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Performance analysis of solar powered Unmanned Aerial Vehicle

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ABSTRACT

One of the main problems in micro Unmanned Aerial Vehicles (UAV) is endurance or flight time since the general domain aircraft use conventional fuel. Using conventional fuel is a pollutant, have a limited life and costly. So there is a huge demand for using an unlimited non-exhaustible source of energy as a fuel. As solar energy is one of the available renewable energy, it can be used to increase the endurance of UAV without adding significant mass nor by increasing the size of the fuel system. By considering the basic challenges for a solar powered aircraft which are a geographical area of operation, energy collection and storage, payload and design parameters, a plane was designed & fabricated by incorporating the solar cells onto the wing. Here at first how much energy is available from the sun to power the entire plane was conceptually analyzed and then it was verified with experimental results. Finally, the energy and exergy efficiencies were calculated and analyzed, as exergy is an important tool in addressing the influence of utilizing the energy resources on the environment.

1. Introduction

In today's world, there are more than 11,000 UAVs in service (or planned for future services) by the Military for various purposes [1]. Unmanned Aerial Vehicles (UAVs) are the ones which can fly either remotely or autonomously. In spite of their usage in various applications, they lack in performance due to power restrictions and also nowadays the ability to fly without using conventional fossil fuels is primarily focused both in application point of view and as well as in scientific fields, since the major concerns are an increase in global warming and a decrease in natural resources. Since then, the use of electric aircraft have been widespread but here the crucial issue is their high power consumption when compared to their limited energy storage capability. So if either by increasing the size of the battery or by incorporating more batteries will only lead to increasing the weight of the plane which directly affects the flight time of UAV.

One of the possibilities to increase the flight time is by using unlimited solar energy through solar cells. So, the possible solution to enhance the endurance is by using solar-powered aircraft driven by electric-based propulsion systems in which the power is supplied continuously throughout the day by solar energy which can eliminate fuel and also solve the limited energy storage capability problem. Most of the previous designs of solar-powered aircraft assumed that the solar panels were to be installed on the wing as flat surface parallel to the ground, but Baldock et al. presented a paper that accounted for mounting the solar panels on curved wing surfaces [2], this arrangement helps in installing the solar cells on low camber airfoil. In a UAV the payload plays an important role in deciding the size of the aircraft. In 2013, S. Jashnani et al. discussed the altitude and payload mass as independent parameters and their influence on the size and design of the aircraft [3].

When it comes to the performance of solar cells, the performance of a Photovoltaic system depends not only on its basic characteristics but also on the environmental issues. One such environmental issue is the ambient temperature which plays an important role in the photovoltaic conversion process [4]. The solar cell efficiency is usually measured under standard test conditions (STC), with PV cell temperature of 25 °C, irradiance of 1000 W/m^2 and air mass ratio AM = 1.5, but these conditions are rarely met at outdoor installations, as the ambient temperature and wind speed affect the performance of the module for that particular locality. The open-circuit voltage decreases significantly with increasing PV module temperature (values are up to −0.45%/K for crystalline silicon) whereas the short circuit current increases only slightly (values range between 0.04 and 0.09%/K) [5]. Among the meteorological parameters, the influence of ambient temperature and

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wind speed have been considered for the present study.

As it is known that the energy efficiency represents only the quantity of energy and does not consider the irreversibility's associated with the system. But in the exergy analysis, the losses associated with the system are considered. Saidur et al. [6] reviewed the literature on exergy analysis of solar energy applications, he found that thermal efficiency alone is not sufficient to choose the desired system; therefore, it is necessary to apply the concept of exergy for the specific design of the systems in order to achieve better performance. Joshi et al. investigated the performance characteristics of a photovoltaic, for PV alone, the exergy efficiency was found to be varying in the range of 8–14% for a typical set of operating parameters [7]. Sahin et al. [8] and Dincer and Rosen [9] have investigated thermodynamic aspects of renewables for sustainable development. For calculating the exergy efficiency, Viorel Badescu [10] proposed a new way to find the maximum reversible work extraction from a blackbody radiation reservoir.

The purpose of this paper is at first, to present a simple theoretical and practical way of estimating the size of a solar aircraft by calculating how much and for how long the solar energy is required for obtaining the level flight. Secondly, in previous studies some researchers have discussed the effect of temperature and wind speed on a simple rectangular solar panel and some discussed the energy and exergy efficiencies on those panels, but here the energy and exergy efficiencies are practically calculated for a solar wing (where the solar cells are installed over low camber airfoil) by considering the mixed effect of both temperature and wind speed.

So, in this paper, conceptual design along with detailed energy and power analysis has been done to check the feasibility of solar-powered UAV. And for the designed prototype the thermodynamic analysis of solar PV cells was performed taking into account the effect of temperature along with the wind. Then finally the exergy analysis has been done in order to provide a physical basis for understanding, refining and predicting the variations in solar PV behavior.

1.1. Principle of operation

The main principle is to make use of available solar energy by converting it into electricity through solar cells. Here the cells are arranged in series on top of the wing to get the required voltage in order to safely charge a 3S battery (3 Lipo batteries are connected in series and be used as a single unit) and from there the battery power is supplied to the motor for throttling during constant level flight. Here the plane was built using lightweight balsa wood [11] and carbon fiber rods [12]. In the central part of the wing, the construction consists of spars, ribs, and the skin. The spars (made of carbon fiber) will handle the tension and compression forces on the wing, the ribs (made of balsa wood) are intended to give the wing the desired airfoil shape and also to stabilize the construction and the skin is also a part of the construction to resist the forces on the wing, which covers only the top surface with 1 mm balsa sheet in order to make a non-conductive flat surface for the integration of solar cells. One of the main aims of this paper is to check, whether the power available from the sun will be able to power the entire plane which in turn helps in increasing the endurance from a couple of minutes to hours. Here the gross weight of the plane is kept constant which is 2 kg. There was no range requirement since the goal was simply to remain flying, not to reach any destination as shown in Table 1.

2. Theory and calculation

2.1. Estimation of number of solar cells required and its arrangement on the wing

For this design, 3S battery has been chosen for 2 reasons: using more lithium polymer (LiPo) cells in series (>3S) requires more voltage to initiate the charging process, leading to an increase in solar cells and wingspan, which, in turn, increases the weight of the model. On the other hand, if less LiPo cells in series (2S) are used, it will be difficult to supply the required power to achieve a good climb rate.

As for charging the 3S battery, it requires a constant safe charging voltage of about 12.4 V. The solar cells selected for this design were Sun power C-60 monocrystalline photovoltaic cells having single cell efficiency of 22%, these cells were more efficient than most silicon-based solar cells of 15% efficiency [13]. The specifications of Sun power C60 solar cell [14] was shown in Table 2.

According to Table 2, each solar cell gives out 0.57 V which means 22 solar cells are required to meet the targeted voltage of 12.4 V, here two more cells are added for safe side and finally designed for 24 cells. These 24 cells should be connected in series to achieve the required voltage.

Since the number of solar cells is decided, the minimum area required for the wing is calculated. Two possible combinations in arranging these cells in series (Type-1 and Type-2 as shown in Figs. 1 and 2 respectively) over the wing has been discussed below:

The problems occurred in the design shown in Fig. 1 are:

- As the solar cells are arranged in a single row, the wing is too long which requires a tough structure leading to increasing in weight of the plane.
- Controlling the wings to stabilize the plane during flight will be difficult due to lack of ailerons.
- While connecting the electronic circuit of solar cells with tapping wire the two ends of the wire are too far to close the circuit which results in loss of power efficiency.

Whereas in Fig. 2 all these problems are solved as the solar cells are arranged only on the middle portion of the wing in two rows (each row has 12 solar cells) which helps in reducing the total length of the wing to accommodate the solar cells. The side wings (ailerons) are used for stability purpose having a polyhedral angle of about 7° on both sides for easy control of the plane. And also from Fig. 3 it is observed that in Type-1 more tapping wire is used in order to close the circuit which means more loss while transferring

Table 1
Mission specifications.

Parameter	SI units
Gross weight	2 kg
Payload	0.5 kg
Altitude	30–50 m
Average air density	1.22 kg/m^3
Clearness factor	0.9 (1 = clear sky)
Takeoff distance	None (hand toss launch)

Table 2
Specifications of sun power C60 solar cell.

Parameter	SI unit
Mass of solar cell	0.008 Kg
Length and width	0.125 m × 0.125 m
Area of single solar panel	0.0150 m^2
Efficiency of solar cell	22%
Rated voltage	0.57 V
Rated current	5.37 A