Fuel Cell Powered Small Unmanned Aerial System (*s*UAS) Lessons Learned and the Road Ahead

Deryn Chu and Rongzhong Jiang
U. S. Army Research Laboratory,
2800 Powder Mill Rd., Adelphi, MD 20783-1107
Deryn.d.chu.civ@mail.mil

Summary:
Small unmanned aerial systems (*s*UASs) have great potential for many different applications (1-3). The *s*UASs are light-weight, man-portable, and capable of carrying payloads. *s*UASs can be broadly classified by their performance characteristics such as size, weight, speed, and endurance. Currently, small UASs are powered by lithium-ion or lithium polymer batteries; however, flight endurance is limited and requires frequent battery replacement. Frequent battery replacement is due to low capacity and energy density (less than 200Wh/Kg). Numerous research and development efforts have focused on alternative power sources. These alternative power sources technologies include such as solar cells and hydrogen based polymer electrolyte membrane fuel cells. Power and energy systems for *s*UASs will be discussed and presented at the conference.

Key Words: Fuel Cells, Unmanned Aerials System

Small unmanned aerial systems (sUASs) have been used for military applications and have additional potential for commercial applications. These systems provide valuable intelligence, surveillance, reconnaissance and target acquisition (ISRTA) capabilities for infantry units at the battalion, company, and platoon levels. The small UASs need for a long range and extended endurance is important for practical applications. However, Li-ion batteries provide less than 2hrs of flight endurance for a Puma UAS platform. This restricts the endurance, range, and nature of the missions which may be performed by the UAS. Therefore, it is critical to develop and implement alternative power and energy systems for small UASs. Alternative power and energy systems used to power sUASs that have been reported in literature. These included combinations such as batteries with advanced high-efficiency solar cells, a small engine, and high power/energy density fuel cell systems. sUASs have strict specific power and energy requirements. Batteries can have a wide range of specific powers, but have limited specific energy. Fuel cells have the promise to achieve both the specific power and the specific energy requirements. Over the last decade, numerous efforts have been put forth to integrate fuel cell power systems into UASs. Defense Advanced Research Projects Agency (DARPA) and Army Research Laboratory (ARL) have jointly studied and developed fuel cells powered UASs since 2009. During this period, we considered all of the current UAS systems (Fig. 1). Based on our extensive research, we concluded the size, weight, payload, and typical flight characteristics of the Stalker UAS made it an ideal candidate to a first adopter of a fuel cell power system. There is a long list of factors that lead to this conclusion; however, two of the most critical considerations were flight altitude and noise. Altitude is an important consideration because fuel cells use oxygen from the air as an oxidant. As an UAS's altitude increases, oxygen levels in the air decrease. The lower oxygen levels can starve the fuel cell of the oxygen it needs and result in a concurrent decrease in fuel cell performance (power and efficiency). For example, the Scan Eagle typically flies above 16,000 feet (4876 meters) and the Shadow typically flies at altitudes in the 4,000 to 8,000 feet range. The Scan Eagle and Shadow UAS platforms use internal combustion engines (ICEs), which require the higher elevations to avoid detection because they make noise. Detectable noise is not desirable for small UASs operating at lower altitudes because it can compromise operational security. On the other hand, small platforms including Wasp and Raven become size (volume) limited making fuel cell power impractical at this time.

High performance fuel cell systems are a logical candidate for small UAS power systems. A fuel cell is an electrochemical device that converts chemical energy of a fuel and oxidant (O_2 from air) into electricity, water, and heat. The cell directly extracts electrons from the fuel through an electrochemical oxidation reaction at anode, and an electrochemical oxygen reduction at cathode; producing electrical power during the process. Hence the energy is directly stored in the fuel and the basic power production process involves no moving parts. This raises the expectations of a silent and vibration free operation.

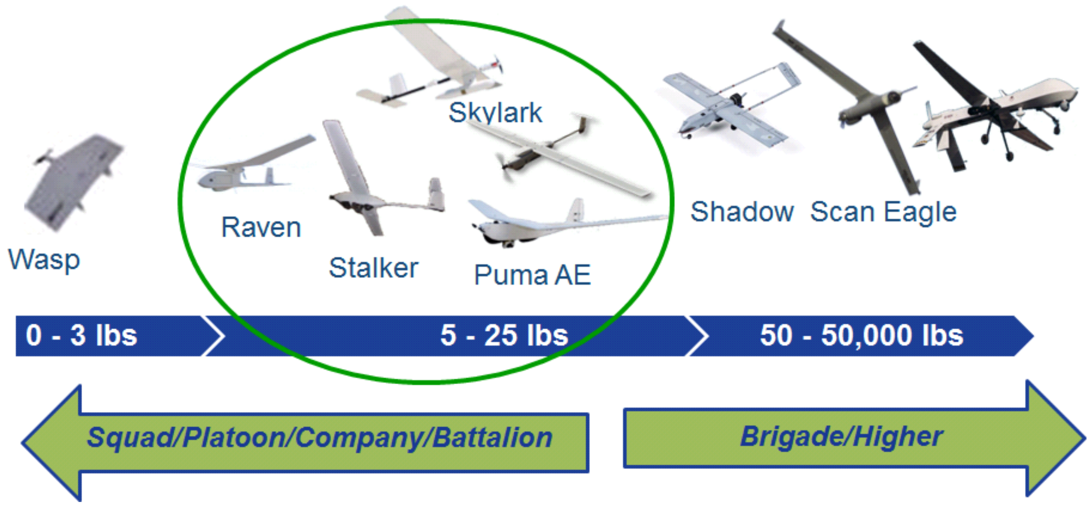

Figure 1. Different Unmanned Aerial Systems.

Considerable attention has also been paid to the type of fuel cell that would be best suited for small UAS applications. There are several types of fuel cells under development. Each type of fuel cell has its own advantages and disadvantages for potential applications. A few of the most promising types include (1) alkaline, (2) molten carbonate, (3) phosphoric acid, (4) polymer electrolyte membrane (PEM), and (5) solid oxide fuel cell (SOFC). PEMFC and SOFC are among the most mature fuel cell technologies which could be suitable for small UAS applications. PEMFCs typically require an extra high purity hydrogen (99.99%). Hydrogen itself has the highest gravimetric energy density based on a mass, however, it has the lowest volumetric energy density based on a volume. This means, such systems are either too large for small UAS or require heavy high pressures storage tanks. The transport and storage of hydrogen is extremely difficult for military missions. In this regard, SOFCs have significant advantage over PEMFCs. SOFCs have much greater fuel flexibility. This allows SOFC to operate on any combustible high energy dense fuel such as propane.

While able to use a higher energy density fuel, the SOFC has several technical impediments that needed to be resolved prior to application in UAS. The impediments include (1) development of a stack design that can tolerant thermal cycling, (2) increased stack durability and reliability such that it can survive the acceleration forces during UAS talk-off and landing (anticipate land force example: 100G 30ms impact), and (3) increased current collector and fuel cell stack tolerance of vibration and shock such that the fuel cell stack can meet the cycle lifetime while maintaining the minimum output power. All of the impediments have been addressed and resolved under the DARPA and ARL's joint program.

Present versions of the 245W fuel cell system powered Stalker small UAS have requested to participate many military exercises and theaters applications. The 245W SOFC system have already been demonstrated in Stalker sUAS platforms and have shown a remarked improvement in endurance (4x increase in flight endurance relative to Li-polymer battery for small UAS). Currently, we plan to develop and demonstrate a high power (350 W) with high efficiency and variable fuel consumption SOFC system for current and future unmanned aerial systems. The new 350W SOFC system can significantly increase specific power relative to the present 245W propane fueled SOFC system (135W/kg vs 94W/kg). An increase in system power to 350W (up from 245W) and power density to 135 W/kg mean the upgraded SOFC power source can provide new capabilities for small UAS applications. These upgrades will be incorporated in the same physical power system package (i.e., size and weight) that is used on the existing Stalker UASs.

To demonstrate and apply the new technology capabilities, the 350W fuel cell stack technology will be incorporated into a 350W portable power system. This power system will be tested/evaluated and subsequently be integrated into Stalker UAS platforms. The new high power and high efficient 350W SOFC to power Stalker UAS plan to field evaluation and demonstration in 2019. In addition, the new 350W SOFC system will also benefit other Army portable power and energy applications. The Army has long term research and development goals and programs for improving fuel cell systems for alternate power and energy. For example, the Army has a need for a soldier-carried, back-pack sized 350 watt power system with improved reliability, performance, and fuel efficiency. For soldier-carried power systems, SOFC systems can increase overall operational energy efficiency. Development a high power and high efficient SOFC system for Army applications is our ultimate goal.

Acknowledgements: The fuel cell powered small UAS system program funded by the DARPA, ARL and OSD Rapid Reaction Technology Office. SOFC system developed by the UltraElectronics AMI and integrated into the Stalker unmanned aerial system by Lockheed Martin, Inc.

References:

(1) http://www.youtube.com/watch?v=98BIu9dpwHU

(2) http://www.youtube.com/watch?v=98BIu9dpwHU&feature=player_detailpage

(3) https://www.youtube.com/watch?v=-CYT4PFV_Hs