HTS Machines for Applications in All-Electric Aircraft

Philippe Masson
Cesar Luongo

FAMU/FSU College of Engineering
Center for Advanced Power Systems
Tallahassee, FL
Outline

- Motivation
- UAPT Project
- More/All-Electric Aircraft
- Applications and design examples
- System Approach
- Examples of electrical system sizing
- Conclusion
Motivation: Environment Preservation

- Need to develop environmentally friendly transportation systems (emissions and noise)
- Electrical energy is very attractive
- Need to design high power density electrical components

Objective:

Revolutionize Aviation

- Increase Safety
- Reduce Emissions
- Reduce Noise
- Increase Capacity
- Increase Mobility
URETI on Aeropropulsion and Power Technology

Aerospace Design Laboratory (ASDL) @ GATech
Revolutionary Concepts, Architectures & Technology

GATech Research Institute
Solid Oxide Fuel Cells

Florida A&M University / Center for Advance Power Systems
Integrated Power Management
High Power Density Superconducting Motors

Aircraft Design & Modeling
Development of high power density fuel cells

Electrical Network simulation
Superconducting motor design

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UAPT HTS Machine Development

HTS Motor Design
- General Aviation
- HALE ROA
- Small Jet

HTS Motor Sizing Model

All-Electric Aircraft Propulsion

System Studies
Towards Electric Aircraft Propulsion

Allows the inter-connected issues of noise, emissions and energy to be addressed simultaneously

Challenges: power density of electric motors and aircraft design with new technology
Modern All-Electric Aircraft Subsystems

- Thrust Generation
- Fuel System
- Fault Tolerant Electrical Power Distribution System
- Electrical Power Generation
- Electric Drive Accessories
- Environmental Control System
- Engine Accessories
- Electric Anti-Ice
- Electric Actuated Brakes
- Electric Actuation

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**Electrical “gear box” concept**

**Turbo-generator motor drive**

- Turbine main shaft speed not limited by fan (better efficiency)
- Redundancy should improve reliability
- Better control of thrust generation
- More flexibility in the turbine location

Need high power density electric machines: HTS technology is an obvious choice
What “Fuel”/ Energy Storage?

- Liquid hydrogen exhibit the highest energy density
- Hydrogen can feed fuel cells or gas turbines
- Storage temperature is ideal for HTS material

Cryogenic machines represent the best solution and a good synergy
• Liquid Hydrogen (LH2) powered aircraft
• Hydrogen cryogenically stored
• Power generated by fuel cells or turbo-generators

Electrical “gear box” concept
• Latest engines have very high bypass ratios
• Most of the thrust comes from fan rotation
• Replacing gas turbine by electrical motor should be possible
Cryogenic and HTS Motors

- Cryogenic copper wound motors could work
- HTS machines would provide better efficiency and lower weight and volume
UAPT Designs for Electric Ducted Fan Application

Small Jet
1.5 MW @ 3000 RPM
Flux trapping and concentration
Bi2223 coils and YBCO TFM

HALE – Hurricane tracker
14 day mission
450 kW @ 3000 RPM
Axial flux configuration
Trapped flux magnets (YBCO)
Power Generation: Fuel cells or Turbo-generator?

- **Fuel cells**
  - No emissions (NOx and CO2)
  - Power density around 1 kW/kg (SOFC)
  - Low efficiency balance of plant
  - Efficiency ~ 55%
  - Too heavy for large aircraft

- **Turbo-generators**
  - Reduces emissions (high RPM)
  - High power density
  - Low efficiency (~30%)

- **Hybrid systems may be a solution (heat recuperation)**
Superconducting turbo generators

- Requires:
  - development of high RPM HTS machines
  - Robust thermal insulation between gas turbine (1000C) and HTS generator (-250C)
- Stationary HTS excitation coils are preferred to allow for high RPM (> 10 kRPM) such as HIA or Supersat configurations

Example of axial flux “supersat” configuration
Example of Actuators: HTS/PM linear Motor

**Application:** Nose Landing Gear

\[
\begin{align*}
\text{Model} & \quad \text{Electrical Actuator} \\
\vec{R} & \quad \text{Wheel} \\
\vec{P} & \quad \text{Stem}
\end{align*}
\]

\[\begin{cases}
\text{Weight} = 1000 \text{kg} \\
\text{Length} = 1 \text{m}
\end{cases}\]

Conventional copper windings
Rare earth permanent magnet

YBCO coated conductors
Operating temperature 77K (LN2)
Rare earth permanent magnet excitation

\[
\frac{\text{Volume}_{\text{Conventional}}}{\text{Volume}_{\text{Superconducting}}} \approx 5.97
\]

\[
\frac{\text{Weight}_{\text{Conventional}}}{\text{Weight}_{\text{Superconducting}}} \approx 8.77
\]
• Weight and volume of power converters and drive have to be maximized for airborne applications
• Off the shelf components exhibit ~ 11 kW/kg power density
• Weight can be decreased by modifying power quality (harmonics filtering)
• Cryocooling should generate a three fold increase of power density
• Reliability needs to be increased
System Approach / Reliability

- 100% of power is only needed during take off
- Propulsion requires ~50-70% of take off power during cruise
- Redundancy of components can lead to improved efficiency
- Different configurations possible
## Sizing Examples

### Electric System Sizing for All-Electric Boeing 737-200

<table>
<thead>
<tr>
<th>System</th>
<th>Weight (kg)</th>
<th>Volume (dm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propulsion (motors)</td>
<td>1346</td>
<td>2149</td>
</tr>
<tr>
<td>PMAD (converters, busses)</td>
<td>960 (300)</td>
<td>960 (300)</td>
</tr>
<tr>
<td>Power plant (turbo-generator)</td>
<td>920</td>
<td>588</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>3226 (2566)</strong></td>
<td><strong>3697 (3037)</strong></td>
</tr>
</tbody>
</table>

**Boeing 737-200**  
- Thrust: 17 400 lb.t.  
- Weight: 3 495 lb = 1585 kg  
- Volume: 2 459 dm³

### Electric System Sizing for All-Electric UAV (Global Hawk)

<table>
<thead>
<tr>
<th>System</th>
<th>Weight (kg)</th>
<th>Volume (dm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propulsion (motors)</td>
<td>717</td>
<td>2594</td>
</tr>
<tr>
<td>PMAD (converters, busses)</td>
<td>690 (220)</td>
<td>690 (220)</td>
</tr>
<tr>
<td>Power plant (turbo-generator)</td>
<td>463</td>
<td>460</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1870 (1400)</strong></td>
<td><strong>3744 (3274)</strong></td>
</tr>
</tbody>
</table>

**Global Hawk:**  
- Thrust: 8 917 lb.t.  
- Weight: 1 581 lb = 717 kg  
- Volume: 2 594 dm³
Available Technology

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**Conclusion**

- HTS machines can be designed to match the power density of gas turbines.
- Many different topologies to fit different applications.
- Liquid hydrogen as fuel and HTS components are in good synergy.
- Hydrogen cooling should enable the use of fully superconducting motors ("free cooling system").
- HTS is an enabling technology for all-electric aircraft propulsion.