (Fig. 7) to check voltage and current, centrifugal fan (Fig. 8) for the purpose of testing, charge controller (Fig. 9) to control the flow of current and also digitally cross-check the power input and output. Figure 10 shows the gear train gear train mechanism that was used as an attempt to increase the rpm of the generator shaft.

Fig.5 Tachometer

Fig.6 Anemometer

Fig. 7 Multimeter

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Fig. 8 Centrifugal Fan

Fig. 9 Charge Controller

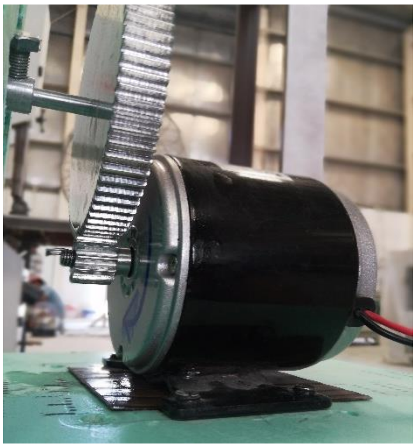

Fig.10 Gear Train

DESIGN, ANALYSIS AND COMPONENT SELECTION:

Design and analysis of turbine shaft using AutoCAD, Creo and ANSYS workbench. The purpose of the shaft is to transfer the mechanical energy of the turbine blades to the selected permanent magnet generator (DC-12 V/24V, 350W, 2700 rpm). Various materials were taken into consideration for the shaft such as stainless steel, nickel, brass etc. Since one of the major objectives of this project is to lift the entire system with the help of a helium balloon, it is important for the selected material to be light-weight, Aluminium was selected taking into account the fact that Aluminium is one of the lightest materials with good strength. Aluminium-2024 T3 was selected on the on the basis of its machinability and surface finishing capabilities. The design was chosen to be kept hollow, since studies show that the strength to weight ratio of a hollow shaft is 44.4% higher than the solid shaft. The designed shaft is chosen to be 600 mm long with an outer diameter of 30 mm and an inner diameter of 25 mm, i.e., 2.5 mm on each side as shown in the Fig. 11.

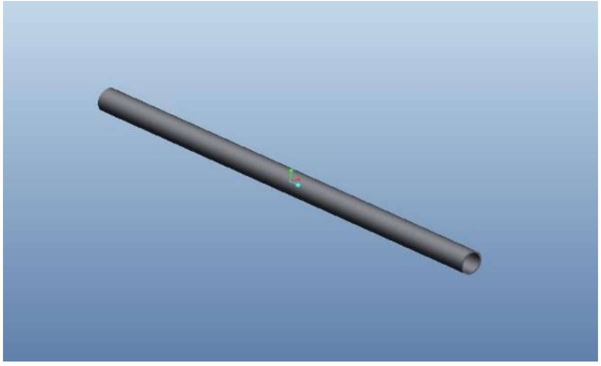

Fig.11 Shaft model using CREO

In order to test for the factor of safety of the shaft, simulation has been done (structural analysis) on "ANSYS WORK BENCH 15" by applying an UDL of 98.1 N and the results obtained are as shown in Fig. 12 and Fig. 13 below.

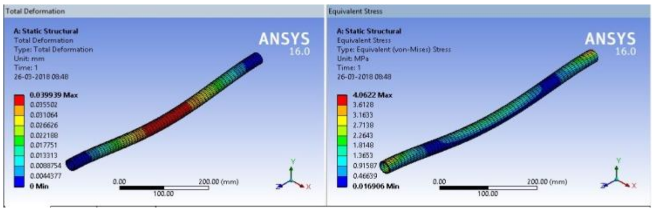

Fig. 12 ANSYS analysis for total deformation, eq. stress of the shaft

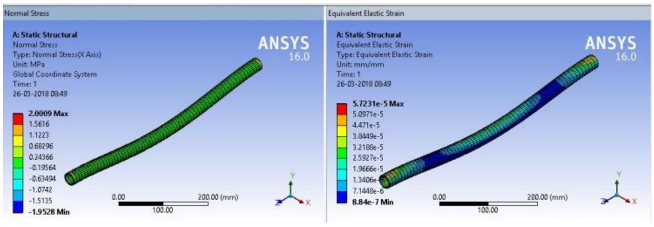

Fig. 13 ANSYS analysis for normal stress, eq. strain for the shaft

From the results, it is shown that the equivalent stress obtained is 4.06 MPa and the deformation is 0.039mm. Yield stress of aluminium is 280 MPa. Since Factor of Safety is greater than one, the designed shaft is safe.

DESIGN AND ANALYSIS OF TURBINE BLADES USING CREO AND ANSYS WORKBENCH:

The purpose of the turbine blades is to convert wind energy to kinetic energy. The design of the turbine blades

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has been done after doing research on various possible designs and their efficiencies. Also, the ease of fabrication has been taken into account. It is necessary that enough torque is generated to rotate the turbine shaft. It is also very important that maximum wind energy is extracted within the weight and size limitations of the design. Observing all these factors, a Darrieus turbine wind blade was selected. It has been designed as a hollow member and is included with stiffeners for strength. The material used is aluminium which makes it a light-weight member.

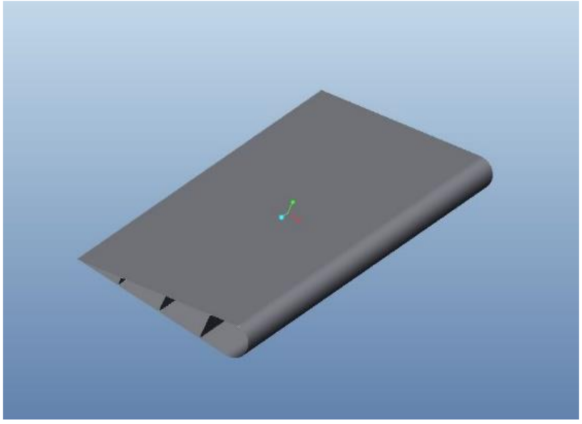

Fig. 14 CREO modelling of the Blade.

In order to find the no. of rotations (rpm), "Modal Analysis" was done on the blade since it is exposed to airflow and thereby leading to vibrations (frequency (Hz)).

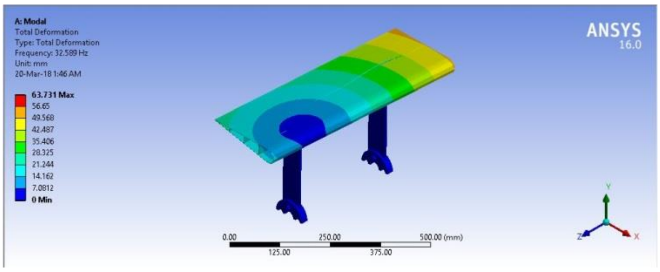

Fig.15 Modal analysis using ANSYS Workbench for the Blade (Mode 1).

From the analysis above, frequency of 32.5 Hz at mode 1 was obtained. It signifies that the maximum no. of rotations for the blade to be stable is 1920 rpm. Above 1920 rpm the system goes into mode 2, where the blade might be unstable.

DESIGN AND ANALYSIS OF CONNECTORS USING CREO AND ANSYS WORKBENCH

The connector assembly is designed for the purpose of connecting the blades to the rotating shaft. It is designed to consist of two parts, a flat plate and a circular plate. The flat plate is connected to the blades using riveting method. The circular plate is welded to the rotating shaft. Bolting of the flat plate to the circular plate was selected which enables the disassembly of the blades and also replacement of the blades. The circular plate area enables the secure attachment of the flat plate.

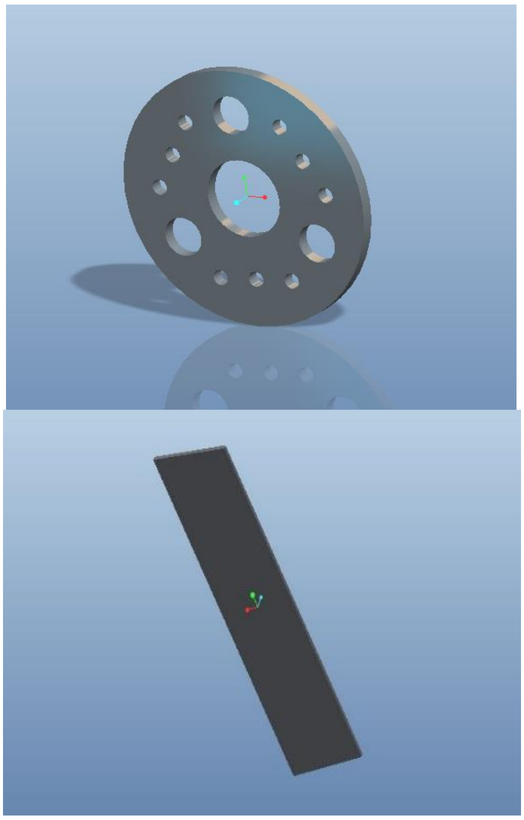

Fig. 16 Circular plate and flat plate in CREO (left-right).

FLAT PLATE ANALYSIS:

Here, main focus of this was to consider the centrifugal force experienced by the flat plate as it is riveted to the blade wing. Therefore, 50 N load was applied. The results of the analysis are shown below. Figure 17 shows the deformation and equivalent stress of the normal plate. It is evident from the figure that deformation and stress is very small.

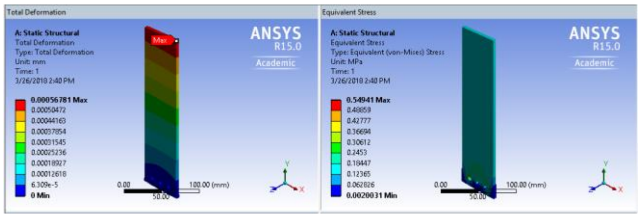

Fig 17: ANSYS analysis for total deformation, normal stress, eq. stress and strain of the plate.

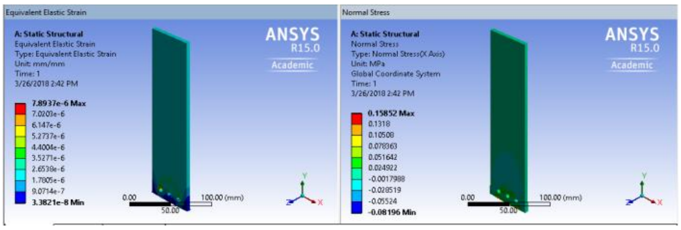

Fig 17: ANSYS analysis for total deformation, normal stress, eq. stress and strain of the plate.

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A deformation of 0.00056mm and equivalent stress of 0.549 MPa were obtained. Therefore, the design is safe.

CIRCULAR PLATE ANALYSIS:

The analysis of circular plate which is actually welded with the shaft and provisions are given so that the flat plate (aligned 120^0) are inserted and bolted. The flat plates are welded to the blade wings. 50 N load on the bolted region is applied since it is taking the load of the wings.

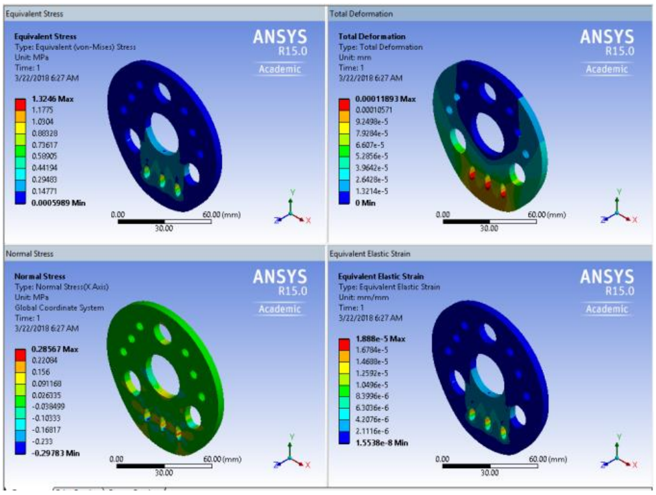

Fig.18.ANSYS analysis for eq. stress, total deformation, normal stress and strain of the circular plate.

A deformation of 0.00011 mm and eq. stress of 1.32 MPa were obtained. Therefore, the design is safe.

FINAL ASSEMBLY IN CREO:

As assembly model was made in Creo for understanding purpose (shown below in Fig. 19)

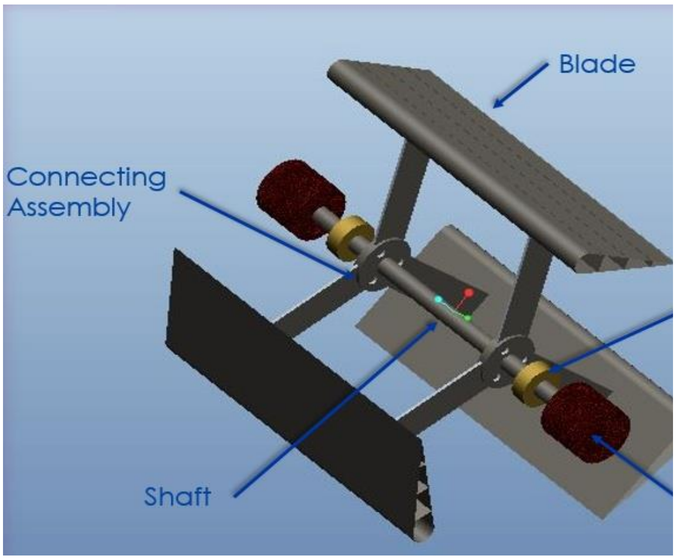

Fig.19 Final Assembly of Wind Turbine in Creo

FRAME DESIGN

The frame was designed in the end, taking into account all the dimensions of the fabricated assembly and the coupling members. Stress analysis was done for the frame, as shown in the Fig. 20 below.

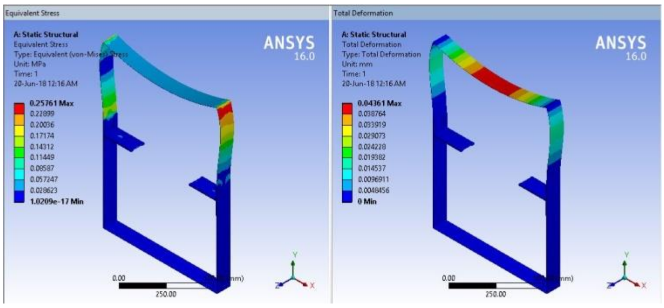

Fig.20 ANSYS analysis for eq. stress and total deformation on the frame

Tensile loads and pressure was applied considering tension for the ropes and weight of the generator and the setup. The design was found to be safe. Bolting with aluminium angle brackets was selected as the joining method as angle brackets are easily available and have sufficient strength to hold the frame in place.

PROCUREMENT OF MATERIALS AND CONSTRUCTION:

GENERATOR SELECTION: The purpose of the generator is to convert mechanical energy transmitted by the turbine shaft into electrical energy that is stored in the batteries. Major parameters considered when selecting the generator were voltage, rated current, wattage and rpm. Weight was also one of the most important factors due to the necessity to lift the generator as a part of the setup. A permanent magnet motor generator was selected as it is reliable and generates electricity at any rpm. It also has an efficiency of 80 % which is good. The most feasible option was found to be a 24V, 350 W, 2800 rpm DC permanent magnet electric motor generator for wind turbine. The usual application of this generator is in modified bicycles and scooters. Additional features of the generator include moisture and corrosion resistance, sealed exterior and coated rotor which also made the inverter a good choice. It is necessary that enough voltage is generated by the generator to charge the battery. This depends on the rpm generated. Experimental approach is adopted to observe the amount of rpm generated. A gear drive or chain drive mechanism can be added to the setup if necessary in the future.

Fig.21 Selected Generator

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SELECTION OF BATTERIES: The purpose of the battery is to operate by converting chemical energy into electrical energy through electrochemical discharge reaction. Battery selection has been done on the basis of research market and its parameters. Voltage and amperes were the parameters to be considered to match the input and output of the generator wattage capacity to store power in the battery and to give variable output. The most appropriate battery was found is 12V,9Ah. Application of this lead acid battery is used in submarines, automotive and traction applications. The reason why lead acid battery was preferred than the car battery because car battery can produce high current which may burn the generator and can even cause electrocution, if anyone holds the conducting tethers which is attached to the battery.

Fig.22 Lead Acid Battery

Working Prototype of the airborne wind turbine consist of various elements. Aluminium material is selected for all parts. Appropriate material selection has been done for obtaining the final output.

Shaft: Shaft is required to convert mechanical energy of the wings into rotational energy then transmitting this energy to generator which in turns uses this energy to generate electricity. Here, an aluminium hollow shaft has been used. Studies show that hollow shaft has more strength and elastic properties when compared to a solid shaft. The dimension of the hollow shaft is of 30 mm outer diameter and 24 mm inner diameter. The shaft is a major part providing structural stability to the entire setup, as three blades are attached to it through connectors and with two generators that are mounted on either ends of the shaft.

Fig. 23 Hollow Shaft

Connectors: In order to attach the air foil wings to the shaft, connecting parts were designed, circular plate and flat plate as shown in Fig .24 and Fig. 26 respectively. The purpose of this connector assembly is to connect the blades to the rotating shaft. The circular plates (x4) of diameter 100 mm and of thickness 3 mm have been welded onto the shaft as shown in Fig.25. The welding used for this process is TIG (Tungsten Inert gas) welding. The flat plates (x6) of dimension 500 mm x 60 mm x 3mm are shown in Fig. 26, where one end of the flat plate is to be sandwiched between the circular plates and bolted. This method of joining enables detachment of the blades, if necessary. The other end of the flat plate has been cut at an angle of 6 degrees. This arrangement gives the symmetrical air foil blades a zero rigging angle. The connection here has been achieved by riveting using L-shaped brackets.

Fig. 24 Circular plate

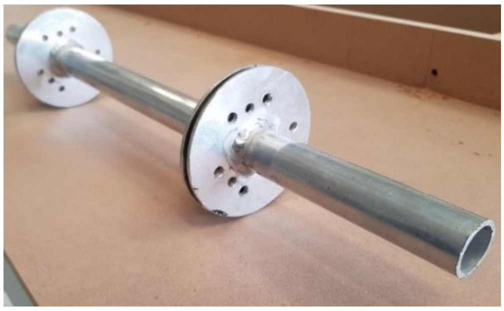

Fig. 25 Circular plate welded onto hollow shaft

Fig. 26 Flat plate

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Polystyrene: In this project, polystyrene (a brittle synthetic polymer) material acts as a reinforcement and can resist compression and bending in the wings. Polystyrene is nothing but hard Thermocol. It is light in weight and has good strength as shown in Fig. 27. The hard Thermocol has been trimmed into air foil shaped wings of dimensions, and then the thin aluminium sheet of 0.9 mm has been pasted using furniture glue onto the Thermocol member. Thus, the air foil shaped aluminium blades have been achieved. The weight of this material is negligible and has high strength which makes this material perfect reinforcement member for the air foil wings.

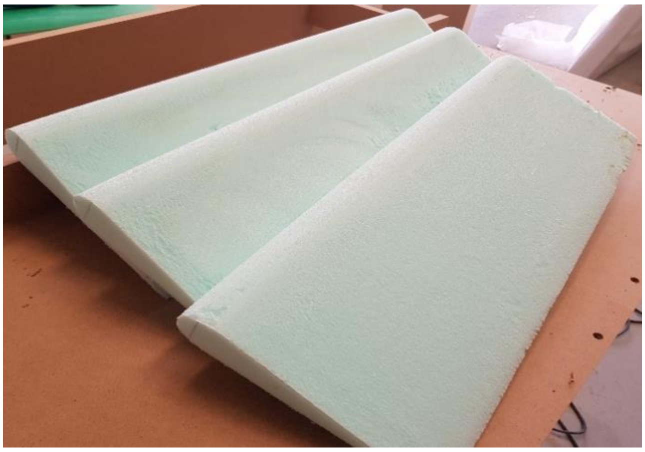

Fig. 27 Hard Thermocol

Blade: This turbine setup is a version of the Darrieus VAWT. Three symmetrical air foil shaped straight blades have been selected for the design. This design has been selected because it can provide good efficiency, has good aerodynamics properties due to its air foil profile, low noise in the wings during its operation and is feasible to fabricate. The air foil shaped wings are shown in Fig. 28. To construct this air foil wings, a 0.9 mm aluminium sheet was used. A 0.9 mm aluminium sheet of dimension 600 mm x 463 mm was cut out and pasted over the rigid Thermocol member to make each blade.

Fig.28 Airfoil Wings

The working prototype of airborne wind turbine consist of a helium shell, cables, winches, tethers, turbine setup (Fig.28) and ground station (batteries, inverter and controller). The turbine setup will be suspended to helium shell using tethers and it is also connected to ground station via tethers and cables. This turbine setup is a type of Darrieus wind turbine which consists of three symmetrical aerofoil wings, a hollow shaft, connectors, generator and battery etc. Here, in our system connectors are used to attach and detach the aerofoil wings from the rotating shaft if necessary. The connector assembly consist of mainly two parts circular plate and flat plate. Circular plate is welded on to the shaft and one end of the flat plate is to be sandwiched between the circular plates and bolted. The other end of the flat plate has been cut at an angle of 6 degrees. This arrangement gives the symmetrical air foil blades a zero-rigging angle. The connection here has been achieved by riveting using L-shaped brackets. The aerofoil is achieved by using a rigid member that is polystyrene (Hard Thermocol), this rigid member is trimmed into aerofoil shape and then the aluminium sheet of 0.9mm is pasted on it using furniture glue. This rigid member also acts as reinforcement and can resist compression and bending in the wings also it is light in weight.

Fig. 29 Turbine assembly

Fig.30 Specially fabricated member for Assembly purpose

The turbine assembly was fitted onto the frame as shown in Fig.31 using a specially fabricated member shown in the Fig.30 which connects the turbine shaft to the generator and was held in place using a bearing fitted to the frame on either ends.

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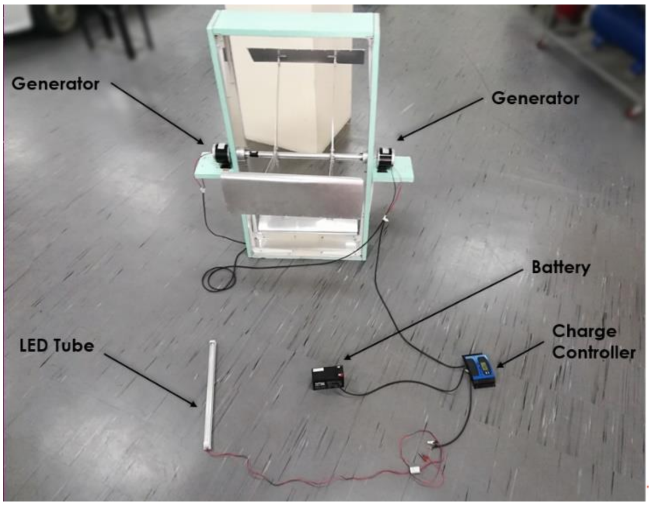

Fig. 31 Final assembly of turbine prototype

RESULTS AND DISCUSSIONS

THEORETICAL ANALYSIS

Using the following formula [15], an expected resulting power was calculated as shown in Table.1.

$$P = \frac{1}{8}\rho\pi D^2 v^2$$

The fraction of the free flow wind power that can be extracted by the rotor is called power coefficient.

$$Power\ Coefficient = \frac{Power\ of\ Wind\ Rotor}{Power\ available\ in\ the\ wind}$$

Taking power coefficient as = 0.4,

Table 1: Expected Wind Power Extraction

Velocity (m/s)	Wind Power (Watts)	Wind Power extracted by rotor (Watts)	Taking Generator efficiency 80% (Watts)	Considering 2 generators (Watts)
0	0	0	0	0.00
2	4	1	1	2.87
4	29	11	9	22.93
6	97	39	31	77.39
8	229	92	73	183.44
10	448	179	143	358.29
12	774	310	248	619.12
14	1229	492	393	983.14
16	1834	734	587	1467.54
18	2612	1045	836	2089.52
20	3583	1433	1147	2866.29

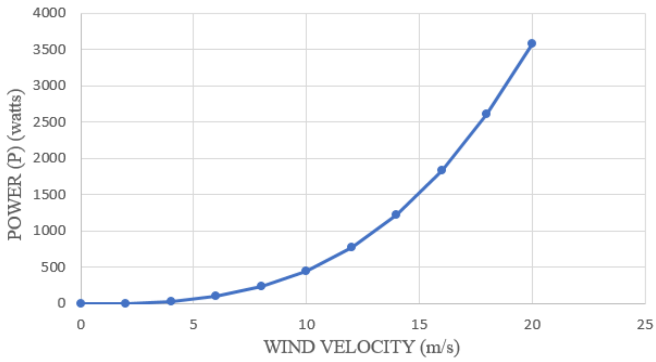

Fig.32 Theoretical Wind velocity (m/s) vs Power (W)

From the graphical representation of the wind power available for the designed turbine at various wind speeds, it is observed that the graph is hyperbolic.

EXPERIMENTAL ANALYSIS

Experiment was carried out using a centrifugal fan of 16' diameter. Different wind velocities were obtained by adjusting the fan distance from the setup and checked with Anemometer. The speed (rpm) generated for different speeds of wind was noted using a Tachometer. Voltage and current was also noted down using Multimeter and cross checked on the Charge Controller. The results were obtained as shown in Table 2. For calculation of power, the following formula has been used,

Electrical Power (W) = Voltage (Volts) x Current (Amps)

Table 2 Experimental Results

SL.NO	WIND VELOCITY (m/s)	SPEED OF ROTATION N (RPM)	VOLTAGE V (Volts)	CURRENT I (Amps)	POWER P (W)
1	**8.0**	150.0	2.4	16.5	**40.3**
2	**7.3**	130.0	2.1	16.5	**33.8**
3	**6.2**	102.4	1.6	16.5	**26.1**
4	**5.4**	96.7	1.5	16.5	**23.9**
5	**4.6**	74.2	0.9	16.5	**15.5**
6	**3.3**	44.7	0.4	16.5	**7.3**

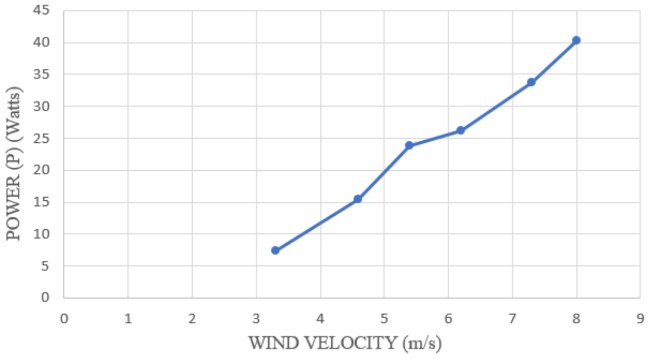

Fig.33 Experimental Wind Velocity (m/s) vs Power (W)

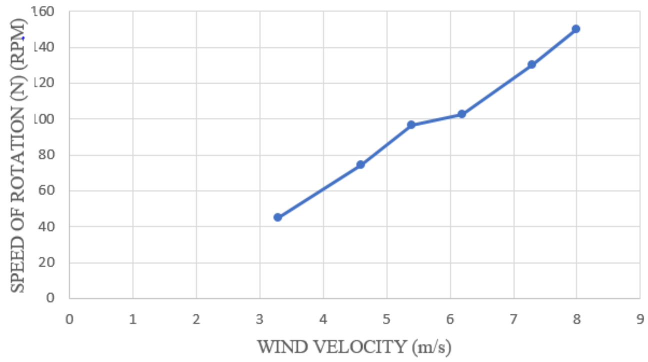

Fig.34 Experimental Wind Velocity (m/s) vs Speed of Rotation (RPM)

It is observed that with increase in wind velocity there is steady increase in rpm and power obtained. Considering the fact that the fan diameter is only 16' and that the flow is turbulent, more power is expected for a steadier flow of air. Comparing Fig. 32 and Fig. 33, there is an increase in power with increase in wind velocity. Hence the results are validated.

MERITS: On comparison with alternative energy source, wind energy is clean energy. There is no form of emissions of gases and other harmful substances. The system once installed gives free energy and is worth the initial cost. The use of airborne wind turbines saves installation and material costs, also these turbines can reach more height than conventional wind turbines. Airborne wind turbines can be moved from one location to another in case of seasonal change. The cost of the project is low as materials like aluminum are cheap and easily available. They are light in weight and have anti-corrosion properties.

The opted design is a Giromill Darrieus wind turbine and is more efficient compared to other VAWT due to its aerodynamic properties.

LIMITATIONS:

Severe weather conditions may require the system to be unlaunched for the particular time period and hence no power is generated if the wind turbine setup is retracted during bad weather. Initial cost for the helium balloon is high. The balloon requires regular refilling as it has a leakage of approximately 10% per 24 hours. It is difficult to get accurate readings of wind velocity as at high altitudes anemometer cannot be used.

CONCLUSIONS:

The above work focused on generating the power using wind energy. Aluminium was chosen as the material for entire wind turbine design setup in order for the balloon to lift it. Aluminum is a lighter material with good strength and it is known as for its machinability and surface finishing capabilities**.** The design is carried out using FEA technique revealed that design is safe and the above selected material is valid. The design shaft orientation was decided to be kept horizontal for the purpose of stability after it is lifted. Vertical orientation may cause the system to sway and can be less stable. The overall weight of the system can further be reduced by using materials like carbon fibre. Although carbon fibre is an expensive material, its properties like light weight and greater strength. CFD analysis can be done to further study the aerodynamics of the system. An aerodynamic self-aligning balloon can be designed. Also, airflow around the system can be studied and design can be improved. The graphs which are plotted reveals that the power and the speed of rotation of the shaft increases with the wind velocity.

Nomenclature:

P = Wind Power (W)
ρ = Density of Air = 1.14 kg/m^3 for a temperature of 35°C
D = Swept Area Diameter, m
v = Velocity of Air, m/s
V=Voltage, V
I= Current, Amperes
N=Speed of rotation, rpm

REFERENCES

1. Dodge, D., 2006, "Illustrated History of Wind Power Development," Telos Net Web Development, Littleton, Colorado.
2. John K. D. Zafirakis, "The wind energy (r) evolution: A short review of a long history", Lab of Soft Energy Applications & Environmental Protection, TEI of Piraeus, Greece, 2011.
3. Global Wind Statistics, "Global Wind Energy Council", 2017.
4. Alexander Bolonkin, Using of High Altitude Wind Energy V. P. of Consulting and Research Co., Brooklyn, USA,2011, PP 75-85.
5. Moritz Diehl, "Airborne Wind Energy: -Basic Concepts and Physical Foundations", KULeuven, Electrical Engineering Department, ArenbergKasteelpark10,3001Leuven, Belgium.
6. Nykolai Bilaniuk, Ph.D., P.Eng. CEO, LTA Wind power, Ottawa, Canada," Generic System Requirements for High Altitude Wind Turbines", volume 1, 2009.
7. W. T. Chong, A. Fazlizan, S. C Poh, W. P. Hew, F. B. Siao, "The design, simulation and testing of an urban vertical axis wind turbine with the Omni-direction-guide-vane*, Applied energy 2013-2012.
8. P. Jaen-Sola, A. S. McDonald and E. Oterkus, University of Strathclyde," A lightweight approach for airborne wind turbine drive trains".
9. Bas Lansdorp, M.Sc and Prof. Dr. W.J. Ockels, Delft University of Technology, the Netherlands," Comparison of concepts for high-altitude wind energy generation with ground based generator", The 2nd China International Renewable Energy Equipment & Technology Exhibition and Conference, Beijing, 2005.

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10. Lorenzo Fagiano and Trevor Marks," Design of a small-scale prototype for research in airborne wind energy , volume1,2013.
11. Prithi seshadri, Dharmalingam. R , [1]Anna University, Coimbatore, [2]ECE Head of the Department, Maharaja Institute of Technology, Coimbatore, Tamil Nadu, International Research Journal of Engineering and Technology (IRJET), volume 4, Issue: 04,217.
12. Iį Sį Hwang, Wį Kang,ġSį Jį Kim," High Altitude Cycloidal Wind Turbine System Design", Procedia Engineering 67, 7th Asian-Pacific Conference on Aerospace Technology and Science,2013,PP 78-84.
13. T.B.M.J. Ouarda , C. Charron , J.-Y. Shin, P.R. Marpu, A.H. Al-Mandoos, M.H. Al-Tamimi, H. Ghedira, T.N. Al Hosary, "Probability distributions of wind speed in the UAE", Conversion and Management 93 (2015) 414–434.
14. H.E. Saber, E.M. Attia, H.A. El Gamal, "Analysis of Straight Bladed Vertical Axis Wind Turbine", IRJET, ISSN:2278-0181, Vol. 4 Issue 07, July- 2015.
15. Sampath S S, Sawan Shetty, Chithirai Pon Selvan M, 2015. Estimation of Power in Low Velocity Vertical Axis Wind Turbine. Frontiers of Mechanical Engineering, Higher Education Press and Springer-Verlag Berlin Heidelberg 2015, 10(2): 211-218. DOI: 10.1007/s11465-015-0338-x.