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Prediction of Day-ahead Photovoltaic Output Based on FCM-WS-CNN

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ABSTRACT

The issue of energy generation from wind is considered one of the main ways to develop renewed energy in some areas worldwide. The important point in generating energy from wind is the permanent wind availability, which is called the existence of effective wind. According to studies, there is no effective wind at ground level in many areas of the world, while this wind is available at altitude. The Accessibility of wind in altitude has led to the development of various technologies in energy production from airborne systems. In this research, airborne wind energy systems technologies have been investigated, and a tethered-glider was designed and analyzed using analytical methods for energy generation at a 200-meter altitude. The main factor in designing a glider is the optimal ratio of lift to drag coefficient; For calculating lift to drag coefficient, the vortex lattice method (VLC) is used in this paper. The results illustrate that a glider with a wingspan of 5.2 meters can produce a maximum of 10 kilowatts of energy over one cycle. Increasing this ratio can increase energy production efficiency.

1. INTRODUCTION

The use of fossil fuels for energy generation via thermal power plants has caused global warming, climate change, and the release of toxic gases. Thus, it is necessary to consider alternative solutions [1,2,3,4]. In this regards, the use of renewable energy is the major solution to protect the environment. Airborne Wind Energy (AWE) systems harvest wind energy using converting the aerodynamic forces acting on the airborne system that flying in crosswind conditions to electricity. Compared to conventional ground wind turbines, this kind of energy system can reach higher altitudes, where the wind is stronger and more continuous while reducing the cost of building a power plant.

Indeed, increasing the altitude increases the mean wind speed and wind power density. Using a tethered airborne system flying at an altitude above 150 meters can be valuable to energy generation. The aerodynamic forces generated by the glider or kite are transferred to the ground through tethered cable, where it is converted into torque and finally into electricity by the ground generator. The basic concept of harvesting energy from airborne systems, for the first time introduced by Loyd [5]. He calculated the maximum energy that can be theoretically obtained with tethered wings. In the recent decade, a lot of research has been done in energy, and several companies have started to make a prototype of this product. One of the most important research related to Ahrens [6] has comprehensively reviewed AWE technologies. In other research, Cherubini and his colleagues [7], presented the technologies in AWE in a review paper.

In another study, Kheiri et al. [8, 9, 10], generalize the classical actuator disc theory to the application of airborne wind energy systems. In this paper, the actuator disc theory was extracted and used in crosswind kite power systems in the straight downwind configuration. The results showed that the extracted power is strongly dependent on the solidity factor of the kite. It was shown that the maximum power that generated in lift mode occurs when the reel-out speed is one-third of freestream velocity. Licitra and his team [11] used an experimental method to assume aerodynamic parameters. This article estimates aerodynamic coefficients from data gathered from flight test campaigns using efficient multiple experiments model-based parameter estimation algorithm. Nejad [12] used a numerical solution model to extract coefficients and aerodynamic forces on a kite. In this model, the angle of attack of kite changes according to the optimal flight conditions to produce maximum energy. Another experimental research related to Schmidt [13] that using the Extended Kalman Filter (EKF) and on a representative model of the flight dynamics in flight test data gathering. The filter is fed with measurements available at the ground station, namely the line angles and their rates, the traction force on the tether, and the wind speed and direction a few meters above the ground. Concerning the aerodynamics of the AWE systems, Mehr et al. [14] analyze the basic aerodynamics of windcraft, specifically looking at how the wing's lift is affected by rotors extracting energy from the flow over the wing. In this research, they employ the combination of a vortex particle method (VPM), vortex lattice method, and a blade-element momentum method in exploring the drag-based windcraft design space. In another article in this field, Malz et al. [15] calculated the energy profile of an airborne system using the data collected from the wind profile. In one of the latest research, Vimalakanthan [16] performed the aerodynamic analysis of Ampyx Glider. This study made a comparison between 2D steady and unsteady calculations using SU2 and OpenFOAM. Calculations are performed for different flap angles and different angles of attack. Moreover, 3D steady SU2 results are compared to the results obtained from Ampyx with OpenFOAM for three different scenarios. Various research works have been done in the field of control and optimization of AWE systems [17, 18, 19, 20]. Several methods, including computational fluid dynamics (CFD), are used to analyze forces and aerodynamic coefficients. CFD methods often require long computation times, but one of the most efficient methods is the vortex lattice method (VLM). XFLR5 software can estimate the aerodynamic coefficients with appropriate accuracy by VLM. Several research projects have been performed to calculate aerodynamic coefficients, including lift and drag [21, 22]. Agten from Delft university of technology, in the master's thesis, used VLM and XFLR5 software to calculate an aerodynamic coefficient of airborne system for Airborne Wind Energy Applications [23]. In this paper, in addition to reviewing existing technologies in the field of AWE systems, a tethered glider will be analyzed by the VLM as a case study, and output power will be calculated.

2. AIRBORNE WIND ENERGY TECHNOLOGIES

The advantage of AWE systems over conventional wind turbines is greater wind access at altitude, shown in Figure 1. Based on existing equations and references, it can be said that the wind velocity and wind power density will increase with increasing altitude.

In terms of technology, airborne wind energy systems are generally made of two main components, a ground system and at least one airborne system that are mechanically or electrically connected to the ground system. The glider system is connected to the ground by a cable or strap, which will be responsible for harnessing the flyer and transmitting energy to the ground. In general, AWE systems can be divided into ground-gen and fly-gen. Figure 2 is shown the classification of technologies in AWE systems.

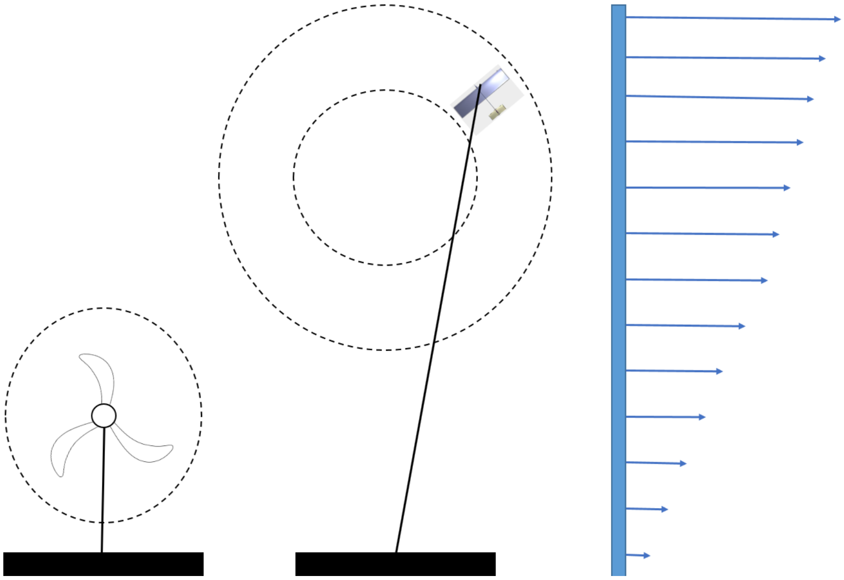

Figure 1: Comparison of classic wind turbines and AWE systems

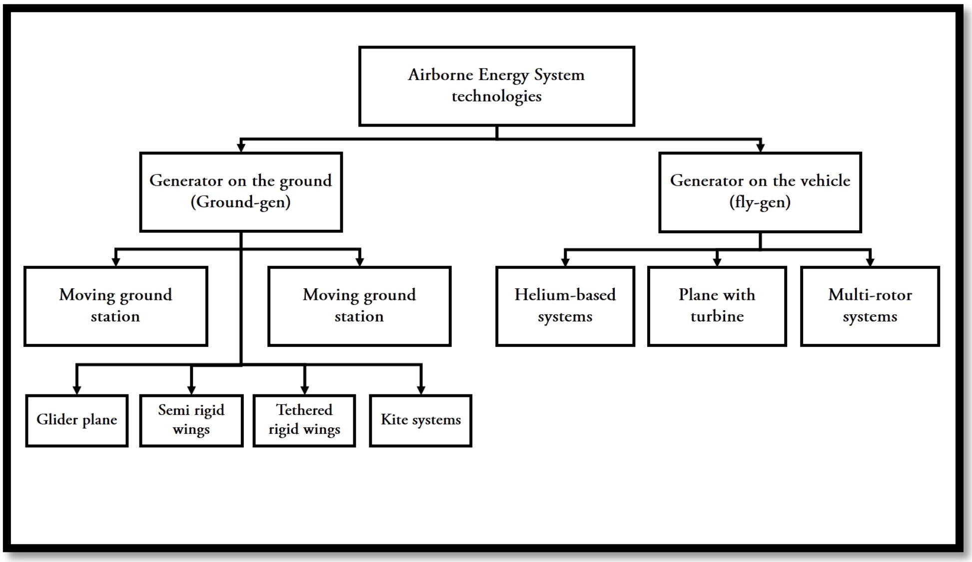

Figure 2: Classification of technologies related to AWE systems

2.1. Flygen airborne system

In the Flygen airborne system, the generator is mounted on the airborne system. In this type, the brushless motor acts as a generator and propulsion system simultaneously. This method generates power by converting wind energy to mechanical power using blades. This power is transmitted to the ground through tethered cable. Part of the power generated in Flygen systems will power the brushless engines. Flygen systems are mounted on various airborne systems such as lighter than air, multi-rotor, and fixed-wing planes.

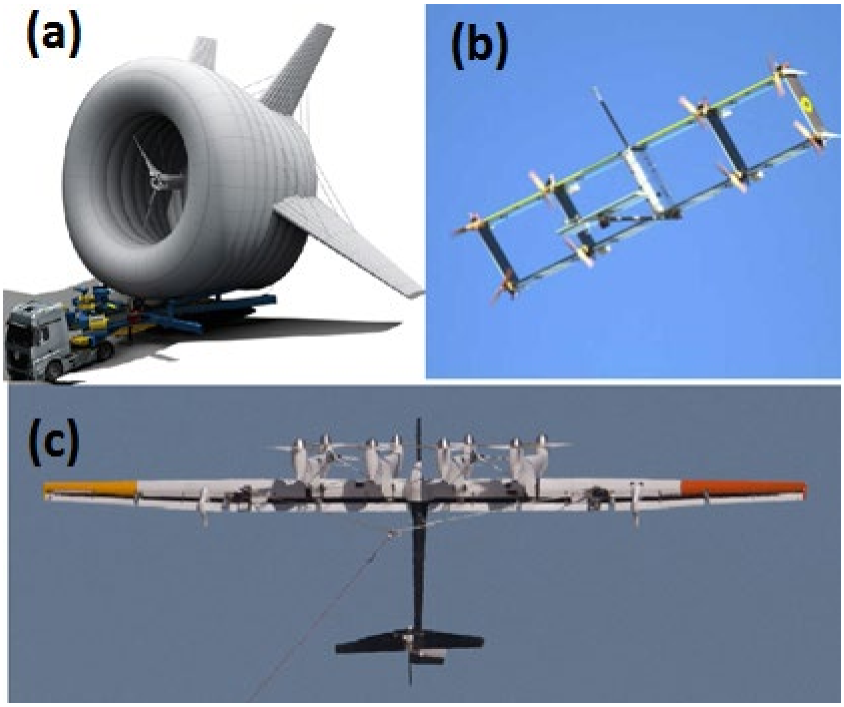

Figure 3: Different types of Flygen technologies, (a): lighter than air helium-based system, (b): a multi-rotor system for energy generation, (c): fixed-wing plane.

2.2. Groundgen airborne system

In Groundgen energy systems, the generator is mounted on the ground, and the airborne system is responsible for energy production. In Ground-Gen AWES, the conversion of kinetic energy into electrical energy takes place on the ground. In Ground-Gen AWES, the ground station is connected to a kite or aircraft via a tether. As electrical energy is generated at the ground, the tether must not be conductive. The electric generator is attached to the rotating mechanism, such as the winch connected to the tether. In this system, traction force is used to generate the electrical energy. The power produced by this system is intermittent. Kite and Glider-plane are the most famous types of Groundgen systems (figure 4).

Figure 4: Different types of Groundgen technologies

3. GOVERNING EQUATIONS

In this paper, the equations are divided into two parts: the first part is equations related to the VLM approach, and the second part is related to pumping cycle equations.

3.1. Linear VLM formulation

The VLM models the lifting surfaces, such as a wing, of an aircraft as an infinitely thin sheet of discrete vortices to compute lift and induced drag. Vortex line solution of the incompressible potential flow is one of the most important parameters In the VLM approach, while the imposed boundary condition is that of zero flow in the direction normal to the wing's solid surface (equation 1) [19]:

$$\nabla\,(\emptyset_\infty + \varphi).n \tag{1}$$

where $\emptyset_\infty$ Represents the potential of the freestream flow, φ the perturbation potential, and n the vector normal to the wing surface. The boundary condition is applied on the wing's mean camber surface, made by the camber lines of span-wise airfoil sections [23]. The solid surface is divided into rectangular panels, and the vortex ring singularity elements that are located on the panels. The wake vortices are aligned with the incoming flow velocity. The circulation of each wake vortex is equal to the circulation of the trailing edge vortex formed upstream of it directly. Therefore, the three-dimensional Kutta condition of null trailing edge circulation, presented in equation 2, is satisfied:

$$\gamma_{TE} = 0 \tag{2}$$

where γ_{TE} Is the circulation at the trailing edge of wing. Each vortex ring is composed of six vortex lines, the leading-edge line located on the quarter chord line of the corresponding panel and the trailing edge line placed on the quarter chord line of the panel downstream directly. The direction of positive circulation is defined based on the right-hand rule [13]. The velocity induced by each of the vortex lines of a vortex ring at an arbitrary point is given by the Biot-Savart law [24]:

$$V = \frac{\Gamma}{4\pi}\frac{r_1\times r_2}{|r_1\times r_2|^2}r_0.(\frac{r_1}{r_2}-\frac{r_2}{r_1}) \tag{3}$$

where V is induced velocity and Γ is the vortex intensity. r_1 and r_2 are the position vector From the beginning of the vortex line to the desired point in space and the position vector from the end to an arbitrary point in space, respectively. Also r_0 is the vector from the beginning to the end of the vortex line [19].

3.2. pumping cycle formulation

In AWES systems, mechanical power is produced over the traction (reel out) and retraction (reel in) phases. This paper also assumed that the average power over one cycle Pc is maximal, so traction powerc or traction force in tethered cable is presented in equation 4:

$$T_{out} = \frac{1}{2}\rho V_\omega^2 A(1-\gamma_{out})^2 F_{out} \tag{4}$$

with the dimensionless force factor F_{out}:

$$F_{out} = \frac{C_l^3}{C_d^2} \tag{5}$$

also the tether force in the reel in phase is given by:

$$F_{out} = \frac{C_l^3}{C_d^2} \tag{6}$$

In equation 6, C_l and C_d are aerodynamic coefficients and obtained from VLM. The tether force in the retraction phase is given by:

$$T_{in} = \frac{1}{2}\rho V_\omega^2 A(1+\gamma_{out})^2 F_{in} \tag{7}$$

where $F_{in} = C_d$. Also $\gamma_{out} = \frac{V_{out}}{V_\omega}$ and $\gamma_{in} = \frac{V_{in}}{V_\omega}$, V_{out} and V_{in} Are velocity of traction and retraction phase respectively. Assuming a change of the tether length during the power cycle l_c, the produced energy over one power cycle E_c is:

$$E_c = (T_{out}T_{in})l_c \tag{8}$$

Furthermore, the duration of the cycle t_c is:

$$t_c = \frac{l_c}{V_{out}} + \frac{l_c}{V_{in}} \tag{9}$$

The average power over one cycle P_c is:

$$P_c = \frac{E_c}{t_c} \tag{10}$$

4. A CASE STUDY

A case study considered in this paper is a conventional configuration of a glider plane. This plane has a middle-wing configuration with a zero-twist angle. Tail configuration is also conventional. Glider schematic illustrated in figure 1. It is assumed that gliders fly at 200 meters above the ground, so the tethered length is 200 meters. The wind speed at the desired altitude is around nine m/s—glider specifications displayed in table 1. MH92 15.49% is considered; this kinds of airfoil have a suitable performance for glider plane configurations. In order to simplify, it is assumed that the glider fly at an annulus patern, perpendicular to the wind direction. Also, the effects of tethered cable on aerodynamic coefficients of airborne systems have been ignored in this study.

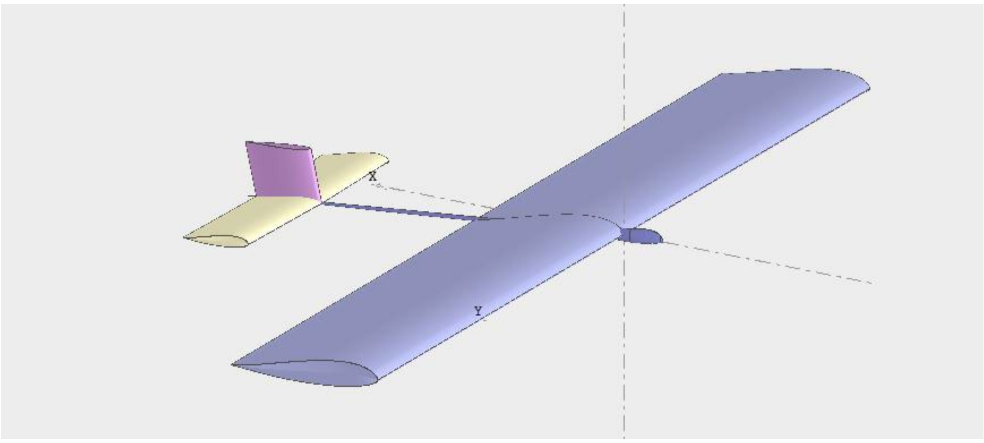

Figure 1: Schematic configuration of a glider plane.

Table 1: specifications of a glider plane

Specifications	Values
Wingspan (m)	5.2
Glider length (m)	2.3
Wing chord (m)	0.9
Wing aspect ratio	5.77
Taper ratio	1
Wing twist angle (deg)	0

4.1 Results

The most important factor in the energy production of airborne systems is aerodynamic efficiency. Airborne systems with the ability to produce more lift power can show higher efficiency in the traction phase. On the other hand, more drag force in the retraction phase can increase the device's efficiency. To calculate the average power over one cycle, it is necessary to calculate the aerodynamic forces and coefficients, including C_l and C_d Of the plane at the first step. The results of aerodynamic analysis using VLM are given. The pressure coefficient distribution on the plane is shown in Figure 2. Also, aerodynamic coefficient including C_l and C_d They are given at different angles of attack based on VLM (Figure 3 and 4).

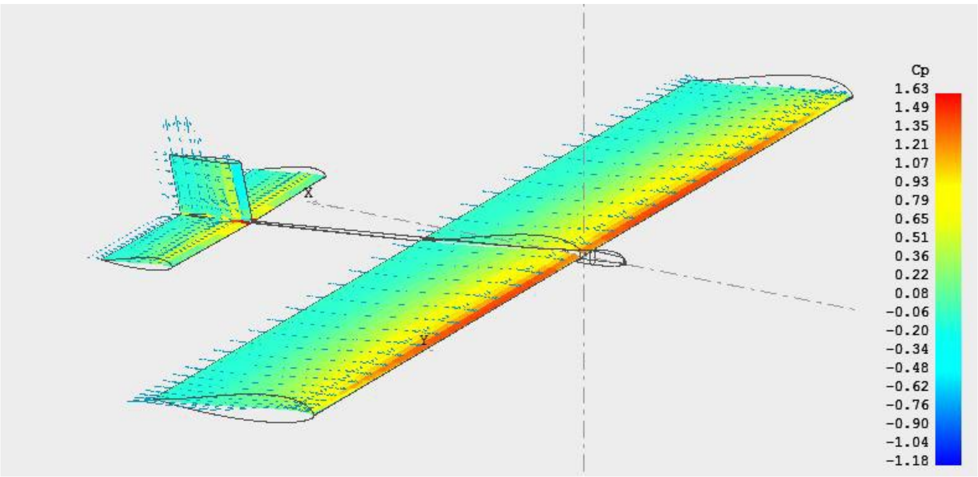

Figure 2: Pressure coefficient on the plane.

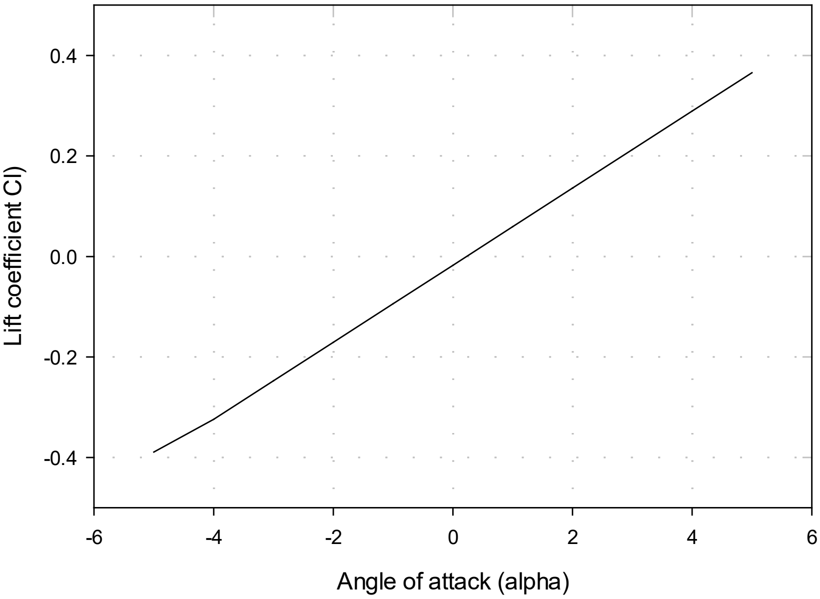

Figure 3: Graph of lift coefficient changes based on angle of attack

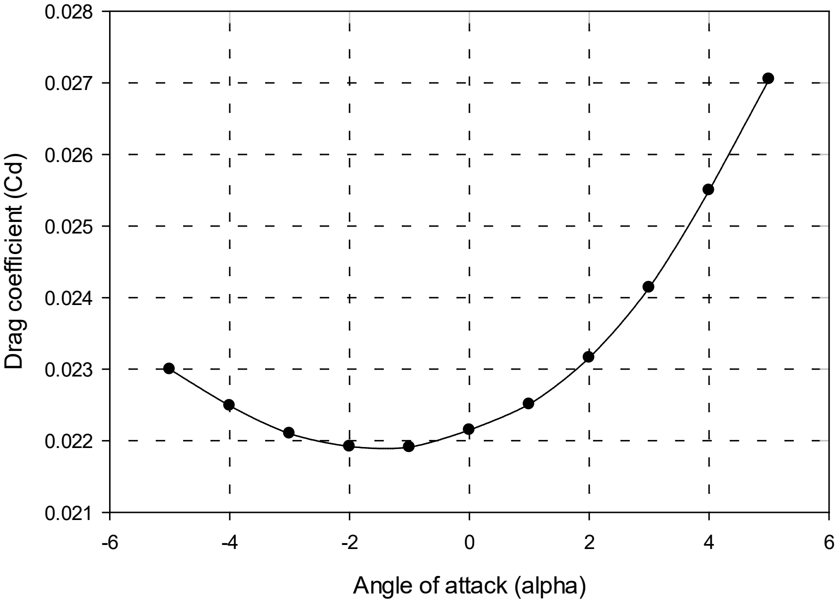

Figure 4: Drag coefficient versus angle of attack

Based on equation 6, $\frac{C_l^3}{C_d^2}$ Is important parameter in reel in or retraction phase. Figure 5 display F_{out} in the various angle of attack. Indeed, increasing the angle of attack causes an increased lift coefficient. This leads to an increase in power generation capacity in the retraction phase. Also, the lift coefficient versus the drag coefficient is given in figure 6.

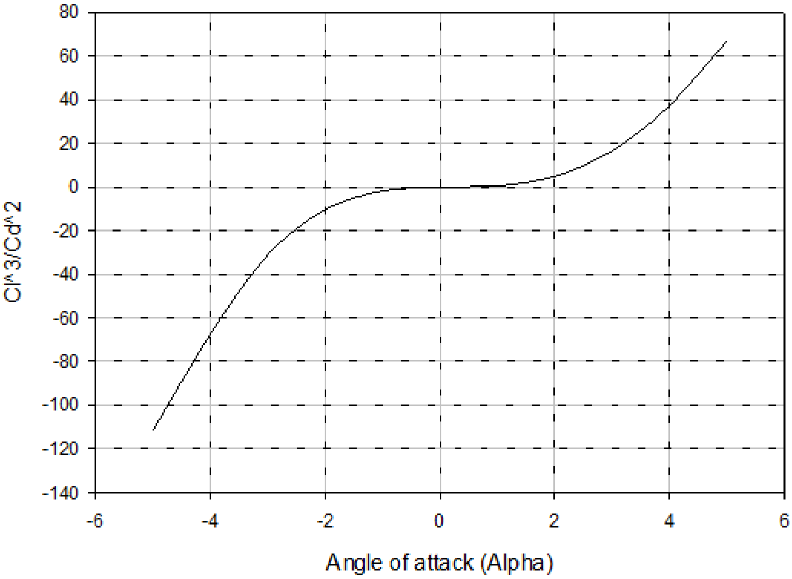

Figure 5: F_{out} versus angle of attack

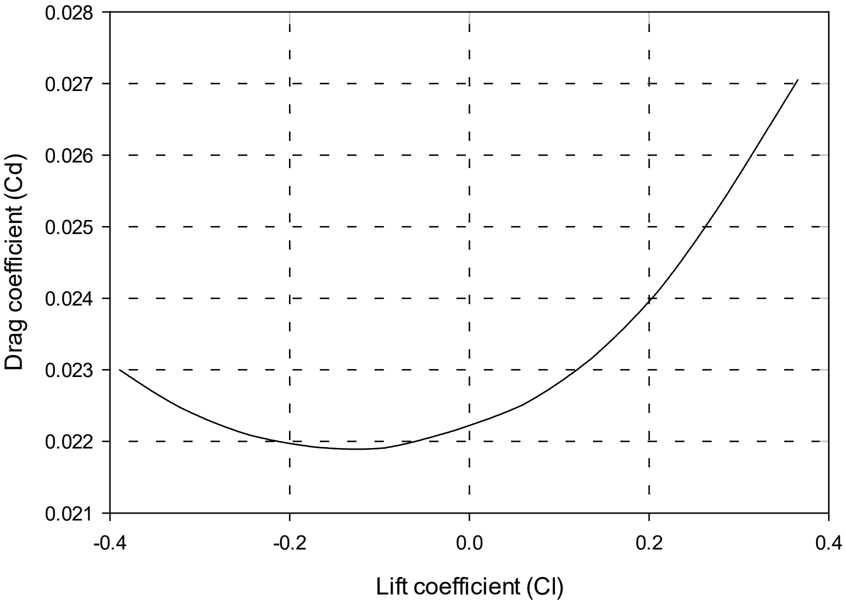

Figure 6: Lift coefficient versus drag coefficient.

By calculating the aerodynamic coefficients, the airborne system's average power over one cycle can be calculated based on the pumping cycle equations. In this research, wind velocity and maximum flight altitude of the airborne system are considered as inputs. Some results are shown in Table 2 according to pumping cycle equations.

Table 2: Output results based on the equations related to the pumping cycle

Parameters	**Values**
F_{out}	1.9405
F_{in}	0.0228
T_{out}	309.38
T_{in}	12.733
l_c	90
Energy over one power cycle (E_c)	26698
Average power over one cycle (P_c)	10012

CONCLUSION

A significant amount of wind energy is not available on Earth and cannot be extracted by classical ground wind turbines. So, airborne wind energy systems are an affordable and low-cost solution for harvesting wind energy. AWES generates power by converting aerodynamic force to electrical power; in this system, a ground generator connected to the tethered cable and changing the flight altitude of the plane leads to a change in cable length, so this change in length causes the generator to rotate and generate energy.

Other parameters such as the effect of tethered length and weight of plane are ignored in this research. This paper selected a fixed-wing plane as a Groundgen airborne energy system for harvesting wind energy at an altitude of 200 meters above the Earth. The main purpose of this research is the calculation of energy generated using an airborne system by pumping cycle method. Also, the equations used in the pumping cycle are based on the maximum energy production in the system. Research results show that a glider plane with a wingspan of 5.2 meters can generate about 10-kilowatt power in every cycle. The main parameter in generating energy in airborne systems is the plane's aerodynamic efficiency, including lift and drag forces.

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