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ISSN (Online) 2456-1290

International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)

Vol 5, Issue 2, February 2020

Design of self-powered surveillance RC aircraft

[1] Muhammad Ahsan Iqbal, [2] Abdul Qader Abdullah, [3] Sharul Sham Dol

[1][2][3] Department of Mechanical Engineering, Abu Dhabi University, Abu Dhabi,United Arab Emirates

***Abstract*— This project specifically incorporates clean energy sources for existing design of self-powered surveillance RC aircraft. Solar and wind energy are the main clean energy sources currently being utilized in aviation applications. Normally these two sources are independently utilized to serve a specific purpose. However, this project essentially merges these two sources of clean energy, and provides an effective approach to power a radio-controlled surveillance aircraft. Theoretical analysis has been conducted to estimate the required parameters; power & battery requirements, weight & payload, surface area and cost. Then these theoretical results are primarily compared with the experimental results available; thus validating the results. Therefore, it is concluded that solar and wind energies can be effectively combined to produce a reliable self-powered RC surveillance aircraft, and can be further enhanced to meet the required specifications for any application; thus, implementing it on a larger scale.**

***Index Terms*— clean energy; RC aircraft; renewable; solar; surveillance; wind**

I. INTRODUCTION

There has been a major increase in energy demand since 1970's. This increase in demand has led to the increase in the establishment of various power plants to meet the requirements. Therefore, in order to limit the dependency on natural resources; renewable energy has been the focus for many countries throughout the globe including in the Middle East.

Renewable energy is the ultimate source of clean and eco-friendly energy that is independent of time and can be replenished to be used in a closed loop. There are many categories of energy source that includes wind, solar, hydropower, biomass, geothermal, ocean and waves. These resources can be deployed using various design optimizations to increase production and efficiency of any certain process [1-5]. This report discusses this aspect of design methodology that can be effectively implemented on a surveillance self-powered RC aircraft. If successful, it can also be implemented to another applications such as search and rescue flights, cloud-seeding planes and military purpose.

Solar energy is one of the most efficient forms of clean energy source that have the potential to reach maximum growth in the near future. One of the recent inventions turned out to be paragon of its kind, was Solar Impulse Plane [6]. This plane was installed with more than 17000 PV cells, having a wingspan wider than Boeing 747 jumbo jet. Moreover, it cruised throughout the globe starting from Abu Dhabi and cruising through the Pacific Ocean and finally landing at the original destination flying approximately 40,000 km, breaking almost seven World Records. This master piece had batteries weighing almost quarter of the whole weight (2.3 tons) and were charged during daylight. During the day, it was cruising at about 29,000 feet and 5000 feet lower at night to conserve power.

Ram air turbines (RAT) are micro wind turbines that typically serve an option for electric power source for aircrafts under emergency situations. Power is produced as kinetic energy is extracted from the flow of the airstream based on plane's speed. RAT's serve their purpose typically during emergency to power control equipment in the aircrafts, but they can be optimized to generate power for small-scale radio-controlled surveillance aircrafts [7]. It can be installed either under the fuselage or the under the wing to produce optimum power for the RC plane to continue operating.

One of the RAT applications includes, the crop dusters that has pressurized spray systems on an aircraft to deliver certain ingredients required for the crops. These aircrafts are equipped with ram air turbine system with 8-inch-long titanium blades capable of producing 4000 Watts of power at air speeds of 350 mph. This generated power can be fully utilized to operate all the functions available regardless of any emergency. The optimization of ram air turbine on a RC aircraft, can add to its overall drag, but this addition in drag is compensated by the power production.

Photovoltaic systems work on the principle of converting heat from the sun into electricity. PV cells, commonly known as solar cells. They have been playing a pivotal role in our daily lives. They come in a range of systems depending on the output requirement. These systems have been implemented to generate electricity for factories, warehouses, and other utility purposes around the globe. Moreover, several research activities have been conducted to optimize the design of photovoltaic cells with exotic materials, and these attempts have led the efficiency to improve from 4% to 46% in the recent years.

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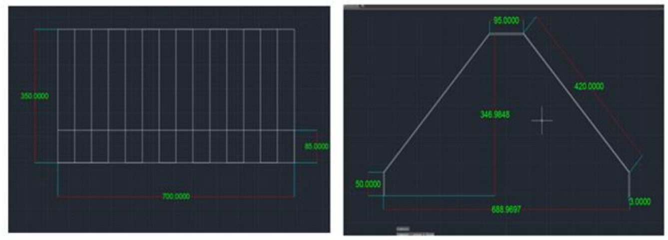
PV cells are arranged in series and parallel forms to increase the overall output; currents, voltages, and power levels. They are commercially available as modules ranging from 10 Watts to 300 Watts. Typically, one single PV cell is capable of producing about 0.5 Volts. The main constraint for using solar cell in aircraft, is the weight. It is mandatory to select the type of PV cell with maximum efficiency and lower weight. Hence, one of the most optimum PV cell with high efficiency to weight ratio, is C60 Solar Cell. This specific type of PV cell has the capacity to capture 10% more light, and generate better power at higher temperatures due to low temperature coefficients [8].

II. AIRCRAFT DESIGN

The design of the RC aircraft has been established based on International SAE rules and regulations (Figs. 1-3). The fuselage is optimized with semi-monocoque structure, to enhance its strength, and to make it more resistive to bending stresses. Moreover, aerodynamic approach has been utilized during design phase, and the weight of the aircraft is kept below the provided limit—not exceeding 55 pounds.
Furthermore, the aircraft structure is further enhanced using aerodynamic modifications such as winglets, vortex generators, to optimize lift and drag coefficients (Fig. 4). The fabrication of the aircraft is executed using Balsa wood (having high strength to weight ratio), and all design analysis are conducted using geometric similarity analysis.

Figure 1: Fuselage with dimensions

Figure 2: Vertical stabilizer with dimensions



(a) (b)

Figure 3: Dimensions (a) Horizontal stabilizer (b) Landing gear

Figure 4: Final prototype

III. RESULTS AND DISCUSSION

Solar Power

RC Aircraft Wing Cross-sectional Area = $731\ in^2$ (Fig. 5)
Total Cross-sectional Area available for PV cells = $1462\ in^2$

No. of PV Cells covering our wing span = $\frac{1462\ in^2}{(4.92*4.92)in^2}$ = 60 PV Cells
Each cell's maximum Power: 3.59 W
Combined Power = 60 * 3.50 W = 210 W

Therefore, panel of sixty C60 Solar PV cells has the capacity to produce 210 W. One-hour exposure to the sun light will generate 210 W of power that can be stored in the battery. Hence, the power output will be the Watts * number of hours under exposure.

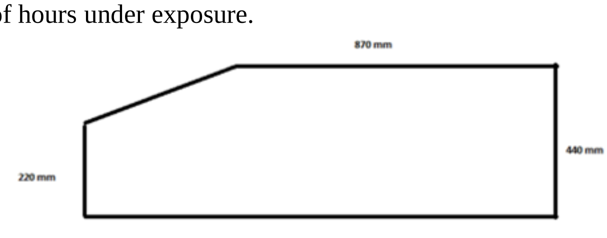


Figure 5: Dimensions of one wing (RC aircraft)

Motor Power

A 1400 kv Turnigy Air Propeller Motor consumes 205 Watts. This means that the C60 Panel installed is enough for the aircraft to generate sufficient power to operate. We can either install a solar panel that has the capacity to generate 210 W in one hour as discussed previously if our surveillance operation is approximately one hour or we can install a smaller panel—let's assume half the size—and expose for more number of hours to generate the required output for the aircraft.

Battery Requirement

It is necessary to size the battery according to the requirement. If we are looking forward to operate the surveillance aircraft for a period of 60 minutes, then the motor will consume 205 Watt * 1 hr. = 205 Wh. Hence, the surveillance aircraft will consume 205 Wh from the battery.
Battery size limitation based on SAE Rules is a minimum of 3000 mah with 22.2 V.

Battery Size requirement = $\frac{205}{22.2}$ = 9200 mah

Battery selected 9500 mah with 22.2 V = 9.5AH * 22.2 V = 210 Wh

Weight Limitation

The weight of the PV cells is another limitation that must be considered before installing the solar panels. The weight constraint under SAE rules and regulations is 55 pounds (25 kg). Weight is a significant factor that is directly proportional to the drag of the aircraft; thus, it is quite important to consider the overall weight as the first priority before designing the aircraft. Since it is for the surveillance purpose, more concentration was done on the wings area (larger span ratio).

Weight of one cell = 14.5 kg/150 piece = 0.0966 kg/piece
Weight of 60 cell panel = 0.0966 kg/piece * 60 = 5.8 kg

Cost Analysis

A single piece of C60 Solar PV cell costs $2.50—equivalent to about AED 9

Cost of 60 Cell panel = AED 9 * 60 = AED 540
Hence, utilizing a panel of 60 PV cells will provide an output of 210 W each hour with an initial cost of 540 Dirhams.

Betz Law (Ram Air Turbine)

Before finding the power extraction from the wind turbine; it is mandatory to explore the atmospheric conditions within our location (UAE). Based on average values nowadays, the followings parameters are listed as follows:

Temperature = $\frac{41+40+40+40+38+41+38}{7}$ = 40º Celsius

Pressure = 99500 Pascal
Based on UAE conditions, [from 9]

$$\rho = \frac{P}{RT} \tag{1}$$

$$\rho = \frac{(99500\,)(Pas)}{(285.058)\left(\frac{J}{kg.K}\right)(40+273)(\,K)} = 1.12 \text{ kg/m}^3$$

Power extraction from turbine based on the Betz Law [10]:

$$P_T \;= \frac{1}{2}\,\rho\, A_T\, v_w^3\, \eta \tag{2}$$

$$P_T \;= \frac{1}{2}\left(1.12\left(\frac{kg}{m^3}\right)\right)\left(\frac{\pi(0.254)^2}{4}(m^2)\right)\left(30\left(\frac{m}{s}\right)\right)^3 (0.40)$$

$$P_T = 306\,Watt$$

Hence, using one Ram Air Turbine can produce about 300 Watt (including all types of inefficiencies) of power at a wind speed of 30 m/s. There is always a specific efficiency of the turbine; this maximum efficiency was first introduced by Albert Betz in 1919 approximately 59.26%. Normally turbine efficiency is somewhere below this value, and common efficiency values lie between 35%-40%. Therefore, considering all types of inefficiencies; unsteady, frictional, not one dimensional flow, 40 % value is selected as an optimum choice for this calculation.

TSR Ratio

TSR ratio is the ratio between the speed of the blade tip velocity and the velocity of the incoming air. This ratio is significant in determining the maximum potential of the power extraction at a certain rpm [11]. If the blades spin too slow, then the wind will pass through the blades without being captured. If the blades spin too high, then blades will spin through the used wind without utilizing them.

$$TSR = \frac{\omega.r}{v} \tag{3}$$

ω: Rotational speed of the rotor (rad/s)
r: length of the blade (m)
V: Velocity of the incoming air (m/s)

$$\omega \;= \frac{TSR.v}{r} = \frac{1.5*30}{0.127} = 355\,\frac{rad}{s}$$

$$RPM \;= \frac{60*\omega}{2\pi} = \frac{60*354}{2\pi} = 3390\;rpm$$

This value denotes that approximately 300 Watts of energy can be extracted from the turbine with an optimum rotational speeds of 3390 rpm at a constant incoming velocity (30 m/s).

Generator Requirement

Selecting a motor/generator for a wind turbine must satisfy the following conditions:

- It must have a minimum volt to rpm ratio of 0.035
- It minimum amperage rating should be 5

Selecting a motor with 24 Volt, 3000 rpm ratio specification, and having to charge a 22.2 V battery:

$$\frac{3000\ rpm}{24\ volt} * 22.2\ volt = 2775\ rpm$$
$$x = 2775\ rpm$$

In order to charge a 22.2 Volt battery using 125 rpm/volt motor, we must provide 2775 rpm from the wind turbine. Therefore, rpm below or above this value will not be suitable for our battery specification. This rpm can be regulated using gear systems or braking systems to satisfy our requirements. The motor/generator opted has the capacity to produce 300 Watts of power. Considering inefficiencies for a generator, this value can be multiplied by 0.80 to know the precise value—that is 240 Watt.

Experimental Data

The experimental data (Table 1) explicitly portrays all the parameters measured using wind tunnel testing. Clearly, the RAT has the capability to reach approximately 300 Watts. Although, there are many factors that can impact the overall performance such as design, dissipations, robustness, weight, material, strength, but the values have lived up to the required expectations [12-15]. This project can be further explored by analyzing rotor dynamics activities, and can be further enhanced to apply it commercially.

Table 1: RAT Prototype Testing

RAT Wind Tunnel Testing							
Pitot Voltage (V)	**Velocity (ft/s)**	**Rotor Speed (rpm)**	**Drag Reading (N)**	**Voltage (V)**	**Current (Amp)**	**Resistance (Ohm)**	**Power (Watt)**
0.1175	50	2790	1.85	14.82	2.53	5.86	37.49
0.1175	50	2440	1.90	12.6	3.18	3.96	40.07
0.1175	50	2160	1.97	10.91	3.69	2.96	40.26
0.185	66	3100	3.10	15.94	5.32	2.99	84.80
0.185	66	2800	3.15	14.20	5.94	2.39	84.35
0.185	66	2380	3.20	11.55	6.80	1.69	78.54
0.257	78	3100	4.40	15.22	9.00	1.69	136.98
0.280	82	3100	4.90	14.90	10.26	1.45	152.87
0.335	89	3100	5.85	14.50	12.83	1.13	186.04
0.538	113	3100	9.20	14.10	19.80	0.71	279.18

IV. FINAL DESIGN

Figure 6: Final AutoCAD Design (Front View)

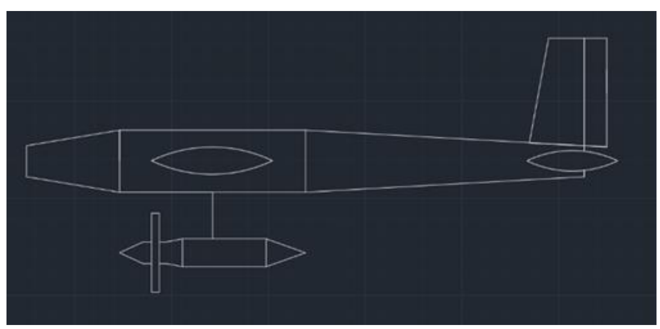


Figure 7: Final AutoCAD Design (Side View)

ISSN (Online) 2456-1290

International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
Vol 5, Issue 2, February 2020

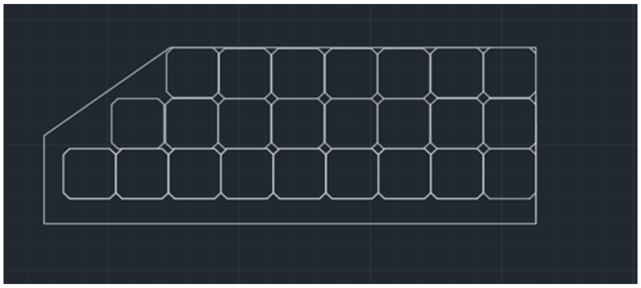


Figure 8: Final AutoCAD Wing Design (Top View)

The design above is sketched using AutoCAD software (Figs. 6-8). This design provides an explicit comprehension of the design optimization using solar & wind resources. Clearly, the RAT protrudes below the fuselage and the solar cells are attached on the top surface of the wings. Moreover, the solar and RAT dimensional specifications utilized in this design are analogous to the design parameters available from research [16].

V. CONCLUSION

This project was designed to integrate clean renewable energy sources to power a surveillance aircraft. RC surveillance aircraft was used as the reference prototype, and was accordingly modified with renewable sources to be self-powered. The cross-sectional area was found for the aircraft wings, and number of PV cells that can be accommodated under this area, were found approximately to be 60 PV cells. Moreover, respective calculations were made, and the power output from solar panel was found to be 210 Watt based on one-hour exposure to sun. This output can be stored in 9500 mah, 22.2 V battery and can be utilized by a 205 Watt air motor to drive the propeller. Furthermore, RAM air turbines commercially deployed for emergency situations, was another concept that can be enhanced to provide continuous supply of power for smaller aircrafts. This RAT was designed, simulated and fabricated within certain constraints, 10 in diameter, maximum air speed 30 m/s, weight limitation and was experimentally verified through wind tunnel testing. The prototype proved to be a success by displaying similar values to the anticipated calculated figures. This turbine had the capacity to extract approximately 300 Watts neglecting inefficiencies of power from the incoming air at 30 m/s. However, implementing this concept on a specific aircraft requires further research. For instance, the effect on aircraft's aerodynamics, comparison between RAT power output and the increase in weight, and further enhancement on materials used in rotor dynamics.

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