Power and Energy for Small Unmanned Aerial Systems

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Abstract
Small unmanned aerial systems have great potential for many different applications. However, one of the major technical challenges encountered by small unmanned aerial systems today is working endurance, which is directly limited by fuselage space capacity for the on-board battery. This restricts the endurance, range, and nature of the functions which may be performed by the small unmanned aerial systems. Developing and implementing a high energy density and high-power density alternative power system is critical for these small unmanned autonomous systems. This work is studies alternative power and energy systems for small unmanned aerial systems.

Keywords
Unmanned Aerial System, Li-ion Battery, Li-Polymer Battery, Thin Film Solar Cell, Polymer Electrolyte Membrane Fuel Cell, Solid Oxide Fuel Cell.

Introduction
Unmanned aerial systems (UASs) have been used by many forces worldwide and were rapidly adopted during the Global War on Terror. Their development enabled the users to operate more effectively, efficiently, and safely in different working environments. However, state of the art battery technology is ill-suited for present and future mission requirements. For example, Li-polymer batteries provide less than 2 hours of flight time for similar small UAS platforms. This restricts the endurance, range, and nature of the functions which may be performed by the UASs. Therefore, it is critical to develop and implement alternative power systems for these small UASs. The other key drawbacks are the weight and size of the small UAS, which restrict the mounting of larger payloads or extra batteries. The objective of this study is to further investigate the viability of power and energy for small UASs extending flight endurance.

Results and Discussions
Several energy storage and power generation technologies were explored to maximize energy stored on-board and to achieve long endurance performance. This study focused on extending the endurance of small UASs, which are considered in the Group I (less than 20 and Group II (less than 50lbs) category [1].

I. Battery:

Fig 1. Battery powered a RQ-11 Raven (top) and RQ-20 Puma (bottom) systems.

A battery is an electrochemical energy storage device that stories energy at the electrodes. Currently, most of the small UASs are powered by either lithium-ion (Li-Ion) or lithium polymer (Li-Po) batteries. However, the flight endurance is usually limited between 60 to 90 minutes before requiring a forced recovery to replace depleted batteries. Lithium polymer batteries are becoming more popular for commercial and military UAS application due to their lower weight and greatly increased cycle life. However, lithium polymer batteries have a greater cycle life degradation rate than that of lithium-ion batteries. For storage purposes, lithium polymer batteries can be stored for one or two months without significant degradation in its state of charge, whereas other batteries will lose a significant amount of their charge during similar storage conditions. For long-term storage, it is highly recommended that the battery be stored at 40% of its full charge. A relevant example is the battery used for providing propulsion power on-board a small UAS. It is highly desirable to have an energy source that offers both high energy density and power density to sustain UAS flight extensive endurance missions. Several other common batteries that can be considered for small UAS applications are sodium-sulfur batteries and lithium-sulfur batteries. It is also important to develop fast charging batteries for future applications. Lithium batteries have degradation issues at high temperatures and serious degradation occurs when the cell is discharged below two volts. Additionally, when overcharged, they will experience capacity loss or thermal runaway. Figure 1 shows battery powered Raven (top) and Puma (bottom) small unmanned aerial systems [2-3].

II. Thin-Film-Solar-Cells:

A solar cell is a simple semiconductor device that converts light into electric energy. Some important characteristics of solar cells include that cell output voltage constant with the varying sunlight intensity and is independent of cell size, and decreases at a rate of 2mV/C as temperature rises. On the other hand, cell current is relatively stable at high temperature and is directly proportional to sunlight intensity and cell-size. Therefore, to obtain a high output power, solar panels need to be operated at lower temperatures with multiple large sized cells connected individually. The additional power provided by solar cells to sUAS with electrically powered propulsion systems will increase UAS flight endurance and flight time and will give users with added field surveillance capabilities. The idea is to hybridize the use of a thin-film-solar-cell with a lithium battery to power small UAS. A hybrid battery/thin-film-solar cell system would extend Raven or Puma flight endurance and has been studied by the Air Force Research Laboratory (AFRL) for the last two decades [4-5]. The AFRL partnered with UES, Inc. and Microlink Devices, Inc., to integrate a new lightweight, flexible, high-efficiency solar panel onto a small, unmanned aircraft system (UAS) platform (Fig.2). This would allow a Raven/Puma to be powered by a solar cell during the day and use its rechargeable battery for night operation. This approach needs Raven/Puma that incorporate larger wing surface area would benefit from this approach due to the increase in output power, along with better lift capability. Also, a DC-DC converter would be required allow for the solar cells to recharge the battery. This provides a desired output voltage and delivers maximum power from the thin film solar cells to the battery and load. Although promising, the thin film solar cell efficiency needs to be improved or using a high efficiency triple junction solar cell is needed for this application. However, using solar cells is highly dependent on the sun, and thus intermittent and difficult to predict, so a battery must still be used be to meet the UAS power demand.

Fig 2. Air Force Research Laboratory partnership with UES, Inc. and Microlink Devices, Inc., has integrated new lightweight, flexible, high-efficiency solar panels onto a small, unmanned aircraft system (UAS) platform [4-5].

III. Fuel Cell:

A fuel cell produces electricity from an external fuel supply as opposed to the limited internal energy storage capacity of a battery. In simple terms, a fuel cell is an electrochemical device that converts hydrogen fuel directly into electricity, water, and heat without combustion. A fuel cell will continue to operate for as long as the externally stored fuels are supplied. Considerable attention has also been paid to the type of fuel cell that would be best suited for small UAS applications. The main fuel cells discussed in here are H_2 based polymer electrolyte membrane fuel cell (PEMFC) and solid oxide fuel cell (SOFC). PEMFC and SOFC are the most mature fuel cell technologies which could be suitable to use for UAS applications.

Department of Energy (DoE) has supported numerous H_2 based PEMFC programs due to their potential to become practical power generators for use in commercial applications, especially for electric vehicles. Several research and development programs designed to develop and demonstrate an H_2 based PEMFC systems for extending Puma flight endurance were supported by the Department of Defense's SBIR program around 2010 [6-7]. However, the issue for PEMFCs are they typically require a high purity hydrogen (99.99%). While hydrogen itself has a tremendous gravimetric energy density (energy/mass), it has an exceptionally low volumetric energy density (energy/volume). This means such systems are either too large for small

UAS or require a heavy high pressures H_2 storage tank. Further, the transport and storage of hydrogen is extremely difficult for practical applications. In this regard, SOFCs have a significant advantage over PEMFCs. SOFCs have much greater fuel flexibility due to higher operational temperatures. The other advantage of SOFCs is that the high operational temperatures produce waste heat, which can be used for endothermic reforming reactions. The challenges for SOFCs lies in finding materials which have both the necessary performance and stability (thermal and mechanical) to operate at high temperatures (~800°C).

Defense Advanced Research Project Agency (DARPA) and Army Research Laboratory (ARL) had jointed development on a propane fueled solid oxide fuel cell (SOFC) system to power the small UAS [8]. Since a robust and rigorous SOFC system is needed for this special application, a tubular SOFC stack design was chosen. The SOFC was hybridized with a high power density Li-polymer battery to power the small UAS; this system is shown in Fig 3. A block diagram for fuel cell and battery hybrid power system is shown in Fig. 4. Initial power flows from the battery to start the fuel cell. After the fuel cell reaches normal operation and provides power with battery, the UAS takes off and begins its mission. The fuel cell recharges the battery during the UAS's cruise flight.

In partnership with Adaptive Materials Inc., Army Research Laboratory completed an evaluation of a 300W propane fueled ground SOFC system for its performance and thermal cyclic durability. The system performance and thermal cyclic durability met the performance expectation.

Fig. 3. SOFC/Li-polymer battery hybrid power system to power small UAS. Left photo is a lithium polymer battery and right photo is a solid oxide fuel cell.

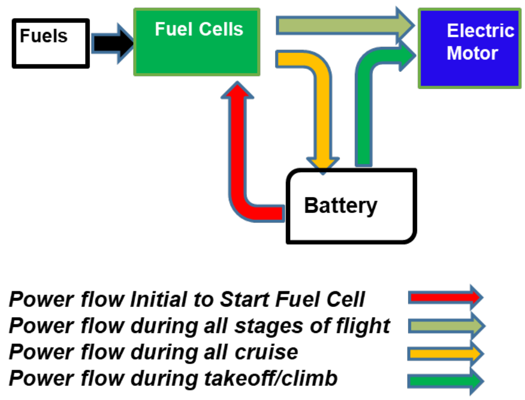

Fig. 4 A general block diagram of the fuel cell with battery hybrid power system.

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Summary:

The battery is an energy storage system, and its energy capacity is a function of its battery size. Currently, the energy density of Li-ion or Li-polymer batteries are a limiting factor for UAS flight time. Although there is no great solution, SOFCs are currently used by the military as a power and energy solution to power UASs. High energy density batteries need to be developed for a long endurance UAS mission. Thin-film-solar-cell conversion efficiency is not high enough to power a small UAS, but better than 30% high efficiency triple junction solar cell may be a possible solution to power small UAS. PEMFCs are a viable technical solution to power portable electronic and equipment systems, but the effective use of PEMFCs in the practical applications would be a logistical problem since they require a safe, high-energy density, transportable, reliable source of hydrogen sources. Solid oxide fuel cells provide a fuel flexible advantage but need to be improved thermal cyclic durability. With respect to a UAS application, the fuel cell system power density is an extremely important figure of merit.

A fuel cell with a battery hybrid power system is the best power system to power small UAS for a long endurance and long-range missions. Fuel cells will offer lighter, more energetic power sources than are currently available, will extend mission time, reduce weight, and decrease the logistical burden associated with batteries. Batteries will offer high power density for UAS during take-off and climb. Some of the remaining challenges are meeting the size, space, and weight constraints for fuel storage on-board these small UASs. Understanding the performance characteristics of power system is clearly important for realizing the optimum cost/weight/volume/performance ratios.

Acknowledgments
The author would like to thank the Department of the Army's International Cooperative Research and Development (ICRD) program for its financial support of this project.

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