Trends in UAV Propulsion

Liban Emanuel
Trends in UAV Propulsion
UAV Propulsion Requirements

- Reliability
- High power to weight ratio
- High efficiency in the flight envelope
- Low emission of IR, Radar and Noise signatures
- High Electrical Output for the UAV function and payloads
- Low LCC
- Compliancne to Civil Aviation Regulation
Domain of usage of different propulsion technologies

- **Turbo-Fan**
- **Hybrid Solar**
- **Hybrid (IC & Electrical)**
- **Hybrid (Battery & Electrical)**
- **Internal Combustion Engines**

Payload (Kg) vs. Endurance (Hr) plot showing the domain of usage for different propulsion technologies.
Relative efficiencies of different engines

- Otto
- Diesel
- Turbo-Fan
- Turbo Jet

Thermal Efficiency [%]

Load [%]
# IC Engines Benchmarking

<table>
<thead>
<tr>
<th>Feature</th>
<th>LCC</th>
<th>Noise</th>
<th>MTBF</th>
<th>Life</th>
<th>Fuel consumption</th>
<th>Power to weight Ratio</th>
<th>Weight</th>
<th>Instalation</th>
<th>Simple</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two Stroke (2)</td>
<td>++</td>
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<tr>
<td>Four Stroke</td>
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<tr>
<td>Wankel (1)</td>
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<td>++</td>
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<tr>
<td>Diesel (3)</td>
<td>+++</td>
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</tbody>
</table>

1. Expensive and unique parts  
2. Simple and cheap  
3. Expensive, Excellent SFC & LCC, Heavy  

Legend: ++++ The best
Four Stroke Engine
Two (2) stroke engine
IC Turbo - charging

BMW - Tri Turbo Diesel engine

Volkswagen TSI engine

VanDyne - Turbo compound
Direct Fuel Injection

Very-High pressure fuel system
Valves control (Semi-Atkinson Cycle)

- Active valve opening control (Atkinson cycle)
- Adaptation of thermo-cycle to loads and power needs.
- 5-15% Efficiency gain
Starter - Alternator

- Efficient
- High Power and Moment
- “Built In“ structure
- Reliable
- Enables Hybrid Propulsion
Electric Wheel Drive
IC – UAV Systems

- Heat Exchangers Scoops
- EFI/DFI
- Propellor (Noise & Efficiency)
- Health Monitoring Systems
- Transmission
- Starter Alternator
  1 L.fuel = Kwh
- Shock Mounts
- Fuel and Oil Systems
- Intake system
- Turbo-Charger
- Exhaust System

Kwh = 1 L.fuel
Thermal efficiency of electrical propulsion

Total well to wheel efficiency 26%
**Trends – Electrical propulsion**

- Efficient high-torque electrical motors with power to weight ratio of 8+
- Increased demand for a/c electrical consumption for payloads.
- "Intelligent" control of power sources and usage
- High voltage systems
- Batteries / Fuel cells with power to weigh ratio 300 --- 600 Watts/Kg

![Graph showing trends in electrical propulsion](image-url)
Energy Density - Elec. Drive Vs. IC Engine

**Battery**
- Battery Energy density = 0.2 kwh/kg
- Controller Eff. = 0.9
- Motor eff. = 0.9
- Energy Output: 0.2x0.9x0.9 = 0.16 kwh/kg

**Fuel Tank**
- Fuel Energy Density = 12 kwh/kg
- Efficiency: Otto= 0.3
- Efficiency: Diesel= 0.4
- Energy output:
  - Otto: 12x0.3 = 3.6 kwh/kg
  - Diesel: 12x0.4 = 4.8 kwh/kg

The ratio between Energy density of IC/ Fuel and Elec. Battery/Motor is 20–30 to 1!!
UAV IC / Electrical hybrid

Propellor

Electrical Motor

Controller

Power Control

Data link to/from A/C command

Compressed H2

dry-fuel cartridges

Fuel Cell

Generator

I.CEngine

Battery pack /control

μ=13%, μ=27%, μ=37%

Hydrides

Liquid H2

I.CEngine
Electrical Propulsion

- Laser-- Radiated Energy, HF
  - Very low efficiency (3.5%)
  - "At starting point"

Elec. Motors
- Weight to power ratio 1:8 Hp/Kg
- Efficiency (0.95)
- Axial Flux/ Halbach
System Consideration

- Motor /Propellor optimisation
- Max. Efficiency @ Design point
- Optimal Useage and Control of Energy Sources

- Efficiency
- Noise
- Power

- Power (Max-Nominal)
- Efficiency

- Heat removal

- Power Control
- Residual Energy
- Routing of energy Sources
- Energy Consumption optimisation
Fuel Cells for UAV’s

- **Trends**
  - Hydrogen storage improvements
  - Onboard Hydrogen generation
  - Use of Methanol
  - “Closed loop” water system

- **Advantages**
  - Higher Energy Density than battery
  - “Fuel Tank Concept “

- **Shortcomings**
  - Complexity
  - Price.
  - Technology not yet mature
UAV - Airborne Fuel Cell
Fuel Cells Application

Technologies

- PEM
- Hydrides/PEM
- Methanol DMFC
- Propane /SOFC
Photovoltaic hybrid propulsion
Hybrid Propulsion
PV Propulsion

- High Altitude Application
- Unlimited Time on station
- Technology of PV cells and batteries are not yet mature for this application
Bio Propulsion

Golden Plover UAV

Consumption - 70 gr. of Fat = Fuel
Flight of 4000 km non-stop 88 hrs / 250,000 Wing Flaps

Take-off weight – 200 gr
Landing weight – 130 gr.
Future Trends

Albatros
“Bio” - Propulsion

We try to understand and learn?

Low Reynolds Aerodynamics
Airfoils
Materials
Smart structures
Summary of trends IC Engines

- I.C Engines will continue to dominate UAV Propulsion due to the high energy density/content of the HydrocarbonFuel.
- UAV Engines benefit from the developments in Automotive Industries.
- More and more UAV’S will require Heavy Fuel capability.
Summary of trends Electrical Propulsion

- “Break Through” in Energy capacity and power to weight ratio of batteries is needed.
- The portable I.T. devices as well as automotive applications are taking the lead.
- Usage for small UAV’S with limited flight duration.
- Important achievements in Electrical Motors and Generators.
Summary of trends Fuel Cells

- Promising technology with higher energy density than batteries (600 wh/kg. and up)
- Bottled high pressure hydrogen with PM are practical solution for small long-range UAV’S.
- Cryogene-hydrogen systems can increase range and payload.
- Other Fuel-Cell systems are complex and require considerable effort to mature and to reach reliability.
- In next year or two we shall see Automotive Fuel cells on the market and maybe these technologies can be used in UAV propulsion.
Summary of trends - Photovoltaic Propulsion

Need further advances in:

- Lighter structures.
- Lighter and higher efficiency of P.V cells.
- Batteries or Fuel-Cells back-up need much higher power density.
- Flexible wing flight controls.
- Efficient Low-speed Propellers.
Summary of trends Hybrid Systems (I.C and Electrical)

- Important load fluctuations.
- Big difference between the requirement for duration of High-Power (T.O) and the cruise power.
- The A/C design and structure dictates distributed electrical propulsion.
- Automotive Industry is leading.
The dream
Summary

We still have a lot to learn …

Thank You