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Improving Energy Efficiency in the Operation of Unmanned Aerial Vehicles, Using Energy Hybridization Technique

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ABSTRACT

This work is presented to demonstrate the principles and technical procedure for energy hybridization in optimal Unmanned Aerial Vehicle (UAV) operation. The proposed hybrid arrangement involves a combination of fuel and battery used alternately to optimize flight endurance of the UAV. Calculation of UAV power consumption during flight operation was carried out. Consideration of the velocity, weight, drag and thrust were applied in the process. Results show that 9.18 watts of energy was required to be delivered by either the battery or fuel which is to used separately during sessions of UAV operation. Cumulatively, a total energy delivery of 9.98 watt is required at any instant to ensure a lasting endurance of the UAV. The results form handy recommendations in the configuration of optimal hybrid power for efficient UAV operation.

Keywords: Hybridization, Unmanned Aerial Vehicle, Electronic Speed Controller, Drag Coefficient, Lift Coefficient, Hybrid-Electric Propulsion System.

1. INTRODUCTION

In the past few years, Unmanned Aerial Vehicles (UAV) have received tremendous interest due to the advancement in microprocessors and artificial intelligence (AI) which have given birth to smart UAVs (Adnan et al, 2019 and Kyrkou et al, 2019). They have found use in both military and civilian domains such as monitoring, minesweeping, delivery, wireless coverage, and agricultural uses. According to mission requirements, UAV configurations and features vary widely. Thus, in the literature, various types of classifications can be found focusing on different parameters (Hassanalian and Abdelkefi, 2017 and Shakhatreh et al, 2018). Energy usage and consumption in UAV operations play a vital role in its proper classification and categorization. In particular, UAV endurance during its operation is determined by the choice of its energy application and configuration. Effective Energy Management System (EMS) plays a crucial role in ensuring optimal power control which ultimately translates to UAV efficiency in achieving its mission. Several methods are applied in UAV energy configuration aimed at improving its operational efficiency. It has been established that the rapid and dynamic deployment of UAVs and their reliable line-of-sight (LoS) communication links are the main advantages of UAV-based communications (Lokman et al, 2017). However, several challenges are being faced by UAV-based communication to be addressed in order to ensure their effective application. According to Sboui et al (2014), one of these major challenges is the limited energy availability. Truly, the energy available to these battery-powered flying is hardly enough to ensure its optimal efficiency as it is usually split for use to sustain many simultaneous operations at the same time to the detriment of some essential activities. Hence, to extend the UAV operation time before draining its battery, it is important to efficiently manage the available energy for all components in order to save it and hence, increase its overall efficiency.

One reliable and dependable means of improving the craved endurance of operational UAVs is by the use of solar energy. By accumulating solar energy through photovoltaic cells, high endurance can be achieved in UAVs. Even though the sun, which is the source of solar energy, appears and disappears during certain specific times of the day, rechargeable batteries can be installed as alternative of power supply when the sun disappears. According to Rajendran et al, (2016), the stored energy is usable during night times when solar energy is not available. Other sources of energy configuration in UAV operations abound. In this paper, hybridization of energy sources in UAV operations is presented as an efficient, reliable and endurance supporting source of energy. This source of energy is unarguably the most efficient driven energy source. In particular, a hybrid of solar in photovoltaic cells with rechargeable battery when used in alternation for UAV operation produces a cost effective and endurance enhanced scheme in running a UAV. Several researchers have made far reaching incursions in this area of unmanned aerial vehicle operations.

2. REVIEW OF RELATED WORKS

Several researchers have lent their professional contributions to energy supply of UAVs with regard to improving its overall efficiency in relation to its endurance. Some of these inputs are hereby presented.

Rajendran et al, (2016) carried out a study which optimized the overall power ratio by adopting the mission profile configuration of optimal solar energy exploitation. In order to determine the optimal phase definition of the start, ascent, and descent periods, extensive simulation was conducted so as to restructure and optimize the mission profile of UAV thus maximizing the energy available from the sun. Instead of applying a maximization of solar inclination angle for an increase of available energy volume, a vertical cylindrical flight trajectory was adopted in the work. An achievement of net power ratio of 30.84% was made compared to other techniques of UAV energy source configurations. The authors concluded that the proposed mission profile configuration with the optimal power ratio of the trajectory of the path planning has the capacity of effectively prolonging UAV operations, bringing about a massive reduction of battery weight by 75.23%.

According to **Chan and Kam (2019)**, an Unmanned Aerial Vehicle has to perform a number of maneuvers and movements in order to achieve a recommended flight mission and this is expected to consume a certain amount of power. Efficient performances of relevant UAV parts are necessary in order to maximize the cruising time. The authors presented a procedure for the estimation of the power consumption of a composite UAV. Before this is done, it is normally expected that the power consumptions of the UAV parts for a given mission be estimated. The configuration as well as the fabrication of the UAV using truss-type parts made of carbon strand/epoxy composite material was briefly introduced. The power consumptions of the electric parts and the propeller system were evaluated in a systematic way. To verify the theoretical predictions, experiments were conducted. The experimental results validated the accuracy and feasibility of the proposed energy consumption estimation procedure. It was shown that the proposed procedure produced good predictions with percentage errors which were less than 7.4%. The authors recommended the procedure to flight mission planners and UAV designers.

Hwang et al (2018) proposed a method which applied endurance estimation for multi-rotor unmanned aerial vehicle using a battery as a source, considering both steady-level and hovering flights. From the manufacturer, the endurance, efficiency, thrust and battery discharge were determined. The maximum endurance as well as the optimum speed at the minimum required power was reduced as the drag coefficient increased. Conversely, with an increase in the payload weight, the optimal flying speed increased. The proposed method was capable of successfully estimating the flight time with an error average of 2.3%. The method would be useful for designers and UAV mission planners.

From the foregoing reviews, it is obvious that there is still need for an energy source for UAV operation which can endure for as long as necessary to support a lasting mission and operation. This is the major motivation for this research which is for hybridization of the energy source for a lasting and enduring UAV operation. The next section presents the methodology.

3. METHODOLOGY

The methodology involves a presentation of two scenarios: a single energy source and a hybridized energy source. Thereafter, a comparison of the two to determine the efficiency and possible improvement or otherwise would be carried out as a validation of the research. Prior to the preceding methodology, a precursor with regards to the arrangements of single power source: series or parallel configuration as well as the hybrid power arrangement will be presented shortly.

3.1 Use of Hybrid-Electric Propulsion System (HEPS)

Any propulsion system which includes two or more sources of propulsion in one single design and which is capable of being used either in alternation or together is termed hybrid electric propulsion system. Thus the combined advantage of two or more power sources is utilized in creating a more efficient vehicular propulsion system. There are three basic arrangements in HEPS configuration namely, series, parallel and power-split (Amioralis et al, 2015). According to the authors, the major goal of HEPS is to provide the equivalent power, range, cost and safety with a conventional power source. Figure 1 shows a series hybrid configuration of HEPS in which the source of primary compulsion is an electric motor (EM).

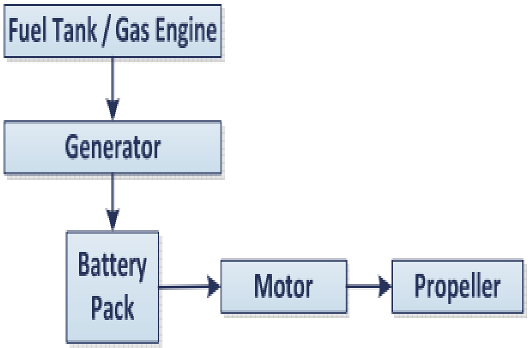

Figure 1: Series HEPS Configuration

In the arrangement in Figure 1, a generator is driven by an internal combustion engine providing power to the motor and an energy storage system. For high demand operation, excess generator energy may be stored in a capacitor, battery or flywheel. In the series configuration, the fuel tank/gas engine, battery pack, motor and propeller are all arranged in series. There is a one way flow in energy usage and consumption.

- **Parallel Configuration**

The parallel configuration of HEPS is shown in Figure 2.

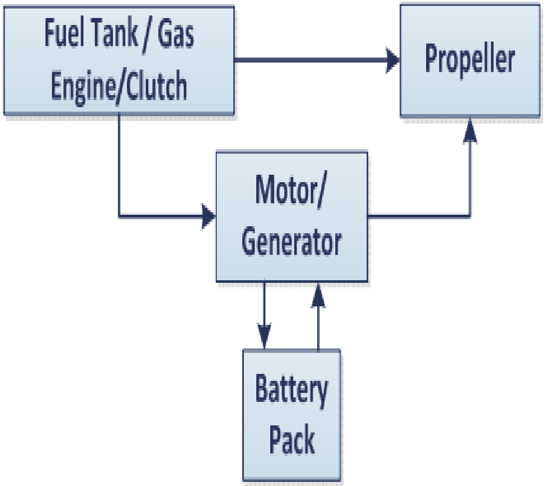

Figure 2: Parallel Configuration of HEPS

The parallel configuration of HEPS is adapted for small UAVs as they benefit more from this arrangement. Increased time on station and range are the major benefits. These benefits are recorded in HEPS parallel configuration compared to electric powered UAV (Harmon et al, 2006).

- **Power-Split (Series-Parallel) Configuration**

Figure 3 shows the series-parallel configuration of HEPS. This is also referred to as power-split energy efficiency method.

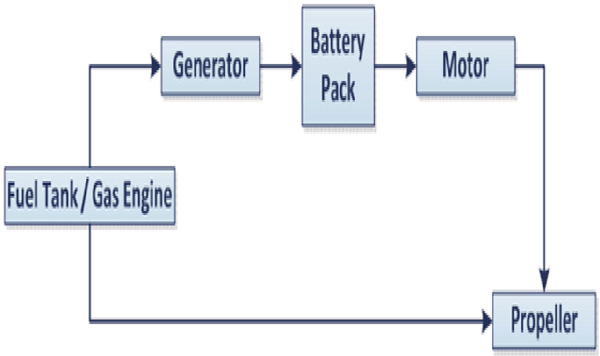

Figure 3: Power-Split (Series-Parallel) HEPS Configuration

In Figure 3 arrangement, due to the decoupling of the combustion engine power and speed from the entire propulsive demand, the engine runs at or near optimal conditions. As already known, there are three modes or phases of UAV operation. These are the lift or ascending mode, the cruise and the landing or descending mode. Being an unmanned aerial vehicle, both lift and landing can be affected in a vertical way. This means that the UAV can ascend vertically. The result is that power consumption during UAV operation is at maximum during the lift mode, less in the cruise mode and least during the descent or landing mode. However, these are merely meant to guide the design effort as battery – fuel energy arrangement is concerned.

3.2 Calculating Unmanned Aerial Vehicle's Power Consumption:

The airplane flies most of the time during the cruise phase, where the forces of lift, gravity, drag, and propulsion are all equal. Our two equations are as follows:

$L = W$ (1)

$D = T$ (2)

Where L is Lift, W is weight, D is drag and T is thrust.

The UAV’s power consumption is given as

$P_{req} = V \text{ x } T$ (3)

Equation (3) results to

$P_{req} = V\ x\ D\ =\ V\ x\ \frac{1}{2}\rho V2SCD$ (4)

Where ρ is air density, S is the wing area and C_D is a coefficient ascribed to the drag.

$C_D = C_{Do} + kC_L^2$ (5)

In equation (5), C_{Do} is defined as zero-lift drag coefficient and calculated using digital datcom software and it is equal to 0.024. As a coefficient, it has no unit.

C_L is defined as the lift coefficient of the UAV and is dependent on the angle of attack during cruise.

However,

$k = \frac{1}{\pi eAR}$ (6)

AR is the aspect ratio of the wing while e is the Oswald efficiency factor. This isa correction factor, analogous to the span efficiency, and measures the difference in drag with lift between a three-dimensional wing or aircraft and an ideal wing with the same aspect ratio and an elliptical lift distribution. As a general and fundamental practice, efficiency is calculated by dividing the output by the input and it has no units. It can be expressed as a percentage by multiplying by 100%. In this presentation, Oswald efficiency factor can be calculated using the following formula:

$e = 1.78(1 - 0.045AR^{0.68}) - 0.64$ (7)

But,

$W = L = \frac{1}{2}\rho V^2 SC_L$ (8)

Thus,

$C_L = \frac{2W}{\rho V2S}$ (9)

Putting equation (8) into equation (5), we get.

$C_D = C_{Do} + k(\frac{2W}{\rho V2S})^2$ (10)

Equations (10) and (4) give the following result

$Preq\ =\ \frac{1}{2}\rho V3S(CDo\ +\ k(\frac{2W}{\rho V2S})2\ =\ \frac{1}{2}\rho V3SCDo\ +\ \frac{3KW2}{\rho VS}$ (11)

Equation (11) demonstrates that Preq is a function of velocity during the cruise phase, and Figure 4 illustrates the Preq versus V diagram for our aircraft.

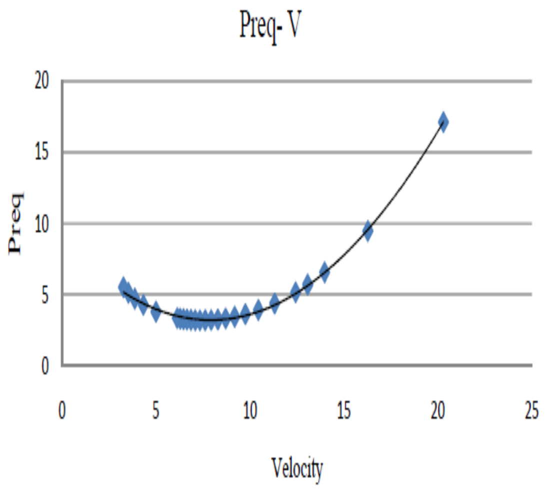

Figure 4: Preq versus V diagram for the aircraft

The bare minimum speed needed for flight is called the stall speed. It can be observed that the lowest power is close to the stall speed for this aircraft, which is approximately 7 m/s. Therefore, at a cruise speed of 10 m/s, 3.9 watts of power are needed.The input power of the motor, which is the equivalent of the output power of the batteries or combusting fuel, may be computed using the following formula:

$$P_{req} = P_{in} \times \eta_m \times \eta_p \qquad (12)$$

Thus;

$$P_{in} = \frac{Preq}{\eta m \times \eta p} \qquad (13)$$

Where ηm is efficiency of the motor, ηp is efficiency of the propeller or rotor.

In the case presented in this work, ηm = 0.5 and ηp =0.85. This means that the power produced by the burning fuel or battery is equal to $\frac{3.9}{0.5*0.85}$ = 9.18 watts.

Servos, receivers, and power lost in the electronic speed controllers (ESC) are a few other reasons of power consumption in an airplane. These devices use an estimated 0.8 watts of power in total. Therefore, 9.98w is the entire amount of power needed for the aircraft.

This means that in a design for the hybridization of power involving fuel and battery for the supply of the UAV power needs, these energy sources should be able to produce, on separate bases, a total available power of a magnitude not less than **9.98 watts.**

4. CONCLUSION

The work demonstrated a hybrid energy arrangement involving fuel and battery. Lithium battery was intended while aviation gasoline was used. Results showed the energy requirements of an unmanned aerial vehicle (UAV) during optimal operation, specifying both the specific energy requirement as well as the cumulative energy. Future work will consider hybridization of battery and solar energy configuration.

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