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An Experimental Evaluation of LTA on the performance of a drone

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Abstract

Contrary to conventional heavier than air (HTA) drones such as helicopters and quad-copters, whereby their lift is aerodynamically created via the air by the motion of an air foil, hot air stays upward using a light lifting gas. This distinctive feature can provide them with a high payload to weight ratio having long endurance, which this research investigates. The experiment set up for comparison is simply a test designed to determine the battery performance of a drone. The test takes into account the time the drone can last while performing a simply hover at 3 meters with no accessories attached to it (i.e. no mount or camera). It also takes into account the time taken to recharge the battery and the battery consumption while the battery is idle. The aim of the experiment is to evaluate if the LTA concept increases battery performance by comparing its flight time while performing a hover at 3 meters with the results of the DJI inspired drone using MATLAB and SIMULINK. The result shows a total number of 565.7928 seconds (9.43 minutes) battery time for the first model and 581.1097 seconds (9.69 minutes) battery time for the second model. This result looks promising for the LTA concept considering that the battery supplies current for a total of 10 minutes for a 30-minute flight as opposed to a DJI Inspired 2 drone that requires current discharge through the entire 30-minute flight.

Keywords: Drones; Experiment; Performance; Simulimk; LTA

1. Introduction

Hot-air balloons are lighter-than-air (LTA) aircrafts that contains heated air, and a gondola or wicker basket, which carries passengers and a source of heat. Researchers have become interested in them due to their inherent properties of high payload to weight ratio, long endurance capabilities and lower fuel consumption [1]. They are used for

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scientific experiments such as; space-flights, astronomical and telecommunications research, aerial surveying to provide valuable data to military, aircrafts applications and the like. They represent a platform that is unique and promising for many applications that involve an extended period of airborne presence [2]. The balloon is always unconditionally stable during flight because the weight of the balloon is always focused at the bottom, below the center of buoyancy. The control of the air balloon relies on the operator, if the operator wishes to descend, he could either discontinuing firing the burner, which leads to the hot air inside the envelope to cool naturally through heat exchange with the atmosphere or open a little opening at the top of the envelope, thus releasing some of the hot air, which reduces the buoyant force. On the other hand, when the air is heated by burning fuel, the balloon gains height [3]. The heated air in the envelope builds a pressure that is greater than the surrounding air as a result the balloon remains inflated. Usually, there is an opening at the bottom of the envelope through which the expanding hot air is allowed to escape, which prevents a large pressure gradient from developing. What this means is that the heated air pressure inside the balloon will end up being a little greater than the pressure in the cooler surrounding air. Therefore, the control input of a hot-air balloon is therefore unidirectional and switches between on and off states, precise positioning of the balloon is not required for most applications [3]. Contrary to conventional heavier than air (HTA) drones such as helicopters and quad-copters, whereby their lift is aerodynamically created via the air by the motion of an air foil, hot air stays upward using a light lifting gas. This distinctive feature can provide them with a high payload to weight ratio having long endurance, which this project investigates.

1.1. Evaluating the concept for longer flight time

Maximum flight time is one of the most active research field in the drone industry. Although, fixed wing drones can provide longer flight duration when compared with rotary wing drones because of their aerodynamic efficiency [4]. Currently most rotary winged professional drones have 15 to 30 minutes flight. Popular conceptions assert that larger batteries would result in an increased flight time. This assumption is correct, however, not justifiable in many design considerations because the increase in size of the battery and flight time does not show a proportional behavior, rather an asymptotic behavior, i.e. an increase in battery size in flight time becomes inefficient at some point [4]. Therefore, this also brings the industry to another field in battery technology which deals with increasing the battery density by altering the chemical composition, this has led to different types of batteries which include; Lithium polymer (LiPo), Lithium ion (Li-on), Lithium Cobalt Oxide, Lithium Iron Phosphate.

In order to evaluate this concept for a longer flight time, we will setup an experiment to compare it with one of the best commercial drones in the industry- The DJI Inspire 2 drone. The DJI inspire 2 drone is an aerial filmography and photography drone. It consists of; two intelligent flight batteries, a camera (which is detachable), and a control system which contains a number of algorithms for intelligent flight modes, sense, and avoidance, etc. [5]. The intelligent flight battery is a 4280 mAh lithium polymer battery with a net weight of 515g and self-heating technology which enables it to operate effectively at low temperatures. Under perfect conditions, the combinations of the two intelligent flight batteries can provide a total flight time of 25-27 minutes.

2. Experiment

The experiment set up for comparison is simply a test designed to determine the battery performance of a drone. The tests take into account the time the drone can last while performing a simply hover at 3 m with no accessories attached to it (i.e. no mount or camera). It also takes in to account the time taken to recharge the battery and the battery consumption while the battery is idle.

2.1. Model for drone application

In order to develop a model for drone applications, we define the properties of conventional drones that would help adjust two key parameters, the major properties are;

- The size of a drone or the space it occupies
- Gross weight a drone can carry.

Having defined these properties, we input these parameters and run it against developed models.

HEAT TRANSFER MODEL (Model 1)

The heat transfer model shows the heat transfer between the system and its surroundings

$$Q_{in} = mc_{air}\Delta T \ldots \quad (1)$$
$$\frac{\delta Qin}{\delta t} = mc_{air}\,(T_{heater} - T_g)$$
$$Q_{out} = Q_{cond} + Q_{rad} + Q_{conv} \ldots \quad (2)$$
$$\frac{\delta Qout}{\delta t} = \frac{\delta Qcond}{\delta t} + \frac{\delta Qrad}{\delta t} + \frac{\delta Qrad}{\delta t}$$
$$\frac{\delta Qout}{dt} = \frac{KA\Delta T}{D} + \varepsilon\sigma A(T^4{}_g - T^4{}_{ambient}) + hA(T_g - T_{ambient}) \ldots \quad (3)$$
$$Net\ heat = Heat\ gain - Heat\ loss,\ \frac{\delta Qin}{\delta t} - \frac{\delta Qout}{\delta t} = \frac{mc\delta Tg}{\delta t}$$
$$[\frac{\delta Qin}{\delta t} - \frac{\delta Qout}{\delta t}]\,\frac{1}{mc} = \frac{\delta Tg}{\delta t} \ldots \quad (4)$$

(Model 2)

$$Q_{in} = mc_{air}\Delta T \ldots \quad (1)$$
$$\frac{\delta Qin}{\delta t} = mc_{air}\,(T_{heater} - T_g)$$
$$Q_{out} = Q_{cond} + Q_{rad} + Q_{conv} \ldots \quad (2)$$
$$\frac{\delta Qout}{\delta t} = \frac{\delta Qcond}{\delta t} + \frac{\delta Qrad}{\delta t} + \frac{\delta Qrad}{\delta t}$$
$$\frac{\delta Qout}{dt} = \frac{KA\Delta T}{D} + \varepsilon\sigma A(T^4{}_g - T^4{}_{ambient}) + hA(T_g - T_{ambient}) \ldots \quad (3)$$
$$Net\ heat = Heat\ gain - Heat\ loss,\ \frac{\delta Qin}{\delta t} - \frac{\delta Qout}{\delta t} = \frac{mc\delta Tg}{\delta t}$$
$$[\frac{\delta Qin}{\delta t} - \frac{\delta Qout}{\delta t}]\,\frac{1}{mc} = \frac{\delta Tg}{\delta t} \ldots \quad (4)$$

PERFORMANCE MODEL

The performance model shows how the temperature generated from the heat transfer generates lift. The model was incorporated into both heat transfer models separately, which ends up generating two separate mathematical models due to the difference in the heat transfer models.

$$L = (\rho_a - \rho_g)\,Vg \ldots \quad (1)$$
$$L = Vg\,(\frac{\rho_a}{R_a T_a} - \frac{\rho_g}{R_g T_g} \ldots \quad (2)$$

$R_a = R_g$ (Assume same gas constant), $\rho_a = \rho_g$ (Assume no pressure gradient)

$$L = Vg\rho_a\,(1 - \frac{T_a}{T_g}) \ldots \quad (3)$$

For neutral buoyancy, $L - G = 0, \Rightarrow L = G$

Thus, we can substitute L for G in order to obtain the temperature required to maintain a gross weight G at a steady altitude,

$$\Longrightarrow LVg\rho_a = 1 - \frac{T_a}{T_g},\quad T_g = \frac{T_a}{(1 - \frac{L}{Vg\rho a})},\quad L = G$$

$$T_g = \frac{T_a}{\left(1 - \frac{G}{V g \rho_a}\right)} \ldots \tag{4}$$

$T_a = T_0 - 0.0065h,\ \rho_a = \rho_0\left(1 - 0.0065\frac{h}{T_0}\right)^{4.2561}$

$where,\ T_0 = 288.15\ K\ and\ \rho_0 = 1.225\ kg/m^3$, from newton's law of motion:

$$m\ddot{x} + R\dot{x} + kx = F \ldots \tag{5}$$

$The\ system\ is\ assumed\ to\ be\ undamped\ and\ offers\ no\ form\ of\ resistance, therefore$

$R = 0$, and $k = 0$, $\Rightarrow m\ddot{x} = F,\quad m\frac{\delta u_x}{\delta t} = L - G,\ \left(V\rho_g + \frac{G}{g}\right)\frac{\delta u_x}{\delta t} = L - G$

$$\frac{\delta u_x}{\delta t} = \frac{1}{\left[V\rho_a\left(\frac{T_a}{T_g}\right) + \frac{G}{g}\right]}\left[V g \rho_a\left(1 - \frac{T_a}{T_g}\right) - G\right] \ldots \tag{6}$$

$$\iint \frac{\delta u_x}{\delta t} = \chi_{(t)} \ldots \tag{7}$$

2.2. Aim of experiment

The aim of the experiment is to evaluate if the LTA concept increases battery performance by comparing its flight time while performing a hover at 3 meters with the results of the DJI inspire 2 drone using MATLAB and SIMULINK.

2.3. Objective of experiment

In order to achieve this;

- A control will be incorporated into the model in order to maintain a steady altitude of 3 m
- A simulation will be run against the maximum flight time of the DJI Inspire 2 drone (30 minutes) to determine the total number of seconds the battery was on during the 30-minute period

2.4. Designing a control for the system

The type of control is simply a thermostat that sends an on/off signal equal to 1 (on) or 0 (off) to the heater. The thermostat takes its input from the altitude and velocity feedback signal from the performance model and compares it with a set altitude of 3 m and a set velocity of 2 m/s with a hysteresis value of 2. Therefore, the thermostat sends an on signal when both criteria are not met and sends an off signal when at least one of the criteria are met. The other signal that runs into the OR operation caters for acceleration downward (also a set value of 2 m/s). Figure 2.1 shows the control algorithm for the thermostat while figure 2.2 shows entire hot-air balloon system.

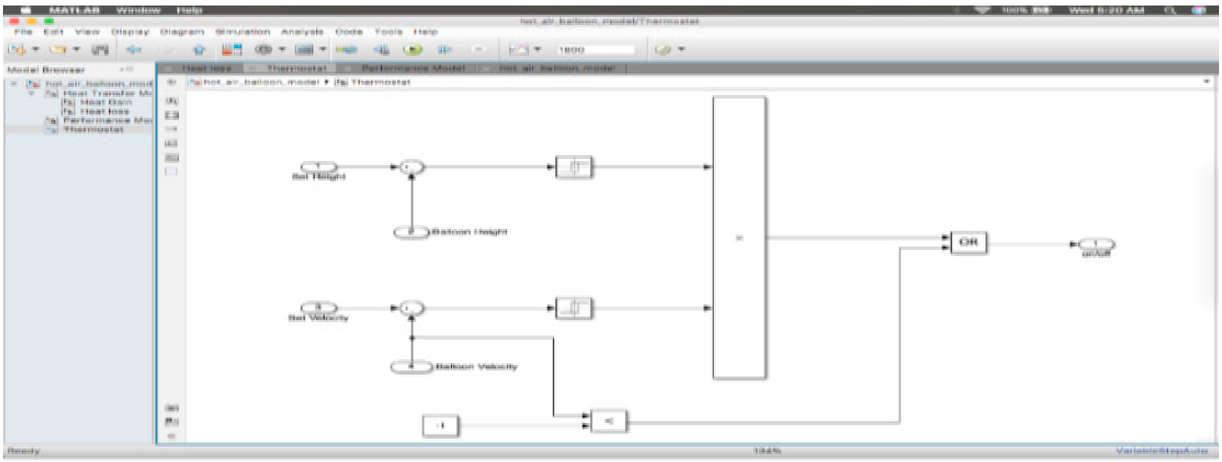

Figure 1: A Simulink build showing the control algorithm for the thermostat

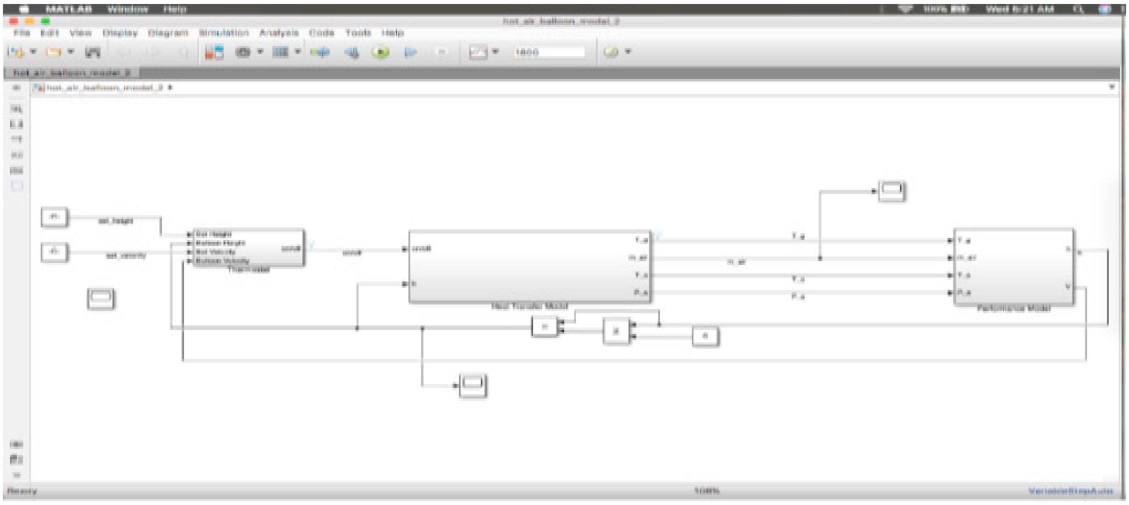

Figure 2: A Simulink build of the entire hot-air balloon system

3. RESULTS

Based on the control, the system is simulated for comparison

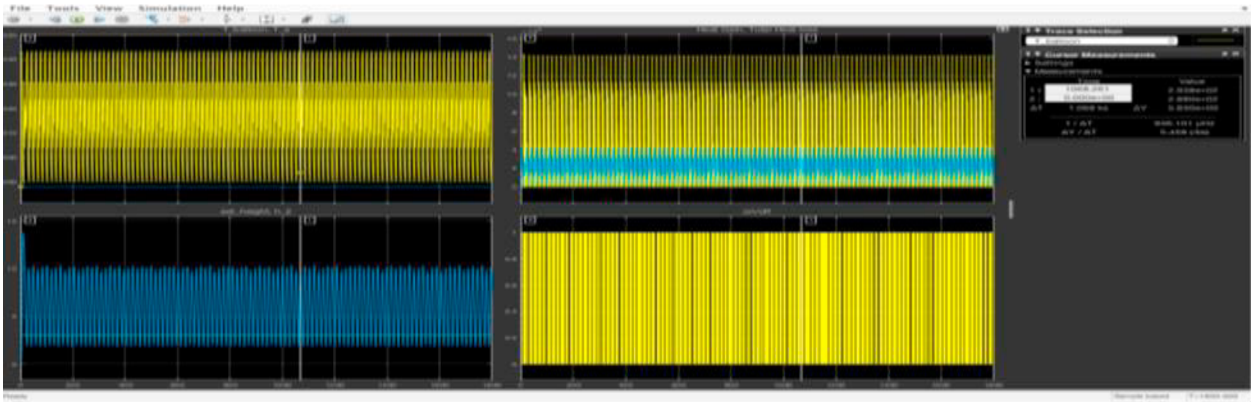

Figure 3: Results of simulation from experiment setup

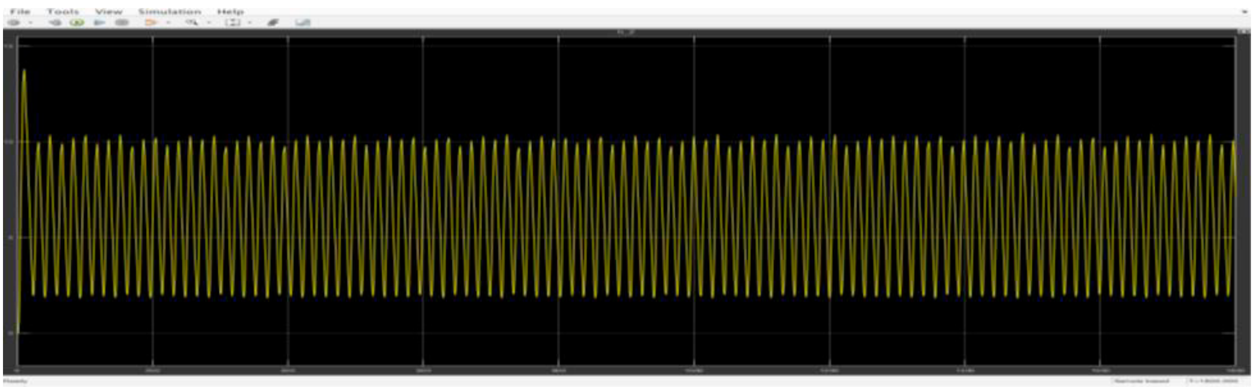

Figure 4: Altitude signal from experiment setup

5. Discussion

This section introduces the result of the experiment that was simulated using MATLAB and SIMULINK [6], which is to determine if the LTA concept increases battery performance by comparing its flight time while performing a hover at 3 metres with the results of the DJI inspire 2 drone. The result is obtained by analysing the on/off signal at the bottom right of figure 3.1. The analysis is a code written on MATLAB to check the total number of seconds that current was supplied to the heating element assuming that the discharge current rating of the battery is equal to the discharge current rating of the battery in a DJI Inspire 2 drone. The analysis shows a total number of 565.7928 seconds (9.43 minutes) battery time for the first model and 581.1097 seconds (9.69 minutes) battery time for the second model. This result looks promising for the LTA concept considering that the battery supplies current for a total of 10 minutes for a 30-minute flight as opposed to a DJI Inspire 2 drone that requires current discharge through the entire 30-minute flight. Finally, using helium as a light lifting gas will require a careful fluid mechanics study of the helium gas in and out of the envelope as a means of control for the system. Drones find usage in robotic research [7].

6. Conclusion

Two models were simulated and evaluated by comparing their performance with conventional drones (The DJI Inspire 2) for longer flight time. MATLAB and SIMULINK were the chosen software for modelling and simulation considering that they have a large database of free and authentic learning resources. Plus, they have a user community (MATLAB central) where knowledge, questions, answers and open source codes are shared among students, educators and industry professionals. An important conclusion that define a Hot air balloon drone is that the LTA concept has a comparative longer flight time when considered for drone applications due to their high payload to weight ratio.

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