An estimation of long endurance power supply system for a rotary wing unmanned aerial vehicle

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Abstract: *The vast applications of unmanned aerial vehicle (UAV) have made it versatile. However, this battery powered vehicle has a short flight time thereby limiting its performance. Therefore, this paper represents the analysis of two power systems to obtain a better performing system with longer duration. Thus, to obtain a long endurance power system, the regular battery power was compared to the tethering mechanism power supplier. The power utilized by the two systems differed, hence, the performance parameters were compared to obtain feasibility of the system. Both the theoretical and experimental parameters were evaluated to estimate the accuracy. The comparative experiments would help to implement better device for the tethering mechanism to increase its efficiency and comprehend its durability.*

Keywords: hexacopter, battery, tethering system, motor power.

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I. INTRODUCTION

Unmanned aerial vehicle which is abbreviated as UAV is identified as drones too. This small pilotless flying machine which is operated from the ground has the capability of carrying moderate payload and travel around in agreement with the operator. There are various features of the UAV like monitoring, retrieve data, carry payload and travel places which are inaccessible to the humans. Therefore, UAV have found its application in surveillance [1], remote sensing and mapping [2], infrastructure maintenance [3], disaster management [4] and civil security [5]. This particular experiment had been analyzed to collect data for remote sensing application in North Eastern Space Application Centre, where the data collected through satellite is unreliable because of its inability to collect images of every petite location. Thus, the UAV have the capability to travel these locations and collect the images. The experimental work was conducted respectively within the premise of the North Eastern Space Application Centre. Hence, this battery powered UAV needs longer endurance to perform the task completely.

Basically, there are two types of UAV which are fixed wing and rotary wing UAV [6]. The fixed wing UAV has longer endurance than rotary wing UAV whereas they are incapable of performing in adverse conditions. Thus, rotary wing UAV would satisfy the requirement of performing in unfavorable locations with better operation of power to increase its endurance. Hence, an assembled rotary wing of six arms had been utilized for the experiment which normally operates on battery known as hexacopter. There are various technique of powering the UAV such as hybrid system [7] and renewable sources [8] which are frequently utilized and analyzed. These systems provide comparatively less endurance than tethering mechanism. The tethering mechanism is comparatively new system for the hexacopter which works by supplying uninterrupted power to the UAV by wire from the ground [9].

The majority of tethering experiments analyzed the transfer of data to the ground by wire and a few other experiments analyzed the transmission of power to operate the UAV, however, accurate performance factors were unavailable. Since, the requirement of power hugely varies depending upon its application therefore any deviation in the required quantity would crash the UAV.

The present analysis was performed to develop a longer flight time assembled hexacopter as per its requirement. The regular flight time of any UAV is 15 – 20 mins, within this short time the completion of the required task would be impossible. Considering the advantage of tethering mechanism to supply uninterrupted power, the given task would be completed in a single round. The power required by the hexacopter would differ if the tethering system replaces the battery. Therefore, the assembled hexacopter was first analyzed both theoretically and experimentally by battery operation and its performance characteristics were estimated. This estimation of parameters helped to determine the range of power required for operating the hexacopter by the tethering experiment and relatable range components were utilized. Therefore, the assembled hexacopter was analyzed theoretically and experimentally with the required range components. And, the performance characteristics were recorded. Thus, comparing the performance characteristics of both the systems, the tethering mechanism could be developed further to enhance its performance.

II. THEORETICAL ANALYSIS

The assembled hexacopter utilized for this experiment operated on lithium polymer battery and had a flight time of 15 – 20 mins depending upon the payload carrying weight. The take off thrust which is the force required to carry the hexacopter from the ground should be more than the total weight of the assembled hexacopter. Therefore, the most recommended factor being twice the total weight of the UAV which is generally accepted. There were experiments done by utilizing more than twice factor of thrust which made it more efficient, however, the recommended twice factor suffice the need of all UAVs without any damage. Thus, the present assessment was done by considering twice-factor, the take off thrust must be twice of the total weight of the assembled hexacopter. The present analysis concentrated the vertical hovering motion of the assembled hexacopter at various altitudes. Thus, the formulae have been specified according to the vertical hovering motion by the hexacopter. To determine the effective factors which influence the hovering characteristics and the power utilized depends on the performance of propulsion system and thrust of the assembled hexacopter. Therefore, the momentum theory [10] which relates the power induced to produce the required thrust by the propeller has been utilized. The momentum theory describes the thrust of the propeller represented by (1),

$$T = (2 \text{ x } A \text{ x } \rho \text{ x } P^2)^{1/3} \qquad (1)$$

where, T represents the propeller thrust in Newton (N), A represents the area covered by the propeller while rotating in m^2, ρ represents the density of air in kg/m^3, P is the power induced by the propeller in watt (W). The power of the propeller in (1) is determined by (2),

$$P = \text{propeller constant x rpm}^{\text{power factor}} \qquad (2)$$

where, the propeller constant is calculated by the ratio of pitch of the propeller to the diameter of the propeller, rpm represents the rotation per minute by the propeller calculated by multiplying the voltage with kv rating of the motor and power factor is the ratio of operation power in kilowatt to apparent total power in kilovolt ampere. The kv rating of the motor estimates the total number of rotation the rotor makes per voltage.

The power consumed by the battery differs from the tethering mechanism; hence, different methods were used to determine the power consumed by the assembled hexacopter. The hexacopter operated on direct current. The battery power consists of single component whereas the tethering mechanism is a combination of wire, converter to supply direct current and power source for uninterrupted supply. The converter is required because the most available current is the alternating current. Thus, the alternating current had to be converted to direct current by a DC power supplier. And, this direct current was transferred to the assembled hexacopter by wire. Therefore, the voltage supplied through the wire encounters resistance [11] represented by (3),

$$R_c = 2\rho_c l \qquad (3)$$

where, R_c is the resistance of the wire in ohm, ρ_c is the resistivity of the wire in ohm/kilometer and l is the length of the wire in meter. The voltage difference along the altitude covered during hovering is determined by (4),

$$V_m = V_v - R_c I \qquad (4)$$

where, V_m is the motor voltage in volt, V_v is the voltage supplied by the DC power supplier from the ground and I is the current in ampere (A). Therefore, the power utilized varied at different altitude of hovering.

The propulsion system which includes the battery, motor and propeller perform an important role which utilizes the maximum power. Thus, it is necessary to determine the efficiency of the propulsion system [12]. Equation (5) represents the efficiency of the propulsion system,

$$\eta = \frac{\sqrt[3]{T}}{VI\sqrt{2\rho A}} \qquad (5)$$

where, η represents the efficiency of the propulsion system, T is the thrust in Newton (N), V is the motor voltage in volt, I is the motor current in ampere (A), ρ is the density of air in kg/m^3 and A is the area covered by the propeller during rotation in m^2. Thus, these equations provide the model calculation required to estimate the performance characteristics involving power in both the systems.

III. EXPERIMENTAL ANALYSIS

The components required for the experiment differed for the two power systems. Foremost, the assembled hexacopter was fabricated with carbon fiber material because they are the most light weight material with greater strength and stiffness [13]. The main sections required to build the assembled hexacopter were frame, propulsion system, radio control system, ground control system and on screen display. The frame has a central metal plate from where the six arms elongated with equal distance shown in fig.1. It was the base for mounting other components.

The propulsion system which included four major components was motor, electronic speed controller, propeller and battery. The propulsion system of DJI E800 specification was utilized. The propeller, shown in fig.2, whose rotation produces thrust, played a pivotal role. The motor shown in fig. 3 converts electrical energy to mechanical energy. The lithium polymer battery shown in fig. 4 which was employed is the lightest available with more energy density. The battery before transmitting power to the motor, it passes through the electronic speed controller (ESC) shown in fig.5. This controller helps to maintain the safe limit of power in motor. Therefore, the battery foremost transmits power to the electronic speed controller which reaches the motor, helping the propeller to rotate. Since, the assembled hexacopter was a six arm copter, there were six respective components of the propulsion system, assembled for each arm.

The radio control system was the controller in the ground used by the operator to control the assembled hexacopter by directing instruction shown in fig. 6.

The ground control system consisted of the transmitter, on screen display and video receiver. The ground station helped to receive the signals transmitted by the assembled hexacopter during operation and the laptop acted as the display screen. The on screen display was a screen displaying the images of the camera in the hexacopter. It also displayed data like battery voltage, current, altitude, GPS location, radio control signals and pitches and roll angles of the hexacopter. Each of these components had its own specifications which are used in model calculations.

There are two other devices which were required for the tethering mechanism, the DC power supplier i.e. direct current power supplier shown in fig. 7 and double core wire shown in fig. 8. The tethering mechanism was done by removing the battery and replacing it with the tethering system. The available power in any commercial or residential complex is alternating current whereas the assembled hexacopter operated on direct current. Thus, the DC power supplier converts the alternating current to direct current. The double core copper wire transmitted the direct current from the power supplier to the assembled hexacopter.

The components mentioned and utilized in the experiment had its range of quantity specified and were useful for model calculation. These quantities of the components are tabulated in table I. The kv rating in the specification signify the number rotations the rotor makes per voltage i.e. the rotor rotates 350 times in a minute per volt. The pitch of the propeller represents linear distance travelled during one complete rotation. The maximum allowable voltage and current of electronic speed controller are 26 V and 20 A, i.e. the motor cannot accept more than these quantities for it to function smoothly.

Fig. 1 Frame

Fig. 2 Propeller

Fig. 3 Motor

Fig. 4 Lithium polymer battery

Fig. 5 Electronic speed controller

Fig. 6 Radio controller

Fig. 7 DC power supplier

Fig. 8 Double core copper wire

Table- I: Specifications of the experimental devices

Devices	Parameters
Diagonal distance of frame	0.80 m
Maximum motor thrust	2.1 kg/rotor
Motor take off weight recommended	0.80 kg/rotor
Battery	6 series lithium polymer battery
Kv rating	350 rpm/V
Weight of motor	0.106 kg
Diameter of propeller	0.33 m
Pitch of propeller	0.11 m
Maximum allowable voltage of ESC	26 Volt
Maximum allowable current of ESC	20 Ampere
Battery capacity	10 A hr
Battery voltage	22.2 V
Net weight of battery	1.4 kg
Battery power	222 W
Input rating of DC power supply converter	0 – 230 V AC
Output voltage of DC power supply converter	0 – 32 V
Output current of DC power supply converter	0 – 20 Ampere DC
Current carrying capacity of copper wire	24 Ampere
Resistivity of copper wire	7.8 ohm/km
Weight of the copper wire	6 kg/100 m

Battery capacity indicates the time of operation within the available current i.e. it could discharge 10 A in 1 hour. The input rating of DC power supplier represents the range of alternating current the converter could accept. The output rating of voltage and current signifies the maximum possible quantity it could accept. The current carrying capacity of copper wire signifies the maximum current it could transmit. The resistivity represents the resistance in the copper wire for a particular length of wire. Therefore, these specified data could estimate particular values of the formulae used in model calculations. Thus, the estimated parameters for the model calculations are mentioned in table II.

These constant parameters were determined with the help of specified parameters in table I. Hence, the model calculations could be estimated for both the power systems at different hovering altitude by the assembled hexacopter. These assessments to determine the characteristics that influence the power utilized by an assembled hexacopter would help to estimate the efficiency of the power mechanism deployed to supply long endurance power.

Table- II: Estimated quantities and constant parameters for model calculations

Estimated quantities	Parameters
Density of air, ρ	1.22 kg/m^3
Area of the propeller, A	0.085 m^2
Propeller constant	0.33 m
Required current by the hexacopter	16.8 Ampere
Operating power of battery	372.96 watt
Power factor for battery	0.89
Power factor of tethering system	0.85

IV. RESULTS AND DISCUSSIONS

The model calculations followed by experiments were done for two power systems at different hovering altitude. Foremost, the battery powered system was calculated for which the voltage and current required by the motor at 7 different altitudes with 1m variations were determined. Equations (1), (2) and (5) were utilized to estimate the power and thrust from the voltage and current parameters. Therefore, theoretical variations of motor power, thrust and propulsion system efficiency at different altitudes were calculated for battery power.

Similarly, for tethering mechanism, the model calculations were done which differs with battery power calculations. Foremost, the model calculations of tethering system had to determine the power required by the motor to hover the assembled hexacopter at various altitudes. Equation (3) determined the resistance of copper wire at different heights. Equation (4) could estimate the voltage of the hexacopter respectively. Therefore, after estimating the voltage and current utilized at 7 different heights of 1m variation, the thrust, power and propulsion system efficiency were determined respectively.

Subsequently, the experiment was conducted for the two power systems without any payload. Initially, the assembled hexacopter was powered by battery and the operator maneuvered it at 7 different heights. The on screen display placed in the ground revealed the height climbed, voltage and current of the battery. These parameters helped to determine the thrust, power and efficiency of propulsion system.

For the tethering experiment, the battery was removed from the hexacopter and the battery connector was connected with the double core copper wire. The other end of the wire was connected with the DC power supplier, which was receiving alternating current from the nearby complex. This set was shown in fig. 9. Thus, the supplier was converting the alternating current to direct current, which was utilized by the assembled hexacopter. After connecting all the devices, the experiment began by increasing the voltage supplied form the DC power supplier. After reaching a height of 1m, the on screen display displayed the height and voltage reading. The fig. 10 shows the hovering of the assembled hexacopter by tethering system. The current readings were recorded from the DC power supplier. After obtaining the voltage and current parameters, the thrust, power and efficiency of the propulsion system were determined for the 7

different heights. Therefore, the data recorded for both the model calculations and experiments had to be compared graphically to recognize the feasibility of the system. Foremost, the electrical power utilized by the battery and the tethering system at 7 different altitudes had been compared in fig. 11. The difference of required power by the motor is in average 20% to 30% more in tethering system because of the transmission loss in wire. Whereas, the theoretically recorded values of tethering mechanism is comparatively more. However, in practical calculation there has been an increase in consumption of power as the height increased. Thus, the loss of voltage in transmission through the wire could be minimized to reduce the difference in power.

The table III demonstrates the variations of thrust parameters for the different cases of the two power system. Equation (1) has been utilized to determine the thrust parameters for theoretical and experimental parameters. After observing the thrust parameters, all the magnitude decreases linearly without much difference. However, there is variation in battery power and tethering system thrust data. The thrust is comparatively more in tethering system due to the more power utilized by it and the extra weight of the copper wire. This could be reduced by using wire of less weight and resistivity in wire.

The variations in propulsion system efficiency with altitude have been tabulated in table IV. By observing, these calculated parameters, the efficiency of any particular propulsion system remain uniform for all the cases. Whereas, the value of efficiency could be more if better effective propulsion system is utilized.

Fig. 9 Experimental set up of assembled hexacopter with tethering system

Fig. 10 Hovering of the assembled hexacopter

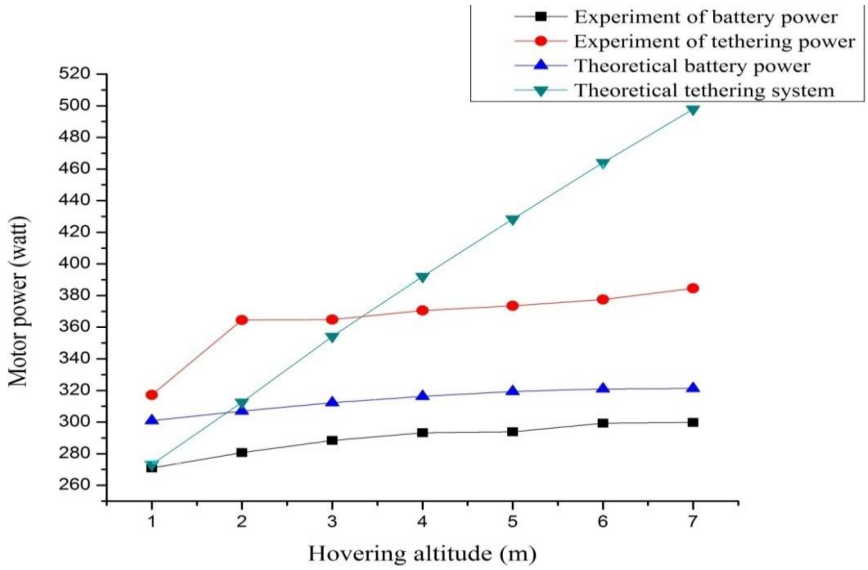

Fig. 11 Graph of motor power vs hovering altitudes

Table- III: Variations of thrust parameters along the altitude

Altitude (m)	Theoretical thrust of tethering system (N)	Theoretical thrust of battery power (N)	Experimental thrust of tethering system (N)	Experimental thrust of battery power (N)
1	59.88	43.13	58.43	43.47
2	59.27	42.26	58.29	43.09
3	58.99	41.43	57.87	42.64
4	58.43	41.72	57.30	42.35
5	57.87	41.34	56.73	40.82
6	57.34	40.88	55.86	40.35
7	56.78	40.40	55.13	39.62

Table- IV: Efficiency of propulsion system for different input power of motor at various altitudes

Altitude (m)	Theoretical efficiency of propulsion system for battery power	Theoretical efficiency of propulsion system for tethering system	Experimental efficiency of propulsion system for battery power	Experimental efficiency of propulsion system for tethering system
1	0.389	0.390	0.389	0.400
2	0.389	0.391	0.389	0.412
3	0.388	0.392	0.389	0.423
4	0.388	0.392	0.389	0.435
5	0.388	0.393	0.389	0.447
6	0.388	0.393	0.389	0.458
7	0.388	0.393	0.389	0.469

Thus, by considering all the evaluated outcome of the model calculations and experimental data, there is a moderate variation in power factors of both the systems. The tethering system has shown better performance, however, there is a greater scope of improvement. Thus, the analysis had been comprehended accordingly.

V. CONCLUSION

The main objective of the analysis was to test a better power source for long duration operation of the assembled hexacopter. Therefore, the tethering system had been selected for the analysis and its performance was compared with the normal battery power. The factors which influence the power utilized during operation were considered for analysis. Thus, the thrust variations with the power utilized was deduced which decreases with less power utilized. And, the propulsion system efficiency remained the same and was not affected by the change in power. Hence, to control the thrust, the power utilized could be more refined. Therefore, the tethering system showed enhanced operation with longer endurance, however, there is a limit to the acceptance power of the motor. Therefore, the power could not increase from a specific value of current and voltage and the hovering altitude was limited. This could be improved by utilizing better equipments for the tethering system to have minimal loses of power during transmission. The vertical movement of assembled hexacopter that is hovering had been considered for the experimentation whose characteristics would differ during translational movement. As the power utilized would depend on more factors.

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