# Zinc-Air Batteries for UAVs and MAVs

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## 1. Introduction

Electric Fuel's zinc-air battery technology has been implemented in man-portable battery packs for the military, with specific energy of up to 400 Wh/kg, and additional advantages over lithium technologies in cost, safety and environmental effects. The technology is now being adapted to meet the high-power challenge of UAV and MAV propulsion.

At present, power sources available to the military provide only marginally adequate operating times for electrically-powered UAVs. Zinc-air cells with novel configuration and components will significantly extend the flying time of such UAVs.

The energy requirement of electrically propelled MAVs is even more demanding, where development has been hampered by the lack of a satisfactory battery solution. New cutting-edge zinc-air cells will overcome this barrier, and power a typical 150-gram MAV for 30 minutes. The flexible, planar zinc-air cells can be configured to nearly any shape, thus enabling them to be considered as a structural element of the MAV.

Current work is focused on evaluating the feasibility of zinc-air cells to extend the flying range of both existing and future platforms. Laboratory testing has demonstrated performance approaching the development targets.

## 2. Technology Background

All batteries convert chemical energy to electrical energy through two separate electrochemical reactions: one consuming electrons (at the cathode) and the other releasing them (at the anode). These half-cell reactions are physically separated within the battery, allowing ions to flow between them, but not electrons. It is this separation that allows a battery to produce electrical power: The electrons are made to do work on their journey to the other side of the battery by passing across an electrical load, such as a light bulb, motor, or other electrically powered component or device.

The half-cell and overall chemical reactions in the zinc-air cell are described in Table 1.

### Table 1. Zinc-Air Cell Reactions

**At the anode:**

$$2\ Zn + 4\ OH^- = 2\ ZnO + 2\ H_2O + 4e$$

**At the cathode:**

$$O_2 + 2\ H_2O + 4e = 4\ OH^-$$

**Overall reaction:**

$$2\ Zn + O_2 = 2\ ZnO$$

On the anode side, the reaction in the zinc-air cell is the same as that of the common alkaline battery, wherein zinc, the active anodic material, is converted to zinc-oxide by reaction with hydroxyl ions present in the electrolyte.

On the cathode side, the reaction in both the zinc-air and alkaline batteries involves the reduction of oxygen to create those hydroxyl ions. In the case of the alkaline battery, an oxidizing material (manganese dioxide) is deployed inside the cell to provide the oxygen. The zinc-air cell, on the other hand, employs an air-permeable, hydrophobic, catalytic membrane which extracts oxygen from the atmosphere.

Thus, zinc-air has a weight and volume advantage over most other battery technologies, because one of its two active reagents, i.e., oxygen, adds no weight or volume within the cell. The energy capacity is dependent only on the amount of zinc present in the anode. On the other hand, high power delivery is facilitated by the planar design of the cell, which provides a large electrode surface area relative to cell weight.

Electric Fuel's zinc-air battery attains specific energy that is substantially higher than that of any other disposable battery readily available to the defense and security industries. Specific energy, or energy capacity per unit of weight, translates into longer operating times for battery-powered electronic equipment, and greater portability as well.

While most zinc-air batteries have not historically been known to have high-power capabilities, Electric Fuel has been developing high-power zinc-air cells for more than 10 years, in addition to the high-energy cell used in our military batteries. These cells have been used in applications ranging from heavy-duty electric vehicles to torpedo propulsion. Our mass-produced 4 Ah cell for portable electronics is regularly discharged at current densities (current per unit of active cathode area) four times that of our energy-optimized military battery cell.

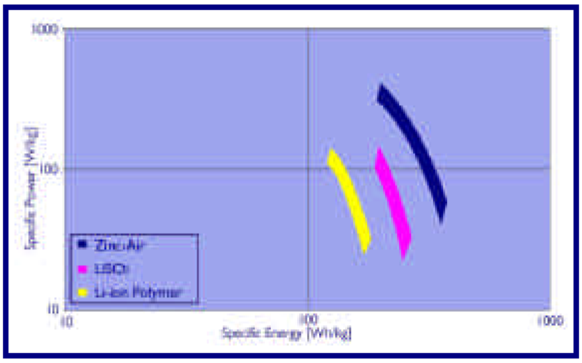
The following table lists some of the characteristics of zinc-air cells that Electric Fuel has developed in the past.

### Table 2. Zinc-Air Performance Characteristics

| Application | Portable power for Consumer electronics | Portable power for military applications | Underwater propulsion |
|---|---|---|---|
| **Cell capacity** | 4 Ah | 30 Ah | 120 Ah |
| **Design current** | 0.2 – 2.0 A | 1.5 – 2.5 A | 100 – 800 A |
| **Cell type** | sealed primary cell | sealed primary cell | plate/gasket fuel cell |
| **Cell structure** | metal | plastic | metal |
| **Air access** | open, diffusion of air | substantially closed, forced air | oxygen overpressure |
| **Zinc type** | gelled thermolytic | gelled thermolytic | compacted electrolytic |
| **Specific energy** | 300 Wh/kg | 400 Wh/kg | 175 Wh/kg |
| **Specific power** | 120 W/kg | 50 W/kg | 500 W/kg |

A “Ragone Plot” comparing typical specific energy and power values for zinc-air and state-of-the-art lithium battery technologies is presented in Figure 1. $LiSO_2$ is a primary (nonrechargeable) battery commonly used in military applications, while lithium-ion polymer batteries are the latest rechargeable batteries available.

### Figure 1. Comparison of Specific Energy and Power




In addition to outstanding performance, zinc-air technology boasts two additional features that make it extremely attractive for military and security use:

- Safety: A zinc-air battery is an inherently safe battery, in storage, transportation, use, and disposal. The danger of fire, explosion or personnel exposure to hazardous materials is lower than in any other battery technology.
- Environment: Zinc-air cells contain no added mercury or other hazardous elements such as lead or cadmium that are often used in batteries, and in fact zinc-air batteries can be disposed of with household trash.

**Safety:** In the event of a short circuit, external or internal, or due to penetration of a conducting object, the cell will discharge at a current limited by the oxygen permeability of the air electrode. The temperature of the cell will rise but there is no fear of thermal runaway or combustion. In addition, exposure of the active anodic material to the environment will also not pose any fire hazard.

**Environmental considerations:** Many battery systems contain materials that are dangerous to the environment. In contrast to commercial zinc-air cells (e.g., for hearing aids) which contain mercury, Electric Fuel is a pioneer in zero-mercury zinc-air cells. Like the chemically similar alkaline batteries, our zinc-air cells are not regulated as to transport and are exempt from dangerous goods regulations. Recycling and any other treatment of the zinc-air cells can thus be accomplished in a process similar to that used for primary alkaline batteries.

### 3. UAV/MAV Zinc-Air Cell Design

Design of a zinc-air cell for UAVs and MAVs had to take into consideration the high power densities required by the respective applications. Table 3 shows the top-level specifications demanded by typical UAV and MAV projects currently under development.

**Table 3. UAV and MAV Development Specifications**

| | UAV development specs | MAV development specs |
|---|---|---|
| ***a. top level specifications:*** | | |
| **Power (initial)** | 300 W | 20 W |
| **Power (cruise)** | 100 W | 20 W |
| **Cruise time** | >2 hours | >30 minutes |
| **Budgeted Weight** | 725 gm (1.6 lb) | 50 gm (1.8 oz) |
| **Voltage** | 24 V | 4 V |
| ***b. calculated values:*** | | |
| **Delivered Energy** | 210 Wh | 10 Wh |
| **Specific energy** | 290 Wh/kg | 200 Wh/kg |
| **Specific power (initial)** | 420 W/kg | 400 W/kg |
| **Specific power (cruise)** | 140 W/kg | 400 W/kg |

In order the meet the very tough requirements of the UAV and MAV applications, the following cell design goals were established:

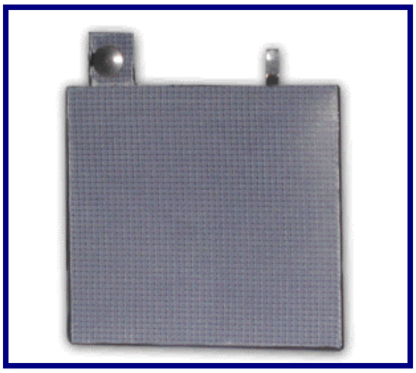
- maximize air electrode area (to achieve and maintain high power)
- develop a uniform, thin anode (to achieve high utilization of zinc at sustained high power)
- minimize parasitic weight, such as cell casing, contacts, etc.

The design of the cell as implemented in laboratory prototypes comprises two air electrodes, a thin anode between the two cathodes, and a lightweight seal around the edges of the cathodes without any actual cell casing. The two air electrodes are connected in parallel, in order to double the current that can be supported by the cell. The arrangement of a cell with two parallel air electrodes is called a "bi-cell".

The size of each bi-cell would be determined by the total power requirements of the application, and the maximum current density capability of the air electrode. On the other hand, the actual shape of each cell, i.e., length and width, would be determined by the physical constraints of a specific platform. Because the cell is thin and flexible, it will ultimately be possible to employ curved cells as part of the vehicle structure, e.g. the fuselage.

A prototype MAV cell is shown in Figure 2. The actual size of this cell is 49 x 49 mm.

**Figure 2. Prototype MAV cell**



### 4. Test Results to Date

Several prototype cells for each application have been built and tested in the laboratory.

In preliminary testing, results are already approaching the weight and time targets at the specified power levels for both MAV and UAV applications. Our results to date are summarized in Table 4.

**Table 4. Performance of Prototype UAV and MAV Cells**

| | UAV cell | MAV cell |
|---|---|---|
| **Dimensions (mm)** | 59 x 65 x 3 | 49 x 49 x 2.5 |
| **Weight** | 30 | 13 |
| **Continuous power (W)** | 4.2 | 5 |
| **Cruise time (hh:mm)** | 1:40 | 0:27.5 |
| **Energy delivered (Wh)** | 7.6 | 2.3 |

Figure 3 below is a graph of cell voltage over time during a constant-power discharge of a MAV prototype cell. Figure 4 below is a graph of cell power over time during a constant-current discharge of a UAV prototype cell. The UAV cell discharge graph starts with the two minutes of high-power for launch.

**Figure 3. Discharge of MAV Cell Prototype**

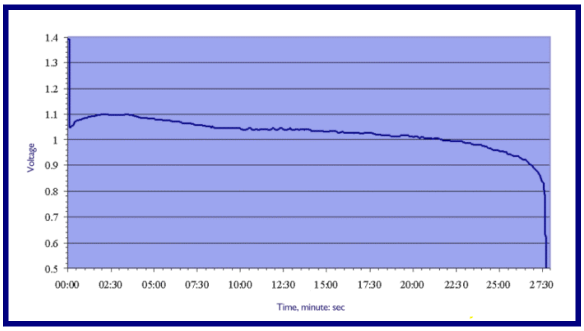
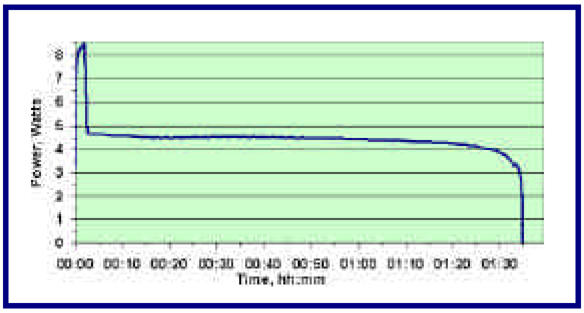
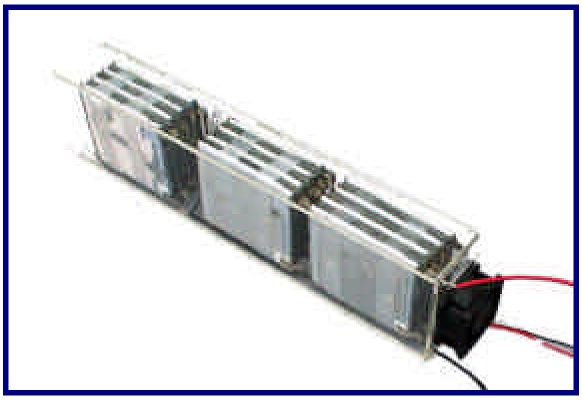



**Figure 4. Discharge of UAV Cell Prototype**




A 21-cell UAV battery was recently assembled and tested on a US Marine Corps Dragon Eye UAV. A photograph of this battery is shown in Figure 5. This first prototype powered the plane for 12% longer than production $LiSo_2$ cells.

**Figure 5. 21-cell Prototype UAV Battery**



### 5. Development Plans

Electric Fuel is currently under contract to demonstrate the feasibility of zinc-air batteries for both UAV and MAV platforms.

Short-term development goals include the optimization and integration of cell components for performance and manufacturability. System-level objectives include refinement of battery envelope design and vehicle interfaces, and actual flight testing.

We anticipate that the first fieldable batteries can be ready in 2004.

### 6. Links

Previous technical papers available at:

http://www.electric-fuel.com/defense/Downloads.shtml

and

http://www.electric-fuel.com/evtech/papers.shtml