Design And Analysis of Buoyant Wind Turbine

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Abstract - *Wind energy is an emission-less and sustainable way of producing electricity. Conventionally wind turbines are classified as onshore or offshore wind turbines but there is another unconventional wind turbine known as Airborne Wind Energy systems or AWEs. The AWEs are further Classified on the basis of where the electricity is generated as Ground-Gen and Fly-Gen. This project involves the design and analysis of the Airborne Wind Energy system (AWEs) which can also be referred to as Buoyant Air Turbine (BAT). The Fly-Gen AWEs differ from a traditional wind turbine in the following way, instead of having a solid upright structure upon which the turbine is mounted the fly-gen AWEs will be floating in the air and will be anchored to the ground by the means of cables. The Buoyant Air Turbine consists of the following components (i) Motor-generator (ii) Turbine (iii) Gearbox (iv) Transmission Cables (v) Balloon. CFD analysis is done for the model designed in CREO, with the help ANSYS by giving input of thermophysical properties of the fluid and faces of inlet and outlet to the model. Lift, Drag and viscous force are obtained for wind velocities 3,4,5,6m/s and discussed.*

Key Words: Airborne Wind Energy Systems, Buoyant Wind Turbine, Fly-Gen, Ansys, CERO, Drag Force, Lift Force.

1. INTRODUCTION

Variations in the amount and kind of energy available to meet human needs for sustenance and labor are intimately tied to the advancement of societies, particularly in their ability to sustain greater populations. Poverty is associated with a lack of access to energy. Water, food, healthcare, education, work, and communication are all essential services that require energy, particularly electricity. So far, the bulk of energy utilized by our society has come from fossil and nuclear fuels, which are today facing substantial supply security, economic affordability, environmental sustainability, and catastrophic dangers. Major countries are establishing energy policies aimed at increasing the deployment of renewable energy technology to solve these issues.

Specifically:

- The United Nations member nations have been committed to a significant decrease in greenhouse gas emissions below 1990 levels since 1992, in order to avoid the most severe effects of climate change.
- Both the European Union and the G8 leaders agreed in September 2009 that carbon dioxide emissions should be reduced by 80% by 2050.

Renewable energy plants have expanded and spread significantly in this environment in recent decades. Wind generators are the most popular form of intermittent renewable energy harvester, with 369 GW of total installed power as of the end of 2014. With an increase of 51.4 GW in 2014, wind capacity, or total installed power, is on the rise. Due to the saturation of in-land windy places appropriate for installations, such growth may slow in the future. As a result, contemporary research efforts are intended to maximize the capacity of power per unit of land area. This is in line with a global industry trend toward single wind turbines with higher nominal power (up to 5 MW), longer blades (to increase swept area), and taller turbine axes (to reach stronger winds at higher altitudes).

1.1 Principle

Airborne Wind Energy is a wind energy system that uses a tether to connect flying blades or wings to the ground. There are two fundamental concepts for converting wind energy into electricity:

Either by using small propeller turbines with generators positioned on the flying wing (first image) or by having the wing or kite pull on the tether and the tether unwind from a drum on the ground, which drives the generator (second picture). This type of ground production requires reeling in the cable (third image), which causes a churning or tumbling action.

1.2 Airborne Wind Energy

The acronym AWE (Airborne Wind Energy) is commonly used in the literature to refer to both the high-altitude wind energy resource and the technology industry. Meteorologists, climatologists, and environmental scientists have been studying high-altitude winds for decades, despite the fact that many problems remain unanswered. Archer and Caldeira provided the first study aimed at analyzing AWE's potential as a renewable energy resource. Their report describes a study that examines the vast global availability of wind kinetic energy at altitudes ranging from 0.5 to 12 kilometers above the earth, presenting unambiguous geographic wind power dispersion and endurance maps density at various heights. The effects of probable kinetic energy extraction from winds on wind and climate are not included in this preliminary investigation. However, the findings of these tests have already piqued the interest of many researchers and engineers, indicating that devices that capture energy from high altitude winds hold significant promise.

More in-depth evaluations of the consequences of the deployment of wind energy harvesters (near the surface and at high altitude) that impose dispersed drag forces upon wind flows have been conducted using complex climate models. Winds flying near the surface (harvested with typical wind turbines) and throughout the whole air layer, according to Marvel et al., may create up to 400 TW and 1800 TW of kinetic power, respectively (harvested with both traditional turbines and high altitude wind energy converters). Even if such a large extraction may result in severe/unwanted changes to the global climate, the authors show that extraction of 'only' 18 TW (i.e. a quantity corresponding to genuine worldwide power consumption) has no significant global implications. This means that a huge amount of power may be collected from wind at various elevations from a geophysical standpoint. Miller et al., who calculated the maximum sustainable world power extraction in 7.5 TW, take a more dubious stance on high altitude winds. Nevertheless, their study is mostly focused on the jet stream winds (i.e. only at very high altitude between 6 km and 15 km above the ground).

Broad range of data and estimations and the high degree of uncertainty, it is possible to infer that high altitude winds might take a major amount of world primary energy. As a result, the topic of Airborne Wind Energy has significant economic and research promise in the coming years.

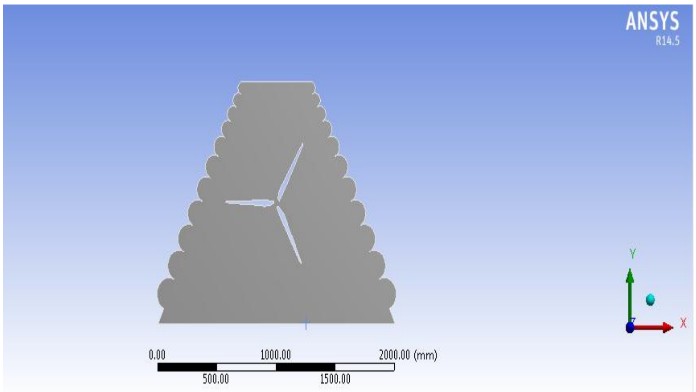
2. CFD Analysis of the CREO Model

CFD (computational fluid dynamics) is a discipline of fluid mechanics that models fluid flows using computers. The calculations necessary to represent the interaction of liquids and gases are done on computers. Software that optimizes the accuracy and speed of intricate simulation situations is the result of ongoing research.

3. Methodology

The same underlying method is followed in all of these ways.

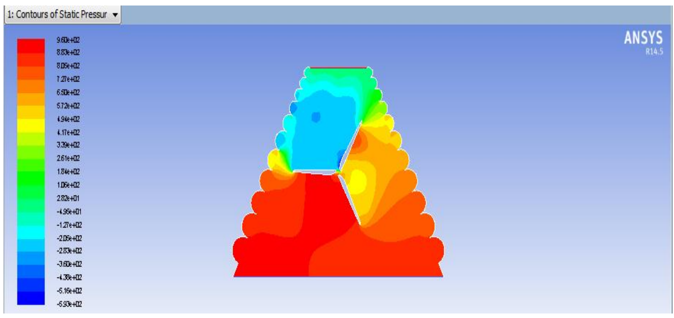
- The problem's geometry (physical boundaries) is specified during preprocessing.
- The fluid occupies a volume that is separated into distinct cells (the mesh). The mesh might be uniform or irregular.
- The physical model, such as the equations of motion + enthalpy + radiation + species conservation, is defined, as are the boundary conditions.
- This entails defining the fluid behaviour and characteristics at the problem's border.
- The beginning conditions are also provided for transitory issues.
- The simulation is initiated, and the equations are solved iteratively as a steady-state or transient, with the results analysed and visualised using a post processor.



4. Results

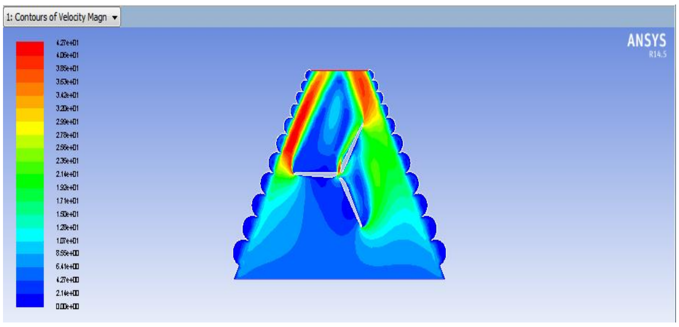
For intake velocities of 3,4,5, and 6 m/s, the pressure and velocity contours are obtained. The density of air is assumed to be 1.225 kg/m3, while the specific heat (CP), thermal conductivity, and viscosity of the fluid are assumed to be 1006.43 j/kg-k, 0.0242 w/m-k, and 1.7894e-5 kg/m-s, respectively.

Geometric Model



Pressure Contour for 6 m/s

International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 09 Issue: 06 | June 2022 www.irjet.net p-ISSN: 2395-0072



Velocity Contour for 6 m/s

Drag force

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Forces
                        Forces (n)
Zone                    Pressure                                 Viscous
wall-_trm_srf           (31.615128 1467.5415 0)                  (0.62935144 0.61902261 0)
------------------------ ---------------------------------------- ----------------------------------------
Net                     (31.615128 1467.5415 0)                  (0.62935144 0.61902261 0)

Forces - Direction Vector (1 0 0)
                        Forces (n)                                 Coefficients
Zone                    Pressure      Viscous       Total         Pressure      Viscous       Total
wall-_trm_srf           31.615128     0.62935144    32.244479     51.616535     1.0275126     52.644
------------------------ ------------- ------------- ------------- ------------- ------------- -------
Net                     31.615128     0.62935144    32.244479     51.616535     1.0275126     52.644
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Lift force

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Forces
                        Forces (n)
Zone                    Pressure                                 Viscous
wall-_trm_srf           (31.615128 1467.5415 0)                  (0.62935144 0.61902261 0)
------------------------ ---------------------------------------- ----------------------------------------
Net                     (31.615128 1467.5415 0)                  (0.62935144 0.61902261 0)

Forces - Direction Vector (0 1 0)
                        Forces (n)                                 Coefficients
Zone                    Pressure      Viscous       Total         Pressure      Viscous       Total
wall-_trm_srf           1467.5415     0.61902261    1468.1605     2395.9861     1.0106492     2396.9
------------------------ ------------- ------------- ------------- ------------- ------------- -------
Net                     1467.5415     0.61902261    1468.1605     2395.9861     1.0106492     2396.9
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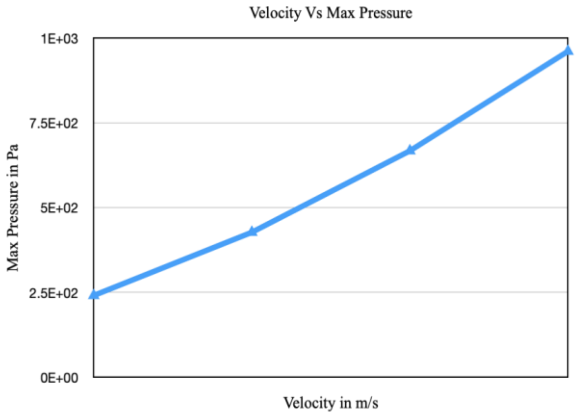
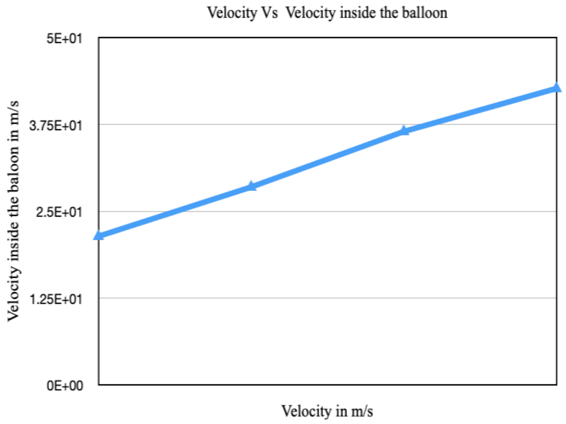
The table 1 shows the results obtained from the CFD analysis.

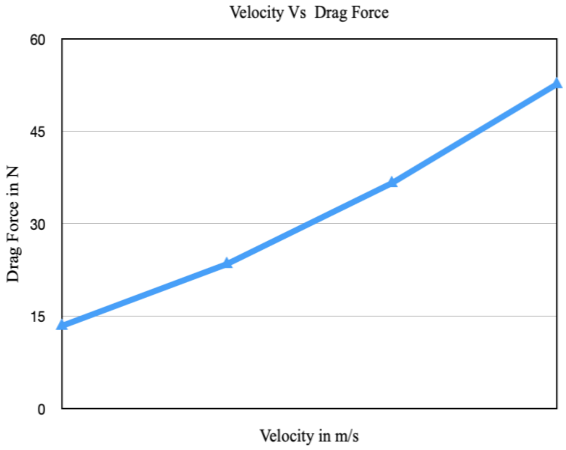
Velocity (inlet)(m/s)	Max Pressure (Pa)	Velocity (outlet) (m/s)	Drag Force (N)	Lift Force (N)
3	2.41e+02	2.14e+01	13.395	600.67
4	4.27e+02	2.85e+01	23.429	1065.39
5	6.67e+02	3.65e+01	36.570	1664.6
6	9.60e+02	4.27e+01	52.644	2396.99

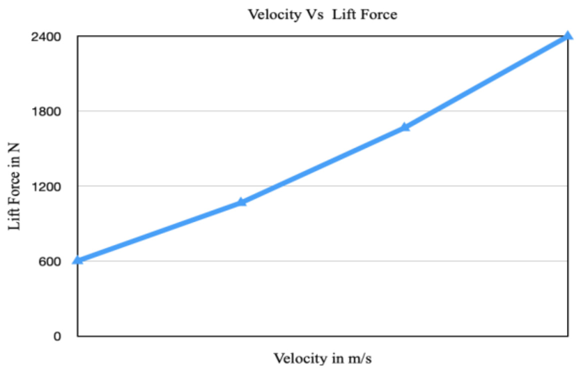
Table -1: Results of CFD analysis

The graphs shown below gives variation of different parameters with respect to the change in the inlet velocity of the fluid.









CALCULATIONS:

A German physicist Albert Betz concluded that any wind turbine can not convert more than 59.3% of the kinetic energy of the wind into rotary mechanical energy. Nowadays, this is known as the Betz Limit or Betz's Law. The maximum theoretical efficiency of any wind turbine is 0.59. This is called the power coefficient and is defined as: **Cpmax** =**0.59** Also, at this higher limit wind turbine cannot operate.

The Cp value is same to each turbine type and it is a function of wind velocity that the turbine is operating in. Once we deal with various engineering requirements of a wind turbine - durability and strength in particular – the real-world limit is below the Betz Limit with values of 0.35-0.45. By taking all other parts into account in a whole wind turbine system - e.g., the generator, gearbox, bearings etc., only 10-30% of the power of the wind is converted into usable electricity. The available power from the wind is given by: Pavail = ½ ρAV^3Cp.

Considering the maximum velocity for wind which is 6 m/s we obtain the following power

Pavail = ½ ρAV^3Cp

Where,

ρ= 1.225 kg/m^3

A= 0.29 m^2

V= 6 m/s

Cp= 0.593

So the equation will become

Pavail = ½ x 1.225 x 0.29 x 6^3 x 0.593

Pavail=22.75 W

So the we have obtained a power of 22.75 W at a wind velocity of 6 m/s.

5. CONCLUSION

The Fabrication of a buoyant wind turbine requires consideration of a lot of parameters like the pressure developed, velocity, viscosity, drag and lift force. The performed analysis on the CREO model developed has produced definite values of max pressure, velocity inside the balloon, drag and lift forces for given wind velocities. According to analysis, it is evident that the inlet velocity of wind affects the behaviour of the buoyant wind turbine. All the parameters that were considered had an increasing trend with the increase in the wind velocity which can be seen in the graphs plotted. Although parameters like drag force, lift force, max pressure and velocity inside the balloon had a significant effect, viscosity however has the least effect on the balloon. These results so obtained will be crucial in designing and programming the ground station to counter the balloon's turbulence and configure the position of the balloon according to the wind direction to receive the optimal amount of wind flow. This also helps prevent damage to the tethers due to the excessive movement of the turbine caused by the turbulence.

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