Increasing the autonomy of electrical MAV : Design of a new electrochemical generator featuring high specific power and energy

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Abstract

The high energy needed for powering electrical MAVs or UAVs can be obtained by using Aluminium-air Fuel cells, which have a high potential energy density.

Such batteries can reach more than 250 Wh/kg, while lithium-polymer batteries are currently limited to around 160 Wh/kg.

A 100 W prototype is being developed to power small UAVs up to 1000 g.

The technical concepts of the Al/air fuel cell are described and the performances obtained with the first prototypes are discussed.

- This project is co-funded by French Agency DGA / SPNum

Required Power

Electrical Flight requires high power to mass ratios

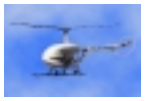
1) For a plane UAV

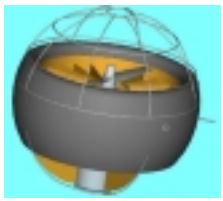
- 80 W/kg for slow horizontal flight
- 100 W/kg for calm flight
- 150 W/kg for acrobatic flight
- 400 W/kg for vertical climbing

(lower ratios can be required for gliders with low wing loads)

2) For an helicopter UAV

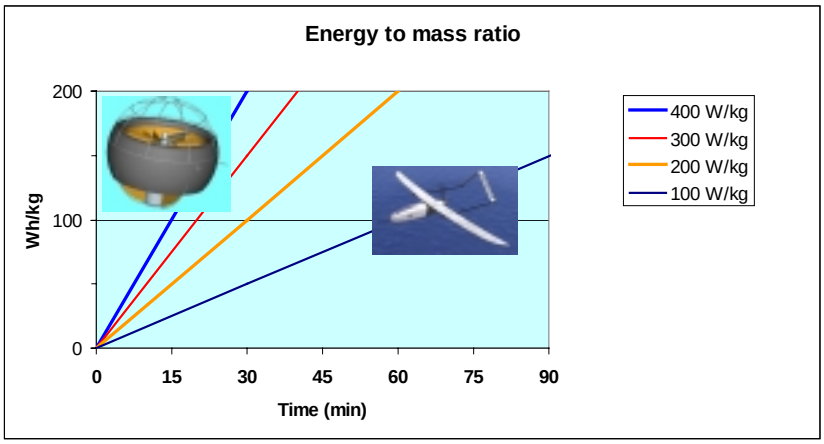
- 320 W/kg for hovering
- 450 W/kg for fast evolution





Required Energy

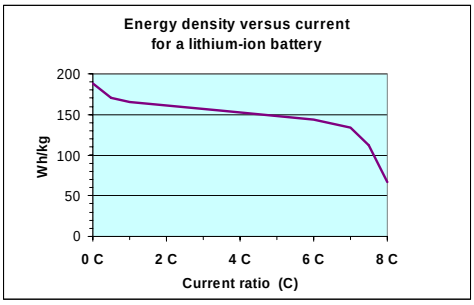
Endurance requires high Energy to mass ratios



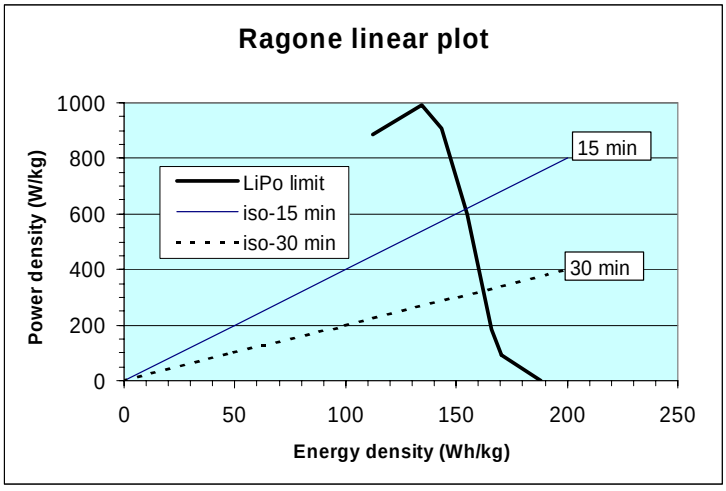
Battery limits

Best available Lithium-Ion batteries provide :

- 180 Wh/kg at very low current
- 160 Wh/kg at 2 C continuous (discharge in 30 min, i.e. 320 W/kg)
- Decreasing to 130 Wh/kg at very high current (5C to 7C continuous)

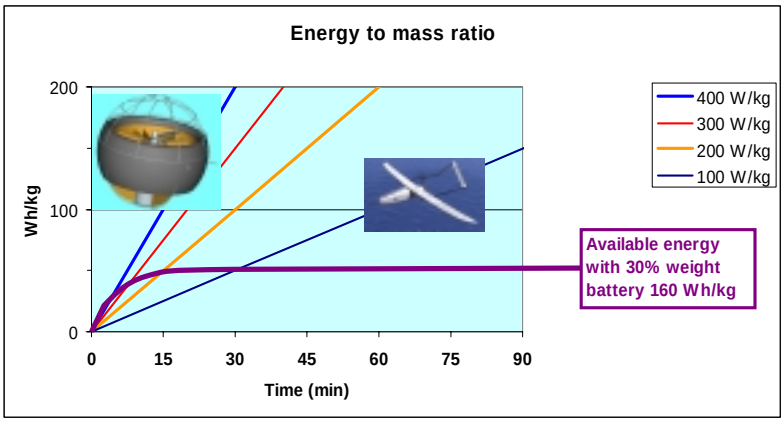


Battery limits



Battery limits

Best LiPo endurance : 5 to 30 min assuming 30%mass battery/UAV ratio

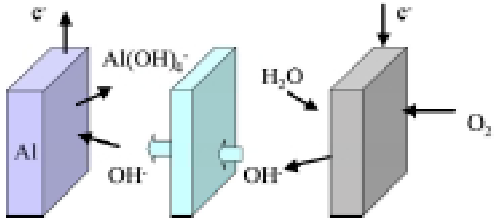


Aluminium-Air Fuel Cell

Alkaline Metal fuel Cell type

Principle

- **Air breathing (cathode side)**
- **Aluminium consumption (anode)**
- **Water consumption (electrolyte)**



Anode (-) Electrolyte Cathode (+)

$$Al + 3/4\ O_2 + 3/2\ H_2O \Rightarrow Al(OH)_3 \qquad (\Delta e° = 2{,}71\ V)$$

Key Issues

- **Corrosion inhibition (H2 parasitic production)**

$$Al + 3\ H_2O \Rightarrow Al(OH)_3 + 3/2\ H_2 \nearrow$$

- **Cathode optimisation (catalyst)**
- **Electrolyte consumption limitation**

Aluminium-Air Fuel Cell

Fuel energy densities

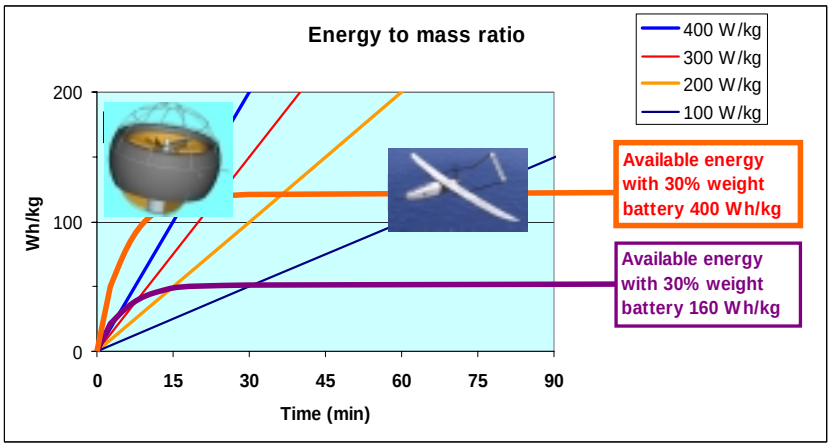
- Theoretical limit for aluminium : 3 Ah/g - 2,7 V
  ➨ 8100 Wh/kg Alu
- Maximal potential 1,6 V, H_2O Consumption 1 kg/kg Alu
  ➨ 2400 Wh/kg fuel [Alu + water]

Fuel Cell Power & Energy densities

- State of the art : Pm = 150 W/kg, Em = 150 Wh/kg
- Possible : Pm = 500 W/kg, Em = 400 Wh/kg

Aluminium-Air Fuel Cell

DROPAC project



Aluminium-Air Fuel Cell

Former Research

- Zaromb cell& US Philco Company (1960) : 500 Wh/kg - 1 A/cm2
- DESPEC (1985) with saline electrolyte (Al/O_2 for submarines) (commercialized by ALUPOWER --> Fuel Cell Tech)
- ALCAN --> Yardner (1989) : 13% efficiency
- Electro-Chem-Technic UK 1997 : small cells for education (No longer available)

Electro-Chem-Technic, Oxford, (UK)

Manufacturers

- Aluminum Power, Inc. (Canada) --> Trimol 2000 800 Wh/kg & 70 mA/cm^2 claimed (No news available)
- Europositron 2003, project of a rechargeable system : 60 kg, 80 kWh (1330 Wh/kg) objectives (no products)

Trimol / Aluminum - Power Inc. Toronto (prototype)

--> No commercially available products

Aluminium-Air Fuel Cell

DROPAC project (CEA + Bertin)

- Power generator for MAV or UAV electrical propulsion
  - Low mass, i.e. high Power density (> 500 W/kg)
  - Surpass chemical batteries (Li-Ion) (>> 160 Wh/kg)
- Performance Objectives
  - 75 W continuous, 100 W maximum power
  - Mass < 200 g
  - Operation time > 30 min

Aluminium-Air Fuel Cell

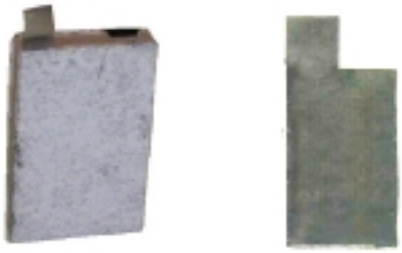
DROPAC prototype n°1 : 9 cm² active surface

- **for basic experiments**

Aluminium-Air Fuel Cell

DROPAC prototype n°2 & 3 : 47 cm² active surface

10 W - 1 V

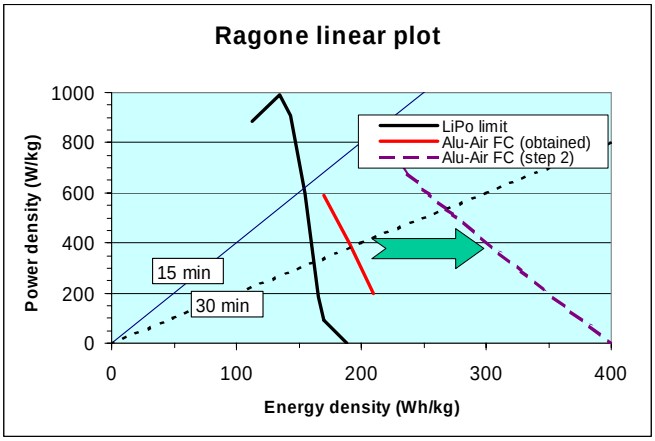


Current achievements :

- **Up to 30 min at 7,5 W, 10 W maximum**
- **Mass 20 g**
- **Power and Energy ratios : 500 W/kg max, ≈ 190 Wh/kg**

Aluminium-Air Fuel Cell

DROPAC prototype achievements and objectives



Aluminium-Air fuel cell

Current development

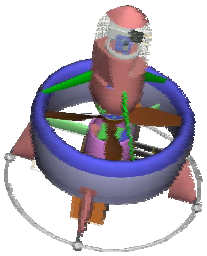
- **Current tests on a complete 10-cells generator (100 W peak), for airborne tests (on a 1 kg model plane)**

- **Laboratory tests for upgraded performances**

Aluminium-Air fuel cell

Future developments

- Reusability (anode + electrolyte change)
- Improve usability (ready-to-use system)



Foreseen applications

- UAV Electrical Propulsion (helicopter or plane types)
- Other systems requesting short duration high power