POWER AND OTHER REQUIREMENTS FOR UNMANNED AERIAL VEHICLES (UAVs)

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ABSTRACT

Unmanned Aerial Vehicles (UAVs), commonly known as drones have been extensively used in military operations during the last decade for surveillance, monitoring enemy activities, collecting information, and even attacking military targets. They have also been useful in several commercial applications, such as delivering small packages to rough terrain locations, medication to emergency locations, and monitoring crops in agriculture. The evolution of camera drones has further extended its use in sports, assessing the maturity of grapes, checking levels of pollution in the sea, and in higher education. A camera drone was used during an Alpine Skiing World Cup Downhill race in 2012 in Canada. A year later a drone was also seen hovering above the field during a National Rugby League game between Australian sides Warringah Sea Eagles and the Sydney Roosters. In September 2014, drones were used at the Pape Clement castle vineyards in Bordeaux, France to assess the maturity of grapes. This paper describes power and other essential requirements for drones to be operational and effective in commercial applications. This is an emerging technology that will change the landscape of logistics and supply chain management. This paper will benefit academicians, researchers, and commercial companies.

INTRODUCTION

UAV (unmanned aerial vehicles) or drones as they are popularly called are in the news lately. It is estimated that around half a million drones were sold last year. Many companies like AMAZON, GOOGLE are planning to use the drones for delivery of goods and disaster relief etc. Currently there is a large push for utilizing a UAV-class vehicle as a viable mode of transportation. UAVs have been used by the military for years to reach remote places on this earth for both defensive and offensive operations. When most of the other standard forms of transportation are either too cumbersome or too expensive to use for fulfilling transportation or delivery needs, UAVs provide a very cost-effective and useful alternative.

Drones that have come to light from various sources are being used in both military and civilian applications. The military applications have been developed by the primary US aerospace companies and have advanced tremendously for use internationally but are not publicized in the open literature. Since these applications have primarily been in the military, their usage is not controlled by the Federal Aviation Agency (FAA). However, FAA has been controlling the flight of UAVs in the public airspace, and is supposedly coming out with more definitive directives sometime this year for commercial UAV usage. A handful of 333 licenses have been issued to companies, universities and individuals for experimental usage of the UAVs. But, there are myriads of activities both in the US and abroad to design and fabricate these vehicles, and to operate them in a limited way in the United States. Many of these UAVs have been battery-operated n-copters designed and manufactured to a large extent in China and are being imported by the public in the United States for recreational and experimental purposes. Some of these UAVs have been gasoline driven vehicles. The gas powered UAVs tend to have higher range of flight time and distance. However, the battery-powered vehicles are clean, less cumbersome and user-friendly for users of all ages. Typically, various battery-driven UAVs and sports drone models are currently available in the market place, and the public is buying them in large numbers. However, the public cannot legally fly them with ease until FAA certification policies are instituted. Having said about the way things are, the battery-powered drones have potentially a variety of usage as described earlier. But, there are some power and weight restrictions on the working of these UAVs. The analysis provided here in a formal way points out these restrictions.

UAVs FOR MILITARY AND COMMERCIAL APPLICATIONS

Military has used UAVs extensively for many purposes. Many corporations especially in countries other than USA have used in sports, agriculture, film-making, higher education, and variety of other applications. Some of the ways in which the drones used now are described below:

Search and Rescue: Unmanned drones are used in Search and Rescue operations as they provide an overview of the situation from the sky without any risk of life. Rescue personnel can also obtain samples of gases present in the environment through drones.

Inspection: Inspections of wind turbines, power lines, pipelines, etc. can be done using a drones, and this can reduce the cost of manual inspections in remote areas. Farmers can use UAVs to survey their fields and crops to accurately assess the health of their yield.

Mapping: Laser scanners, multi-spectral cameras and Waypoint technology make mapping easier for the drones. This data is cheaper to collect with an UAV than manual mapping and is also more accurate.

Unmanned Cargo System: This technology is still evolving with Amazon and Google leading the way. When fully developed this will be cost effective, safe and environmentally friendly way to deliver light weight packages.

Surveillance: By attaching a camera to it and obtaining a live feed, drones can survey any area. Depending upon the range of live feed, drones can be put for surveillance of remote areas.

Aerial Photography: One of the most common uses of drones now is Aerial photography. This has exploded in recent times. First Person View (FPV) of highest quality can be obtained from UAVs. Earlier these kind of shots were only available through the use of helicopter using very powerful cameras. Because drones can hover at lower altitudes compared to the helicopter, the quality of photographs is superior, and it is cheaper to obtain them.

Science and Research: With drones one can monitor remote and unsafe areas like volcanoes, earthquakes, hurricanes, etc., and data recorded from them can be used for research.

POWER AND OTHER REQUIREMENTS FOR UAVs

At present as per Federal Aviation Administration (FAA) guidelines, drones can be operated within the line of sight only [1]. Other guidelines are listed below:

- Fly below 400 feet and remain clear of surrounding obstacles.
- Keep the aircraft within visual line of sight at all times.
- Remain well clear of and do not interfere with manned aircraft operations.
- Don't fly within 5 miles of an airport unless you contact the airport and control tower before flying.
- Don't fly near people or stadiums.
- Don't fly an aircraft that weighs more than 55 pounds.
- Don't be careless or reckless with your unmanned aircraft – you could be fined for endangering people or other aircraft.

For commercial operations of drones, specific waivers from FAA are required. However, the following are some of the challenges facing the drone operations beyond the line of sight:

- Power requirements for ranges beyond the line of sight.
- Requirement of the drone operator to see the drone surroundings for control and maneuverability of the drone.
- Communication link to transmit and receive telemetry operations.
- Requirement of a system like the air traffic control system for the drones so that collision can be avoided.
- Network security of the drones so that the drone communications cannot be hacked or jammed.

ANALYSIS FOR POWER REQUIREMENT

This paper discusses and analyzes specific power requirements for the drone operations. The power Equation (1) follows the standard helicopter equation for hovering [2].

$$\boldsymbol{P} = \frac{\boldsymbol{T}^{3/2}}{\boldsymbol{FM}\sqrt{2\rho \boldsymbol{A}}} \qquad (1)$$

Where P = Hover Power
T = Rotor Thrust

ρ = Density
A = Rotor/Propeller Area
FM = Figure of Merit

For hovering,

T =Weight of the UAV (2)

Power calculation in Equation (1) is the shaft power, that is, a real value of power that produces usable thrust. It contains a value of efficiency of power conversion called the figure of merit, FM, included in Equation (1). According to [2], the figure of merit typically varies from 0.7 to 0.8 in the static case (hover).

The energy is calculated as follows:
E (Joules) = P (Watts) x time of flight (seconds) (3)

Goli [3] presents the use of UAVs in mapping and was able to show the strength of the UAV (Figure 1) to do so. In the design of his UAV, he used some batteries available in the market.

1. Battery is 4000 mAh 4S LiPo (370 g). It supplies 4 amperes continuously for 60 minutes at 14.7 volts and producing 59.2 watts.
2. The same battery supplying 31.5 amperes at 14.7 volts and produces 465 watts of power for 7.6 minutes.

We used the same battery as above for doing our current calculations. The following values were used for power calculation by using Equation (1):
Density of air ρ = 1.2 kg/m3
Radius of rotor blade = 0.127 m, Number of blades = 6

Figure 1. UAV configuration called DJI Flamewheel

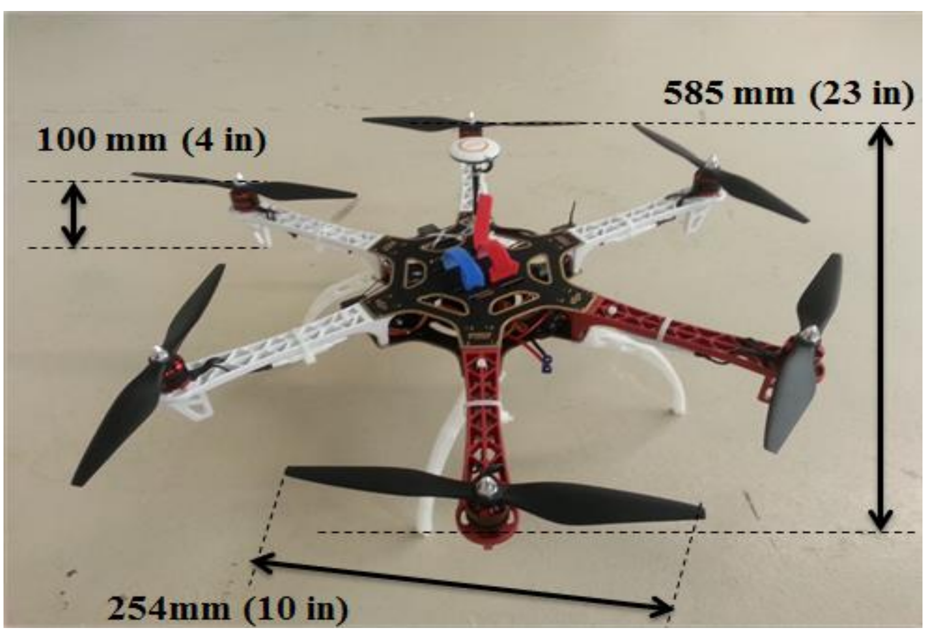


Figure 2. Battery Supplying 4A of current for 60 minutes at 14.8 V thus producing 59.2 W of power. (Costs $52.99)

Battery weight in Figure 2 = 0.37 kg for each unit

Drone weight = 1.655 kg

Payload weight = 0.975 kg

Therefore, the total weight of the UAV = Battery + Drone + Payload

Using these inputs as a guide, some parametric computations were made to provide trends for energy availability and energy required to fly a typical quad-copter UAV. Keeping everything fixed but varying the battery pack size provides the trends of power, as seen in Figure 3. In this figure FM was assumed to be a low value of 0.4. The computations were made for 7 and 14 minutes of flight. Energy was plotted vs. total weight showing crossing of the curves for energy available and energy required. As expected, adding more batteries prolonged the flight time as seen in both Figures 3a and 3b. Adding more batteries has an endurance advantage only up to a degree, as seen in Figures 4a and 4b. One can fly up to 25 minutes by adding 10 batteries, as seen in Figure 4b. Adding more than 10 batteries does not provide any advantage. It was taken a step further in Figures 5a and 5b, where up to 100 batteries were added showing the energy required for a 25 minute flight was diverging away very severely from the energy available. The same trends are apparent in Figures 6a and 6b with a higher value of efficiency (Figure of merit of 0.8). Other variations of useful computations such as the amount of payload that can be carried, given the time of flight, can easily be made.

Figure 3a: Relationship between Energy Requirement and Total UAV Weight

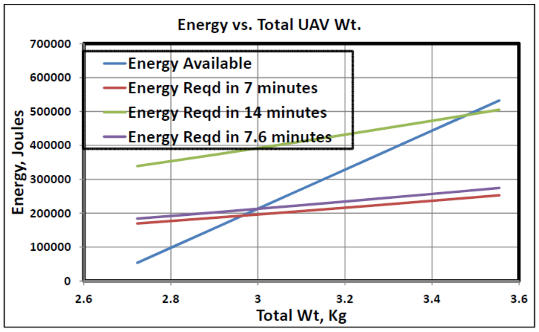


Figure 3b: Relationship between Energy Requirement and Total Battery Weight

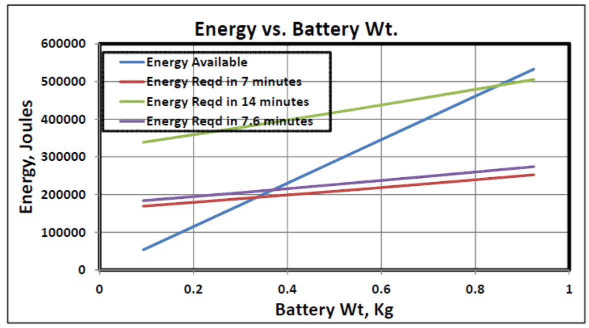


Figure 4a: Relationship between Energy Requirement and Total UAV Weight

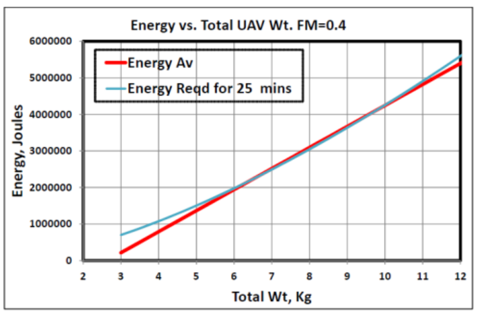


Figure 4b: Relationship between Energy Requirement and Total Number of Batteries

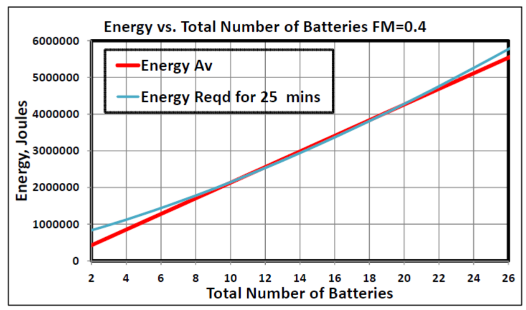


Figure 5a: Relationship between Energy Requirement and Larger Total Weight Range

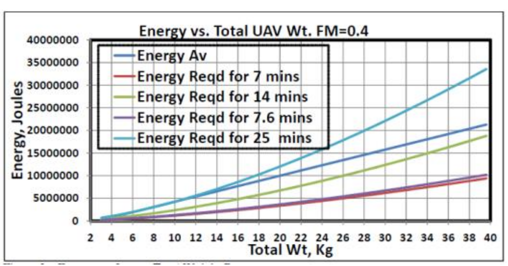


Figure 5b: Relationship between Energy Requirement and Total Number of Batteries

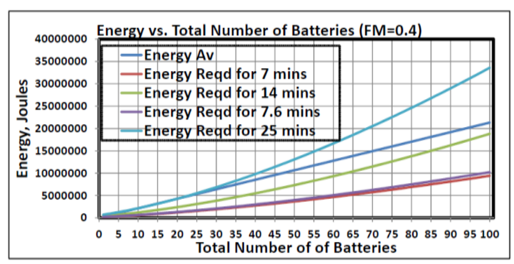


Figure 6a: Relationship between Energy Requirement and Larger Total Weight Range for a Higher FM

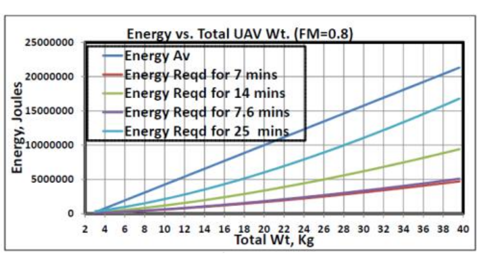
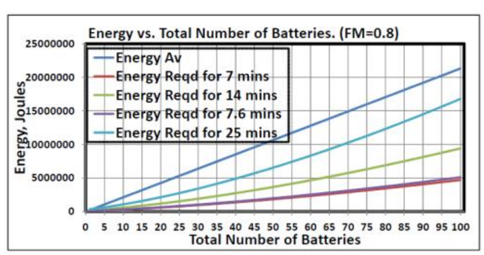


Figure 6b: Relationship between Energy Requirement and Total Number of Batteries for a Higher FM



Conclusion and Future Trends

A simple parametric analysis of the endurance of UAV vehicles with respect to available battery power is provided here. There is some evidence in the industry that Power distribution software are being developed to conserve power by allowing power withdrawal as per requirement of the motor on need basis. An improvement in the figure of merit is required to increase availability of useful energy. Improvements in power density of the batteries through battery technology upgrades are required for efficient and useful UAV operations. A variation of more useful UAV operation is being considered in some quarters where mixed designs of drones for take-off through rotors but maintenance of flight through wings would be used.

6. REFERENCES

[1] https://www.faa.gov/uas/model_aircraft/

[2] Gundlach, J. (2012), "Designing Unmanned Aircraft Systems: A Comprehensive Approach, American Institute of Aeronautics and Astronautics, pp.292.

[3] Goli, Nishan (2015), "Development of an Integrated UAS for Agricultural Imaging Applications," An M.S. Thesis Presentation to University of Alabama in Huntsville, Huntsville, AL.