

# **AIRBORNE WIND TURBINES: AN ALTERNATIVE METHOD TO GENERATE CLEAN ENERGY, ITS' APPLICATION AND DESIGN CONSIDERATIONS**

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**Abstract:** An airborne wind turbine is a wind turbine with a rotor supported on a floating structure in air. It will be independent of location, requiring negligible area of land, and higher energy generation due to good wind speed. The current prototypes being tested have shown high potential of being successful in implementation but further improvements have to be made before it is introduced into the market.

The paper will explore an alternate design of an airborne turbine, suggest various materials that can be incorporated in the design and analyse the power generating capacity of the same, at locations such as sea ports where power demand is very high and ways it can be incorporated with the existing infrastructure to reduce its carbon footprint.

**Keywords:** Airborne wind turbine, helium-graphene aerogel, stability fans, carbon fibre

## **1. Introduction**

An airborne wind turbine is a wind turbine with a rotor supported on a floating structure in air. The general construction of the structure consists of a shell containing graphene aerogel and helium to float the turbine and rotor to an altitude of 200m-300m where strong, stable and consistent winds are available for capture.

It is capable of producing energy double the energy of terrestrial wind turbine of similar dimensions. Currently, wind turbines generates about one percent of the world's electricity, but if a system of floating windmills is effectively used in mass numbers used by tethering it to rooftops, industrial establishments and business locations, it can power the world several times over.

Airborne wind turbines have immense potential to contribute to the energy production. Hence a number of teams have been testing their prototypes and have had promising results. The current challenges include making a floating structure stable in high wind velocity conditions and transmitting electricity to the ground.

## 2. Structure of airborne wind turbine

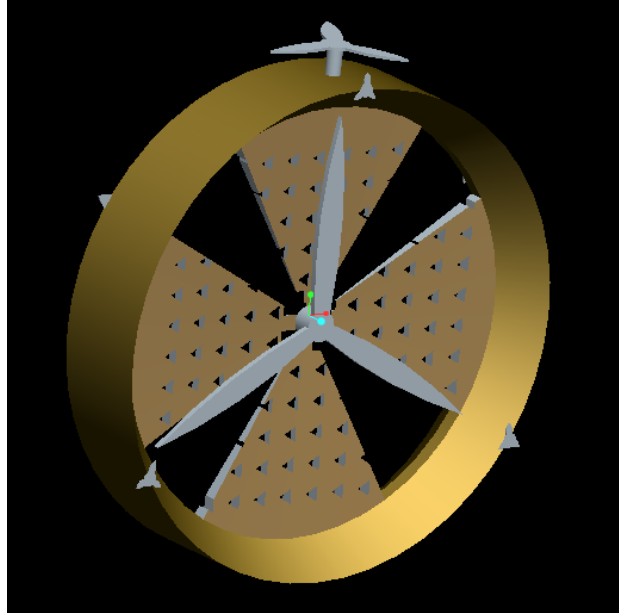


Figure 1: Wind turbine structure with stability fans

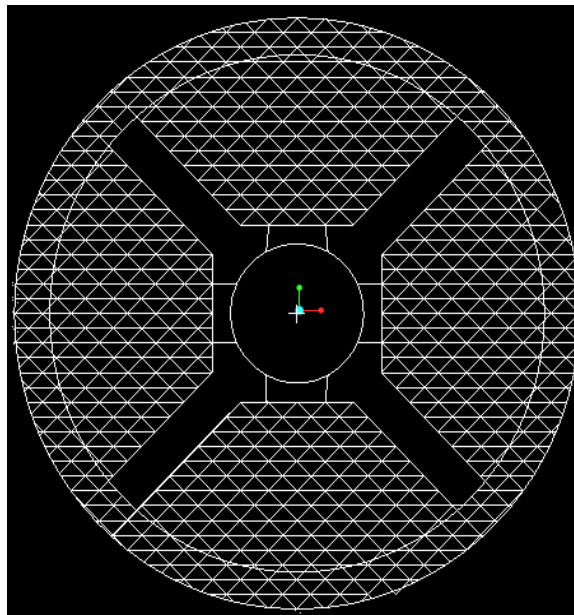


Figure 2: Internal structure of wind turbine indicating the triangular helium-graphene aerogel buoyancy tanks

The airborne wind turbine consists of three parts:

- The outer structure containing triangular helium-graphene aerogel buoyancy tanks
- The turbine-generator set
- The stability fans

The outer structure resembles a ring and tapering towards the centre. The outer diameter is 160m and the inner diameter is 140m. The ring contains the triangular buoyancy tanks to lift the entire structure in the air. Each buoyancy tank is lined with polyester fabric to hold the helium and graphene aerogel mixture.

The properties of graphene aerogel are:

- The density is 7 times lower than the density of air at ground level.
- It is able to take up a load of 35 times its self-weight.
- It acts as an excellent insulation.

Helium has to be present with the graphene aerogel since when placed in air, it soaks the air up like a sponge, making it heavier and will not be able to give the required buoyancy. Hence helium is used so that graphene aerogel can soak it up and yet provide the required buoyancy to the structure.

To support and distribute the weight of the turbine, four triangular sections, right angles to each other protrude towards the centre and the turbine is attached by steel columns. This will ensure even distribution of the weight and reduced vibrations. This is important as the turbine and its' blades weigh about 80T and has to be ably supported, The triangular sections have cut portions within it so as to ensure it allows the wind to flows without imparting excessive axial force to the structure. The triangular sections also contain buoyancy tanks with similar construction as seen in the ring.

The structure is made of carbon-fibre as it low weight, high tensile strength, high stiffness, corrosion resistant and low thermal expansion coefficient in comparison with steel and duralumin which is used in the construction of aircrafts.

### **3. The turbine and generator**

The amount of energy one can extract from a given volume of wind at a particular height at a given temperature and pressure is known as aerodynamic efficiency. The Betz' law states that the maximum possible extractable energy is 59.3% ( $C_p$ ) of total available wind energy from a give volume of wind. Wind turbine designers around the world try to design their wind energy extractor (Blades) to catch up with this limit. Presently available blades have  $C_p$  of around 0.35 to 0.45. While maximum claimed  $C_p$  is 0.52.

The tri-blade horizontal axis turbine is the most efficient and reliable among the ones present in the market for the following reasons:

- The blades of the triblade design are always presented at the optimal angle to the oncoming wind: The pitch of the blades can be varied to extract the maximum energy possible with trivial energy required for adjustments.
- Triblade turbines can be scaled up: The turbines blades can be made larger in length to sweep a larger area to produce more area. The largest built wind turbines have a rotor diameter of 120m generating 8MW of power. Other designs on scaling up would weigh enormously with very low power generated to weight ratio making it impractical.
- Easy to construct and set up: The turbine consists of three blades attached to a hub and the shaft leading into a generator from the hub. It is fairly easier and faster to construct and set up these turbines in comparison to vertical axis turbine.

The wind turbine suggested for the structure is the Repower's 6.2MW turbine which has a rotor diameter of 126m. These turbines are the largest constructed for an offshore wind farm and is able to withstand the corrosive salt laden air. The cutoff speeds of the turbine is 4m/s and considering the average sea breeze to be 8m/s-10m/s, the turbine is highly compatible to suit the requirements.

The turbine would be harnessing the energy for the land breeze and the sea breeze. As these winds blow in opposite direction to each other, the variation of the pitch in the blade has to be about  $200^\circ$  so as to remove the need to rotate and align the entire structure in the direction of the wind.

For every wind speed a there exists an optimum pitch of the blade. The wind speed is measured by an anemometer and the signal is send to microcontroller which in turn controls the motor which would change the pitch of the blade. At wind speeds above rated, the angle of attack of the blades is made zero so that the blades do not rotate, thereby preventing the damage of the blades due to high centrifugal forces.

#### 4. Stability and height adjustment

In high wind conditions, it is expected that the entire structure will tend to roll, pitch or yaw in windy conditions. This will reduce the effective capacity and cause transient fluctuations in power generated by the turbine.

To reduce the undesirable effects of movement of the structure and align it with the wind, it is proposed to have three high thrust fans each on fore and aft. The fan would be placed at  $120^\circ$  to each other on one end and the fans on the other end would be placed similarly but rotated at  $60^\circ$  relative to the fans on the other end.

This configuration has an advantage of stabilizing the structure on all three planes by utilizing stabilizing moments opposite to the wind forces.

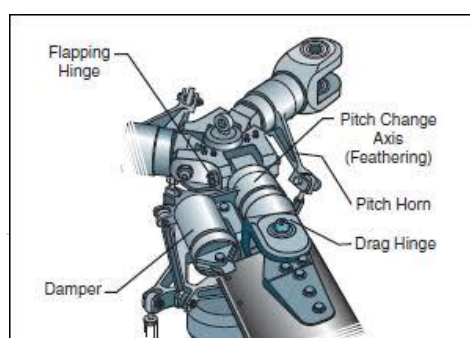


Figure 3: Fully articulated rotor blades

The stability fan on the top of the ring is similar to a helicopter rotor and is used for large stability constructions and to bring the structure

down to the ground when required. It is a fully articulated rotor system with each blade attached to the rotor hub through a series of hinges that let the blade move independently of each other. The blades are allowed to flap, feather, and lead or lag independently of each other. This helps in a dissimilar lift and this is used to counteract against the forces that would tend to destabilize the structure.

Devices such as accelerometer, gyroscope and GPS will have the set point of the structure. In the event of the structure rotating or moving axially, the sensors will feed the data to a microprocessor where an error signal will be generated. The microprocessor can be programmed accordingly to send signals to the required fans to bring the structure to a stable position.

To align the turbine in the direction of the wind if changing the pitch if the blade isn't sufficient, a wind vane will ascertain the direction of the wind and the structure can be rotated accordingly. Even though the direction of land and sea breeze remains fairly constant, in an eventuality of crosswinds, the structure has to be rotated using the high thrust fans.

Due to high wind speeds at an altitude of 200m-300m, the structure will be subjected to rotary and axial movements and this has to be dynamically corrected to keep the power generating efficiency at an optimum level.

Four anchoring cables, two at the forward and two at the aft anchors the structure to the ground and keeps it steady at the particular location. The cables have anemometer attached at various points to determine the altitude where the maximum wind speed exists. To bring the structure at the required altitude, there exists air ballast tanks in the ring which fills up to give the structure the required weight to bring it to the optimum altitude. This also helps in reducing the tension in the anchoring cables due to lift regenerated by the helium-graphene aerogel mixture.

In case maintenance is required to be carried out or heavy weather, the anchoring cables can be reeled in to bring the structure to the ground.

## **5. Transmitting power to the ground**

The biggest challenge in an airborne wind turbine is transmission of power. Copper strands wound together on a steel wire core is to be used to transmit power the ground. As the power generated is three phase, three such copper cables with its respective phase is heavily insulated with rubber coating and wound together to form a large bundled cable. The bundled cable is again wrapped with a rubber coating and covered with a waterproof polyester material to protect the cables from elements of the nature.

To prevent flaying of the cables in the wind, the cable is given only the minimum require slack to accommodate thermal expansion and is free enough to take up the movement of the structure.

The turbine will be rotating at a varying speed due to variation in the wind speed. This would cause a fluctuation of frequency of the electricity produced. To convert the power produced into a stable frequency power, a rectifier and an inverter set is used. The voltage can now be stepped up to feed the power into the transmission lines.

The safeties and maintenance that have to be taken into account are:

- Monitoring of insulation system to prevent a short circuit.
- Renewing of the polyester covering.
- Locking of the turbine in case of excessive wind condition and bringing the structure to ground level to prevent breakage of the transmitting lines.

## **6. Application of Airborne Wind turbines on ports**

Wind is simply air in motion. It is produced by the uneven heating of the Earth's surface by energy from the sun. Since the Earth's surface is made of very different types of land and water, it absorbs the sun's radiant energy at different rates.

The airborne wind turbines would be harnessing the land and sea breeze.

During the day along the coast, the land and water absorb radiant energy from the sun. They do not, however, change temperature at the same rate because they are made of substances with different specific heat values. Specific heat is the amount of heat energy needed to raise the temperature of one gram of a substance one degree Celsius. Water has the highest specific heat of common substances, which means it takes more energy to increase the temperature of water than to raise the temperature of the same quantity of other substances. Because of its lower specific heat, land heats faster and cools more rapidly than water, and the air over the land also heats more rapidly than air over the water. The heated air over the land rises, creating an area of low pressure.

The air over the sea is cooler, creating an area of higher pressure. Winds flow from areas of high pressure to areas of low pressure, thus the cooler air in the high-pressure area over the sea moves to the area of low pressure over land. This is called a sea breeze because the wind is coming from the sea toward the land. At night, the land cools more rapidly than the water, which means the sea is now warmer than the shore, and the air over the sea becomes warmer than the air over the land. The warm, rising sea air creates an area of low pressure, and the cooler air over the land creates an area of higher pressure. The air again moves from higher to lower pressure, from land to sea. This breeze is called a land breeze.

These winds can be harnessed as the wind speeds and directions are fairly predictable. The winds move from sea to land during the day time and reaching its peak speeds just after mid-day when the differential temperature between land and sea is the highest. The speeds gradually drop during dusk and become still when the temperatures over land and sea become equal.

Following are the locations where the airborne wind turbine has a potential to be used:

- Western coastline of England:

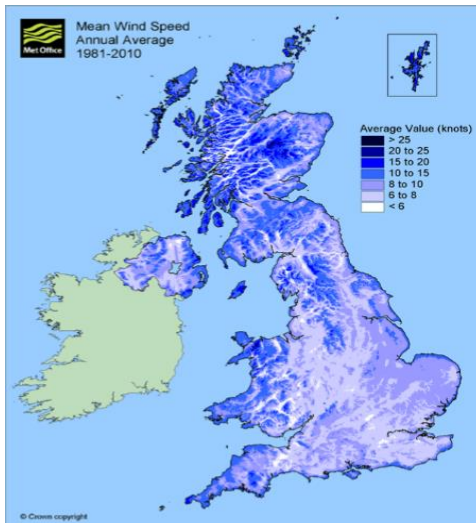


Figure 5: Average wind speeds in UK

The UK map is coloured in different shades of blue, depending on each locations annual mean wind speed. The darker the shade of blue the windier the location. In general, the windiest parts of the UK are the north and west. This is because the prevailing west to south-westerly winds across the UK lead to northern and western areas being typically more exposed than the south and east.

The average speeds prevailing in the northern coastline is about 7.5m/s.

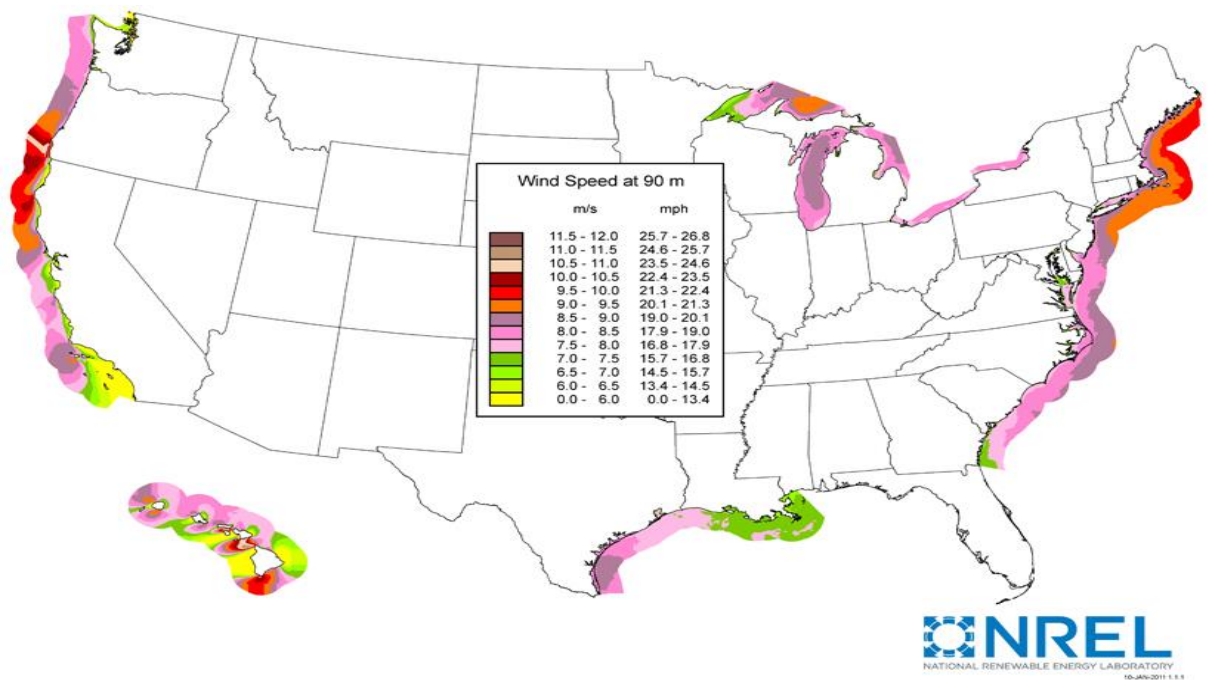


Figure 6: Wind speeds on the US coastline

- US Coastlines: The above graphics indicates the wind speeds along the US coastlines at a height of 90m. The wind speeds along the eastern coastline and the western coastline ranges from 10m/s-7.5m/s. These speeds are optimum to be utilized by the airborne wind turbines,
- An original research paper on “Identification of Potential Wind Energy places in the coast corridor of Andhra Pradesh, India” by V.Lakshmana Rao and P. Satish

concluded that Visakhapatnam, Kakinada and Kalingapatnam as three major locations where wind energy can be harnessed with wind speeds consistently blowing at speeds of 6-8m/s.

## **7. Advantages of using airborne wind turbine**

The distinct advantages that an airborne wind turbine offers are:

- The wind turbines is able to capture higher and consistent wind speeds
- There is no requirement of large tracts of land to be purchased as required in case of windfarms and solar farms.
- The wind turbines can be used in urban areas and can be attached to buildings using cables.
- Wind turbines give an efficiency of 35%-40% as opposed to 10%-12% in case of solar panels.
- To harness solar energy, at least 300 days of sunshine is required and can be tapped in select locations. There is no such requirement for an airborne wind turbine as consistent winds at a high altitude is generally available everywhere.
- The generation capacity of an airborne wind turbine can be increased by increasing the length of the cable. Such flexibility is unavailable in other power generating methods as their capacity is fixed.

## **8. Future of airborne wind turbines**

The airborne wind turbines are expected to become larger and float higher in the air as the materials used for constructing the structure and the cables improve. The challenge that would always be faced by designers is how to bring the power back to the ground safely and cost effectively as the altitude increases.

The next breakthrough in airborne wind turbines would be harnessing the jet streams flowing at an altitude of 10km ay speeds exceeding 200kmph. Such conditions pose very difficult challenges and would require ground-breaking development in sending high power wirelessly, carbon nanotubes and construction materials.

The design suggested by the paper would be viable in the next 5 years. Although the cost of R&D and perfecting the technology is on the higher side, the implementation should be fairly easy. The airborne wind turbines can make the shipping ports green and self-sustainable and can contribute in reduction in environmental damage due to shipping drastically.

## **9. Conclusion**

Airborne wind turbines is an exciting and an innovative method to harness wind energy. It has a distinct advantage over conventional wind farms and the popular solar panels that are being employed. Ports are a major energy consumers and in a bid to make them greener, sustainable and to lower its' carbon footprint, this technology

should be considered. The other application that airborne wind turbines may find its application, albeit in a smaller scale is villages where electricity hasn't been able to penetrate as these wind turbines can be used in almost all the locations. Although the cost of developing this into a full scale product is substantially high, the cost that would have to be borne by our civilization for sticking to conventional sources of energy would be higher.

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