Power Engineering Society General Meeting 2007

HTS Machines for Applications in All-Electric Aircraft

Philippe Masson
Cesar Luongo

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

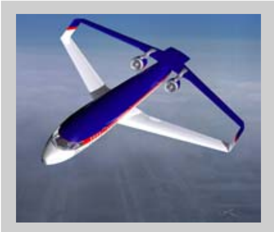
Outline

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

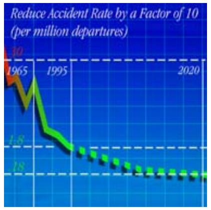
Motivation: Environment Preservation

- 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

All-Electric Aircraft

Aircraft Design & Optimization

AeroSpace Design Laboratory (ASDL) @ GATech

Revolutionary Concepts, Architectures & Technology

Power Generation

GATech Research Institute

Solid Oxide Fuel Cells

Power Management & Electric Propulsion /Actuation

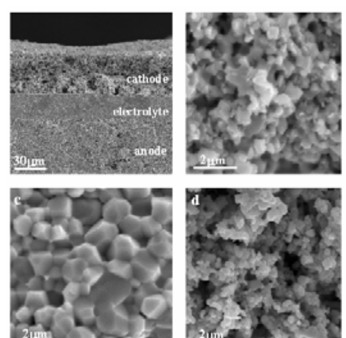
Florida A&M University / Center for Advance Power Systems

Integrated Power Management

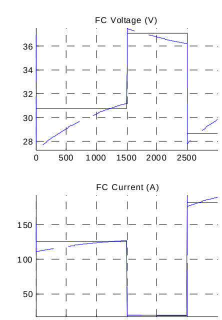
High Power Density Superconducting Motors

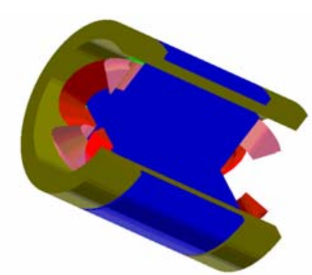
Aircraft Design & Modeling

Development of high power density fuel cells



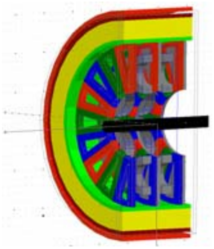
Electrical Network simulation Superconducting motor design

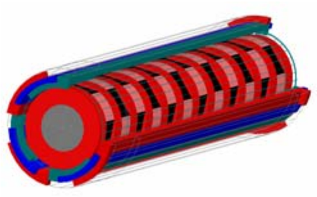


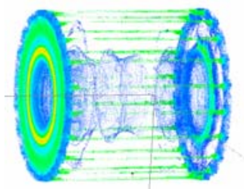


UAPT HTS Machine Development

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

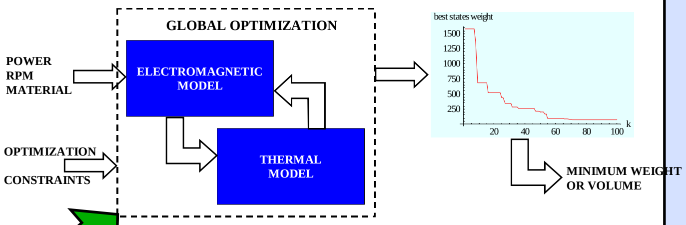




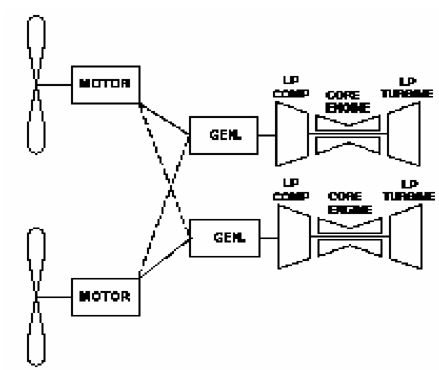


All-Electric Aircraft Propulsion

HTS Motor Sizing Model

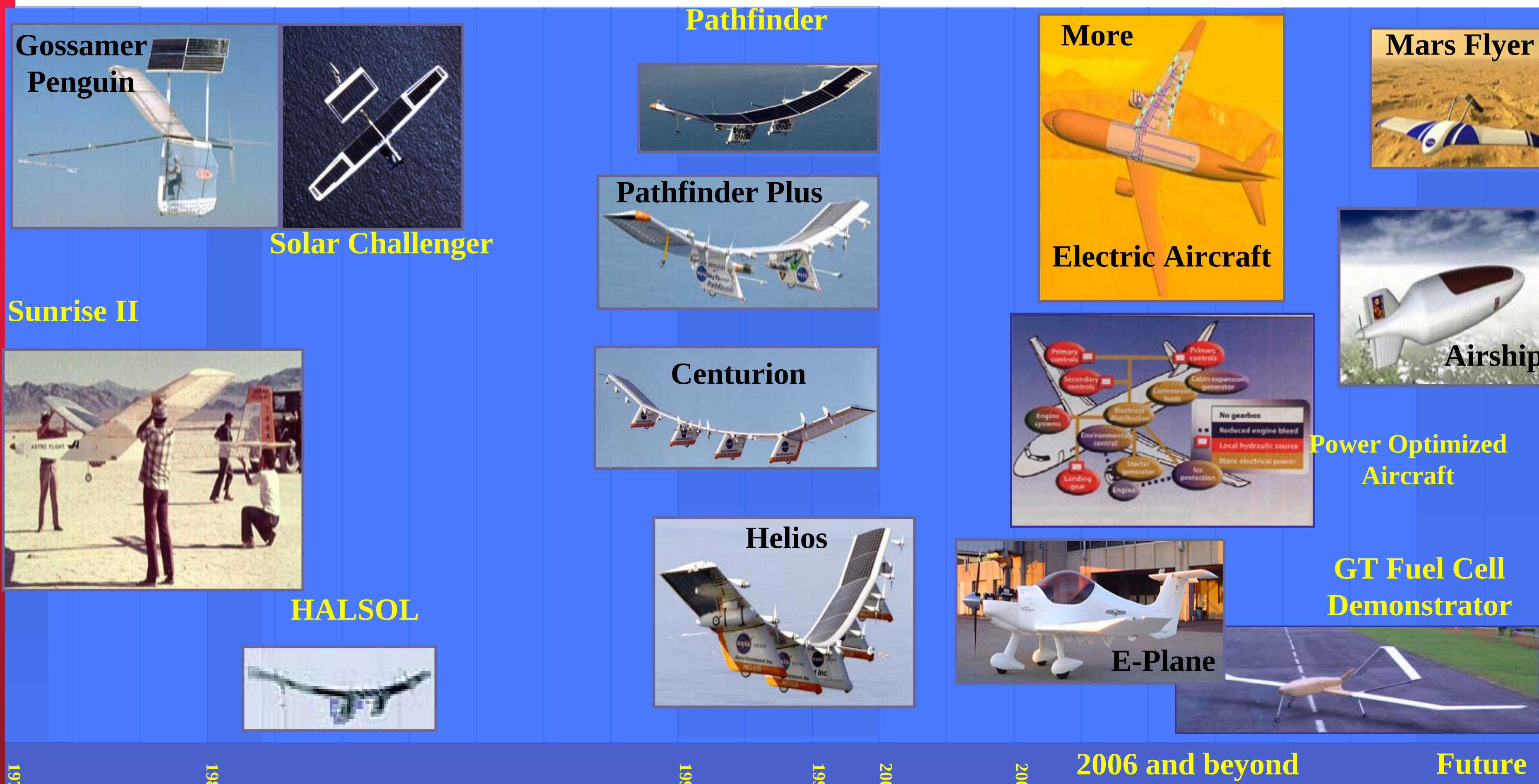


System Studies



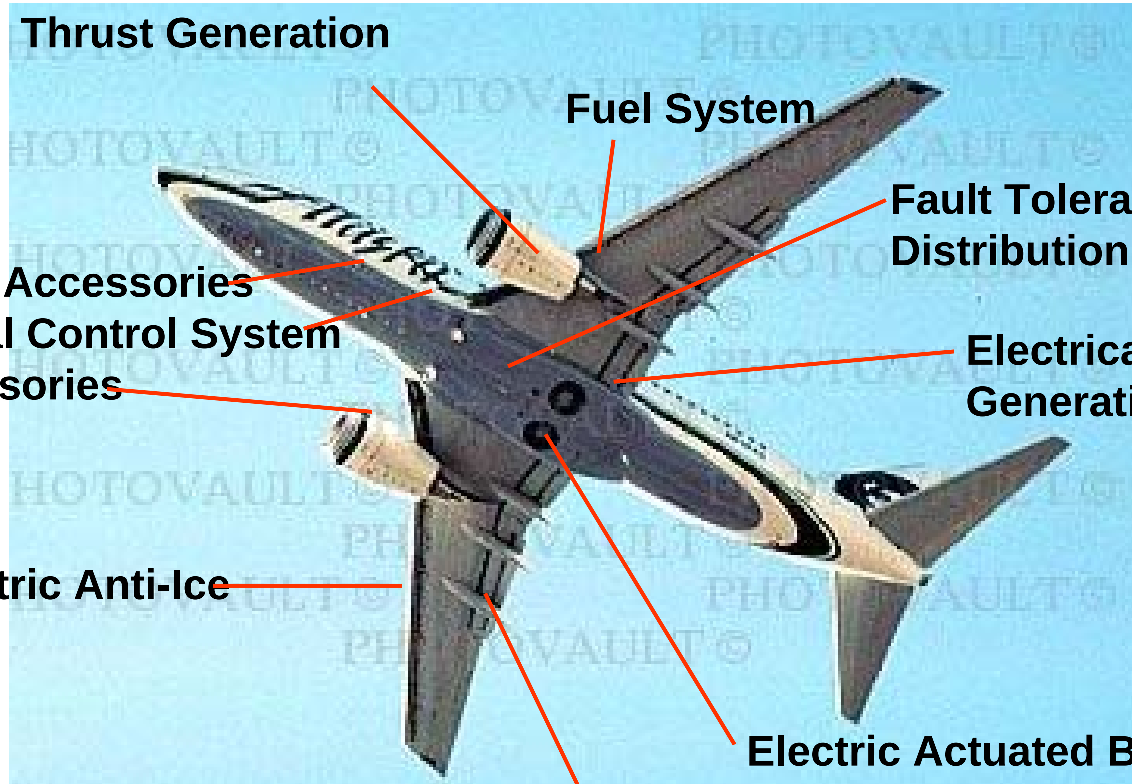
Towards Electric Aircraft Propulsion

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



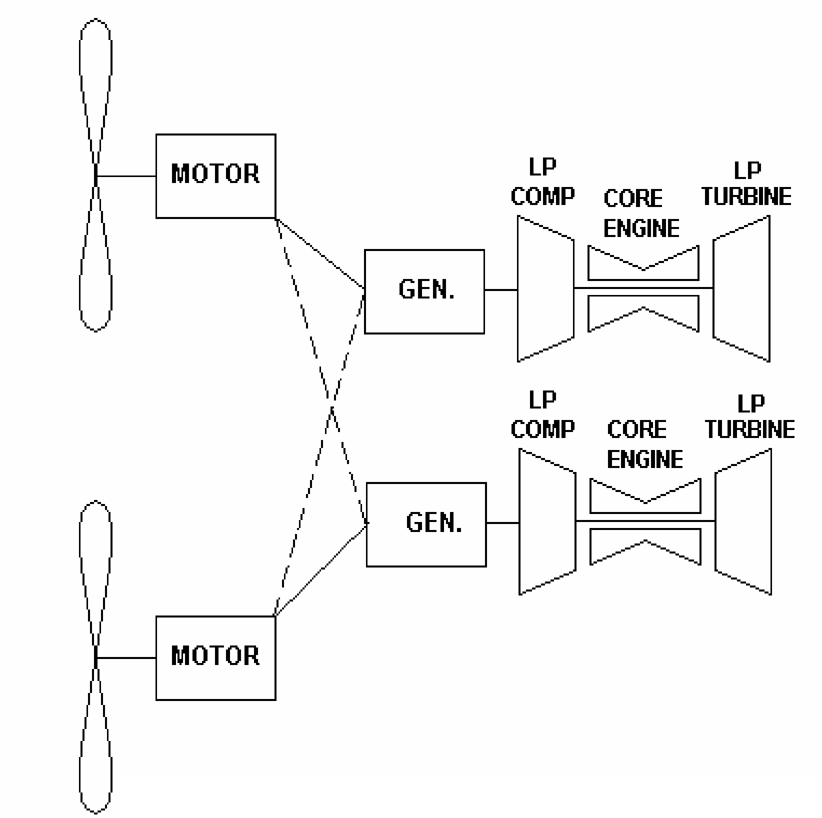
Challenges: power density of electric motors and aircraft design with new technology

Modern All-Electric Aircraft Subsystems



BOEING

Electrical "gear box" concept



Electrical "gear box" concept

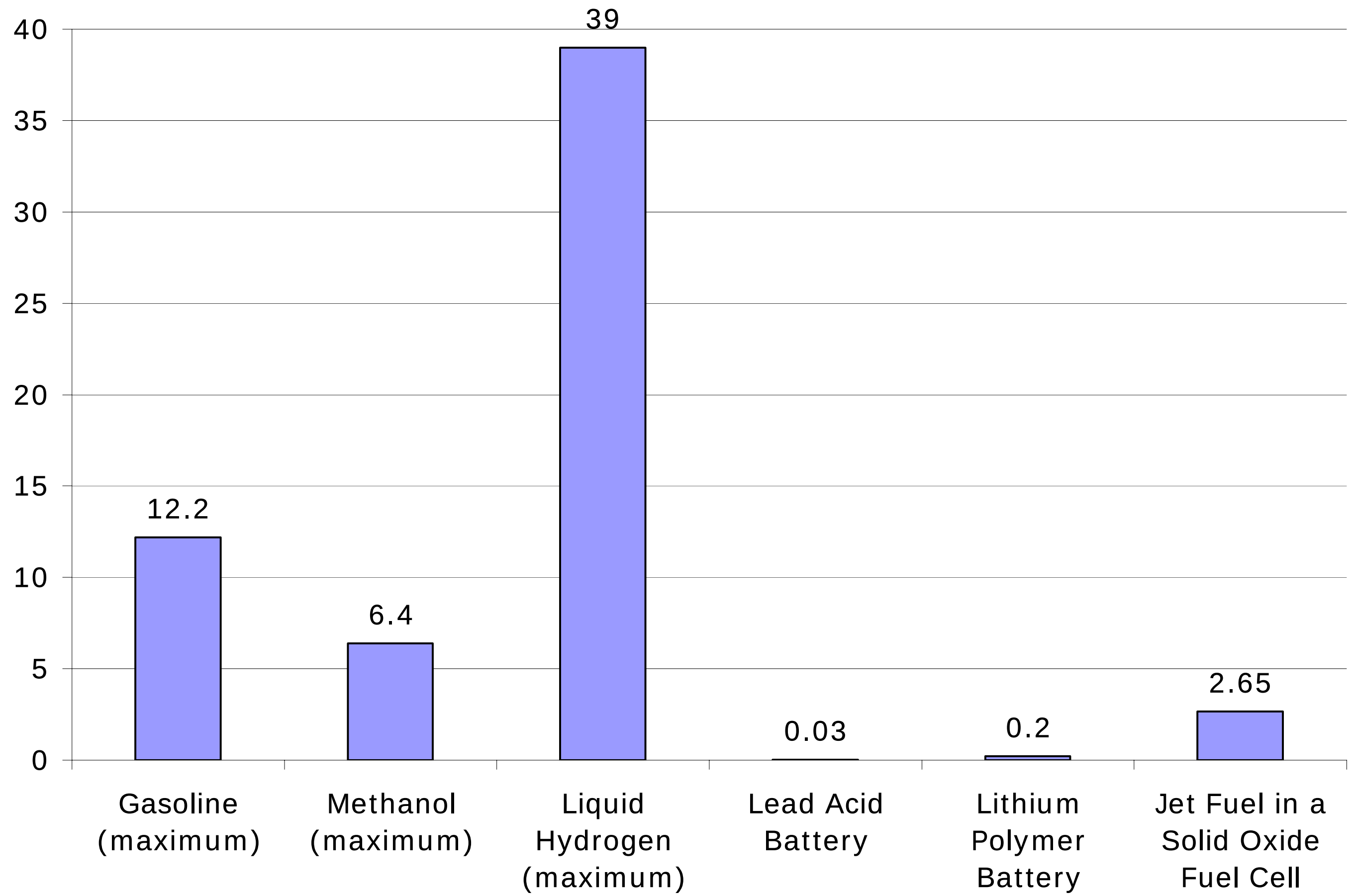
Turbo-generator motor drive

- 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?

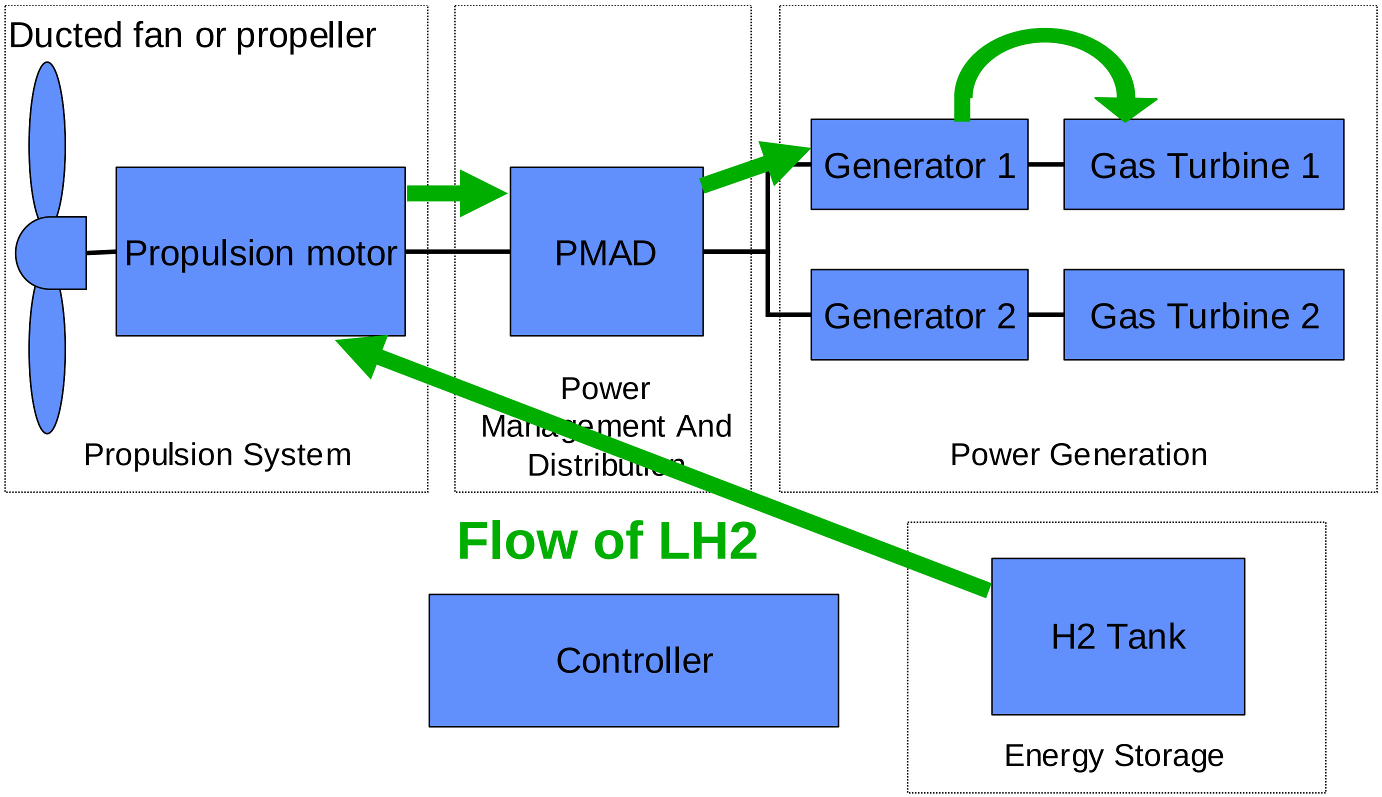
- Liquid hydrogen exhibit the highest energy density
- Hydrogen can feed fuel cells or gas turbines
- Storage temperature is ideal for HTS material



Cryogenic machines represent the best solution and a good synergy

LH2 Powered Aircraft

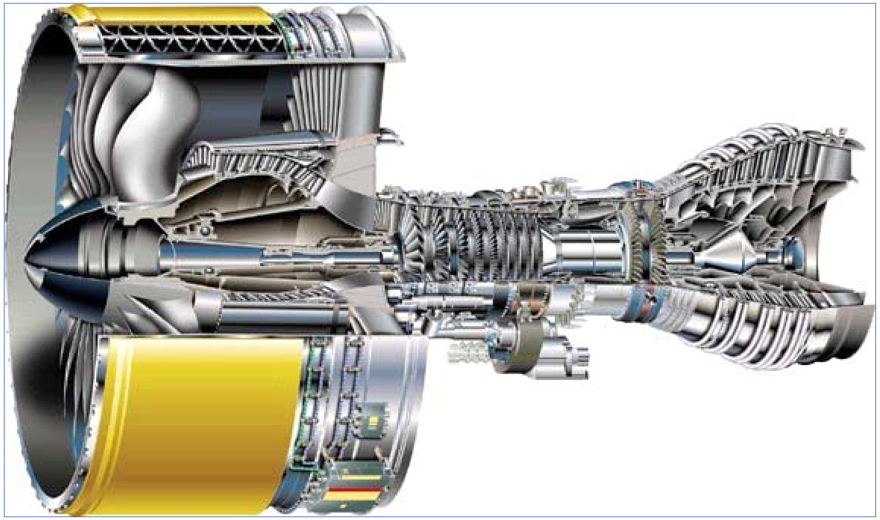
- Liquid Hydrogen (LH2) powered aircraft
- Hydrogen cryogenically stored
- Power generated by fuel cells or turbo-generators



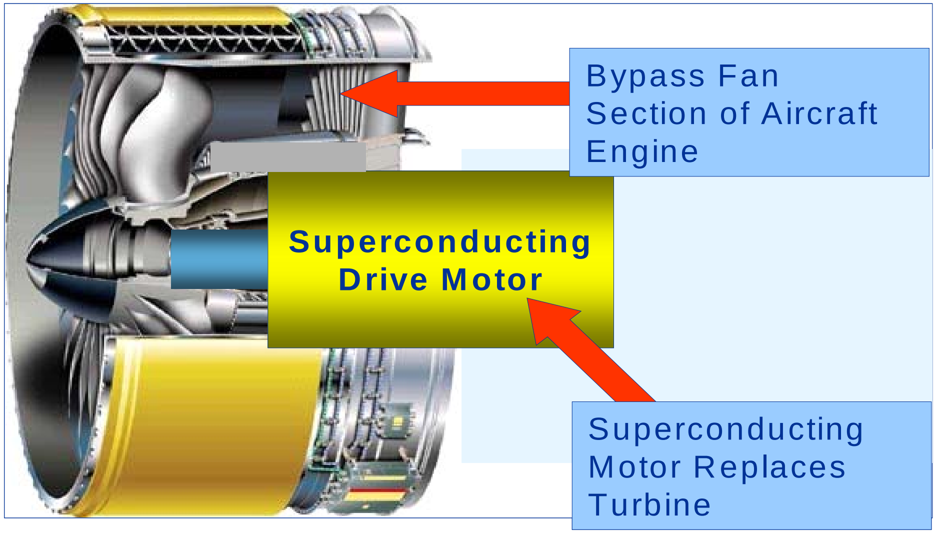
Electrical "gear box" concept

Electrical Ducted Fan / Thrust Generation

- Latest engines have very high bypass ratios
- Most of the thrust comes from fan rotation
- Replacing gas turbine by electrical motor should be possible

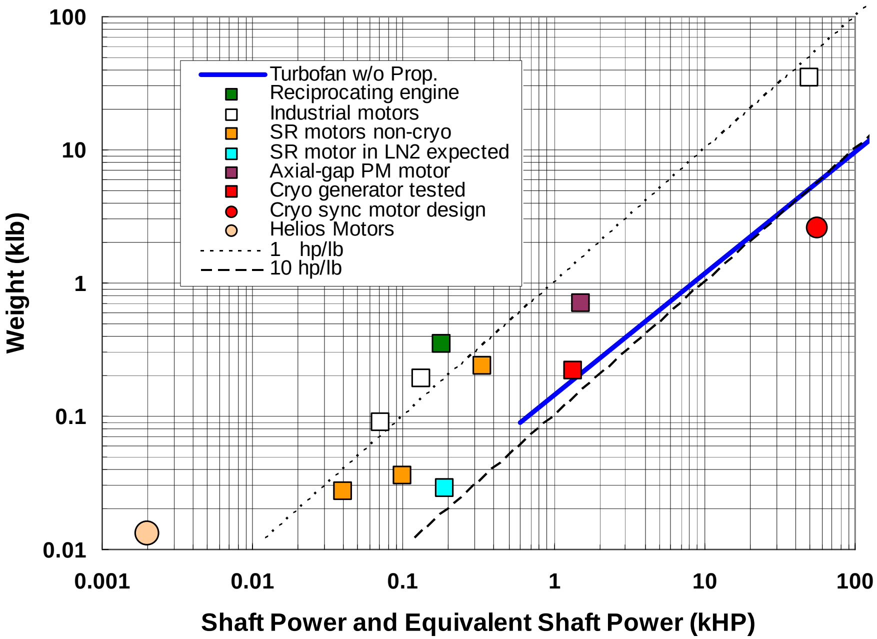


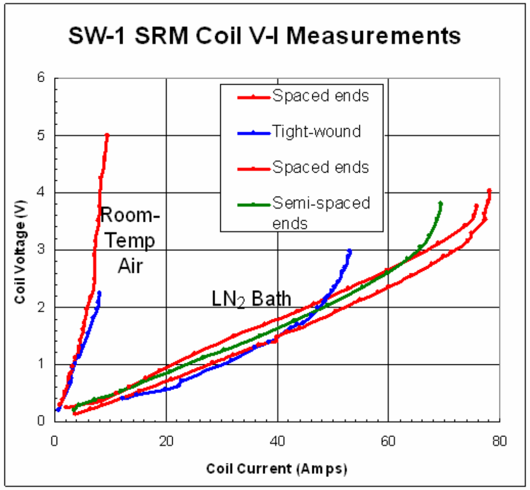
High bypass turbofan



Electrical Ducted Fan

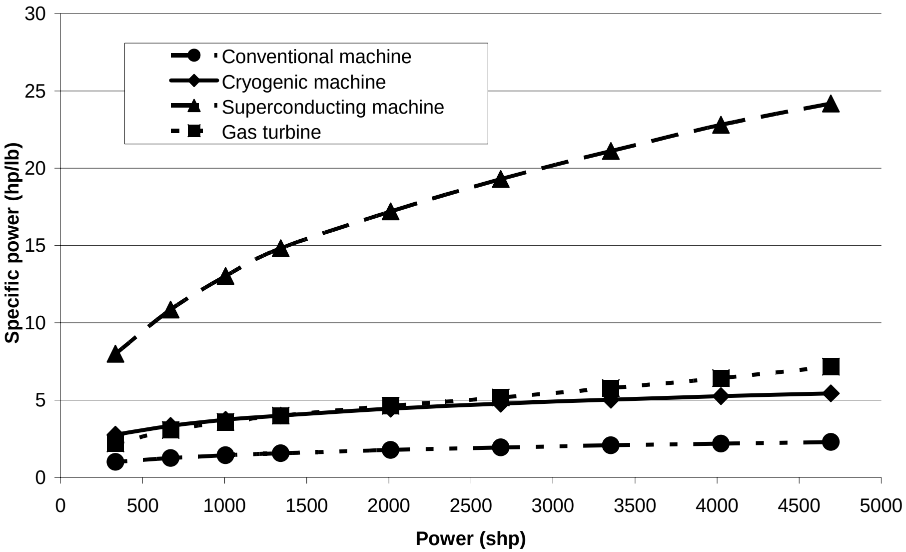
Cryogenic and HTS Motors





Improved heat transfer copper coils for cryogenic machines

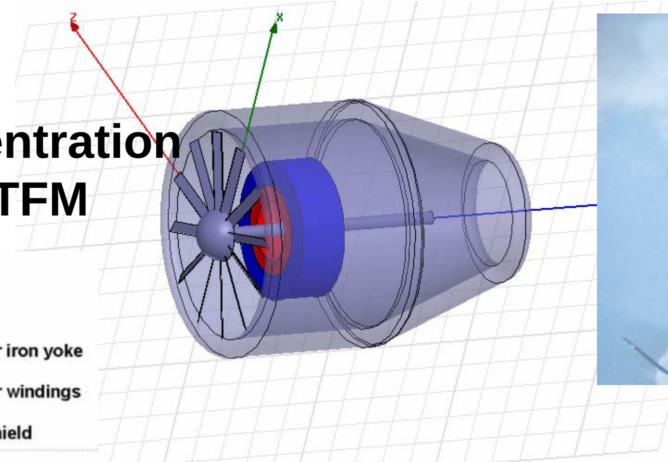
- Cryogenic copper wound motors could work
- HTS machines would provide better efficiency and lower weight and volume

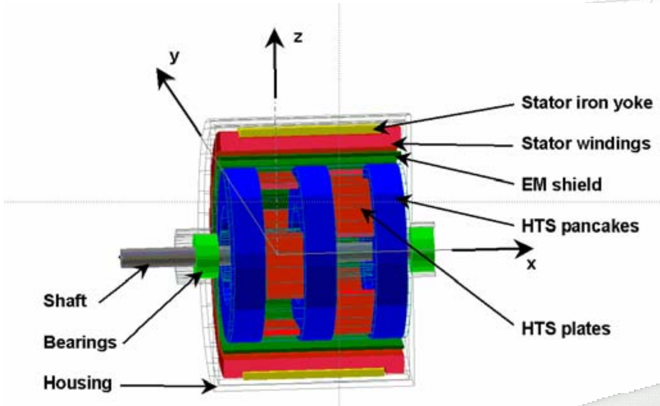


Model predictions

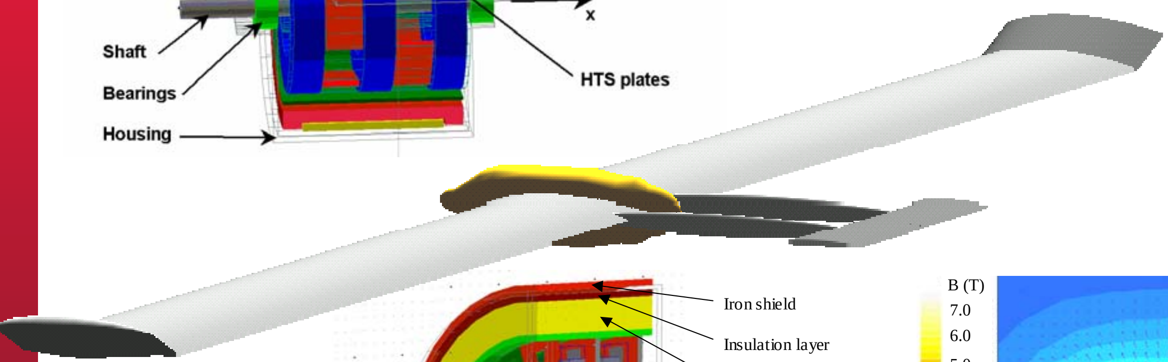
UAPT Designs for Electric Ducted Fan Application

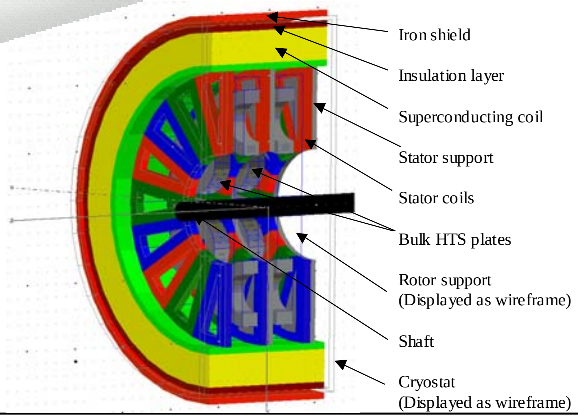
Small Jet
1.5 MW @ 3000 RPM
Flux trapping and concentration
Bi2223 coils and YBCO TFM

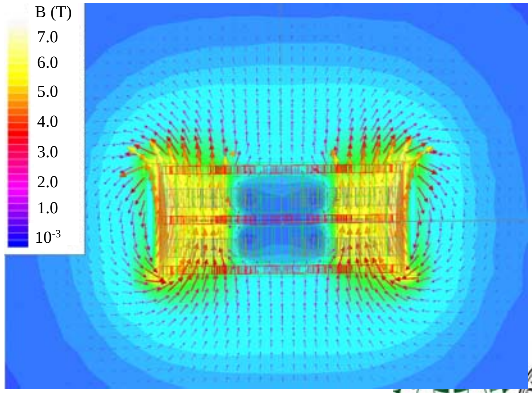




HALE – Hurricane tracker
14 day mission
450 kW @ 3000 RPM
Axial flux configuration
Trapped flux magnets (YBCO)

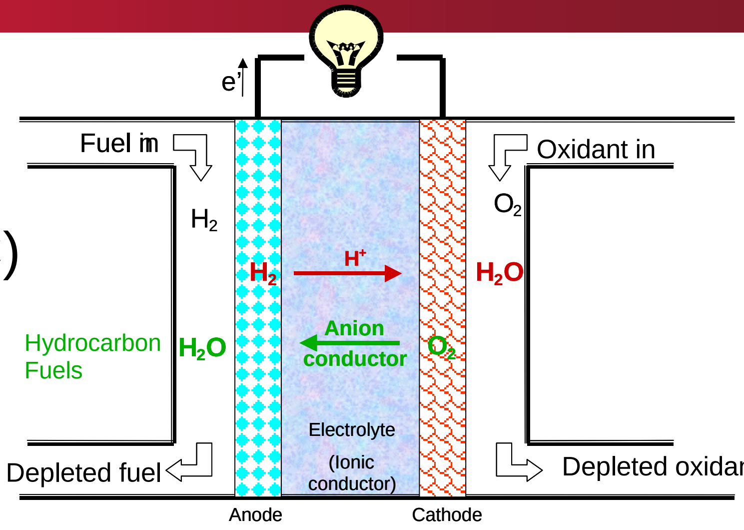




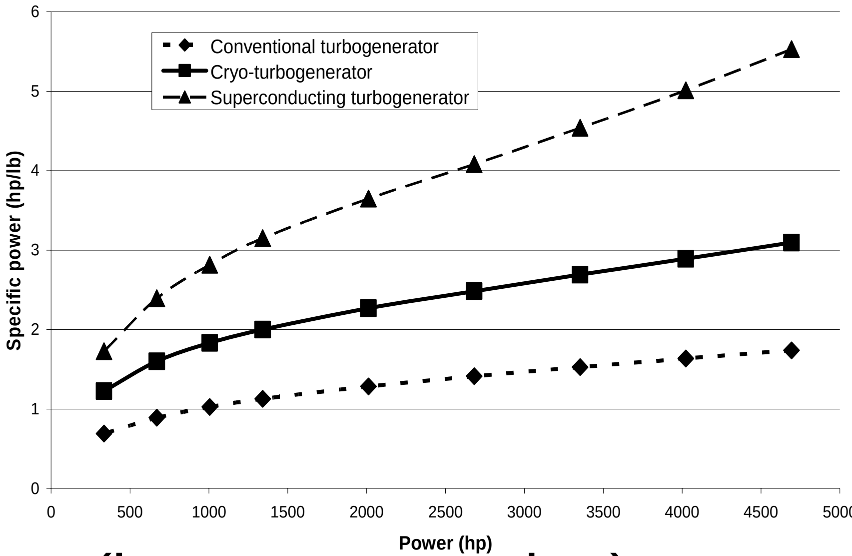


Power Generation: Fuel cells or Turbo-generator?

- 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



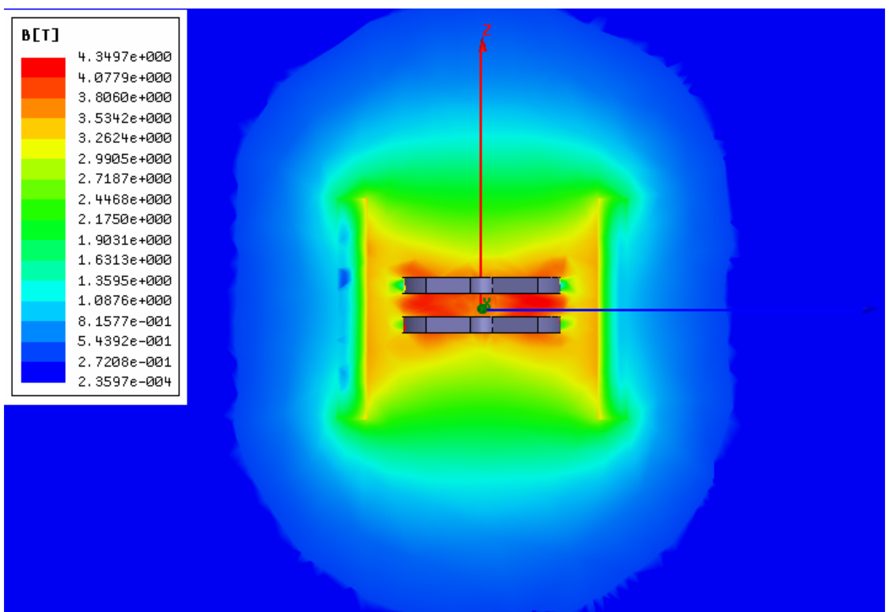
- Turbo-generators
  - Reduces emissions (high RPM)
  - High power density
  - Low efficiency (~30%)



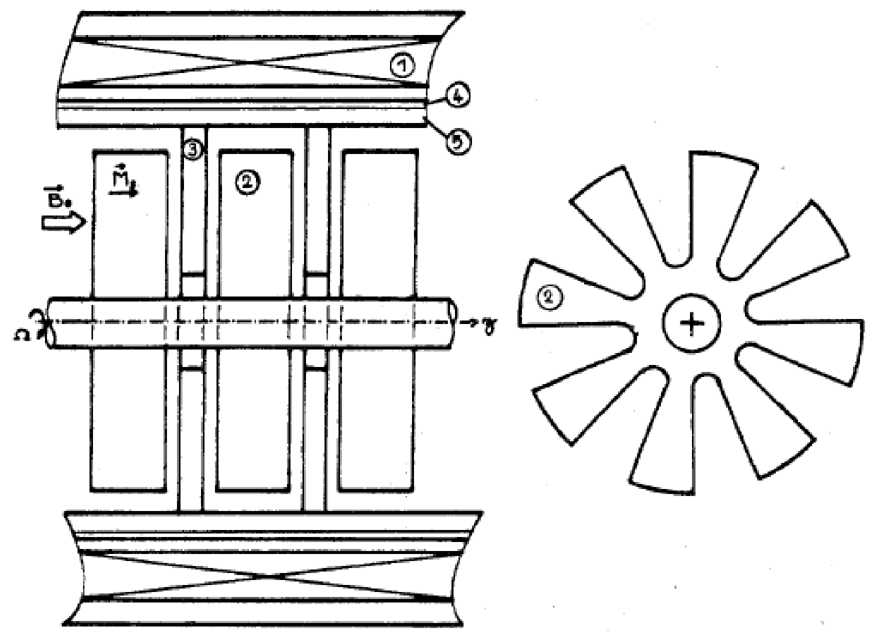
- Hybrid systems may be a solution (heat recuperation)

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



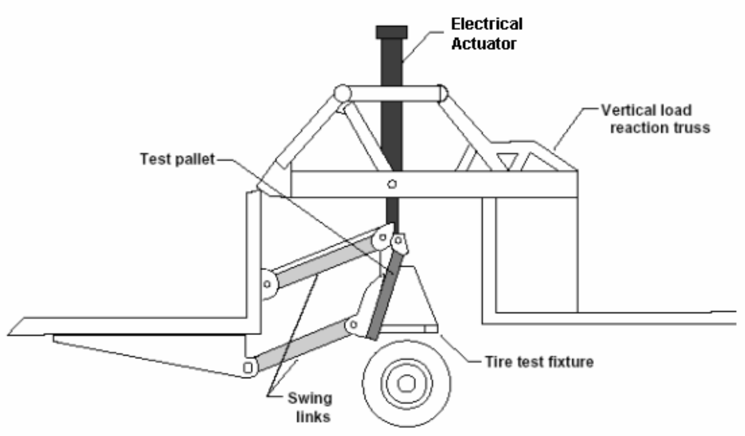
Example of axial flux "supersat" configuration



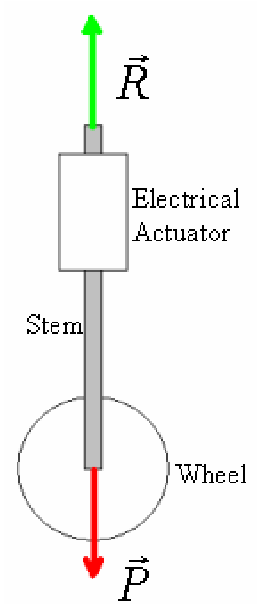
(a) (b)

Example of Actuators: HTS/PM linear Motor

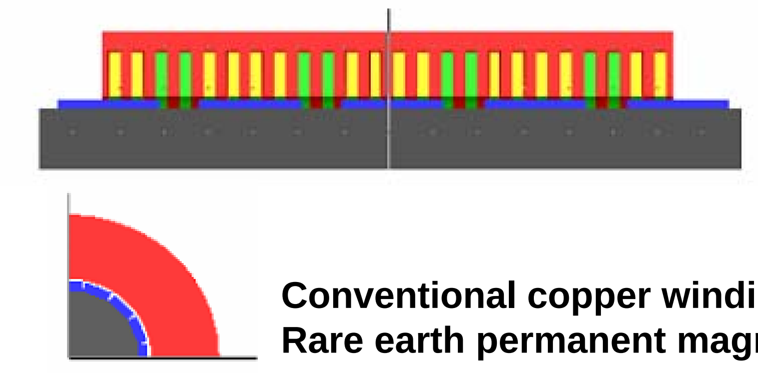
Application: Nose Landing Gear



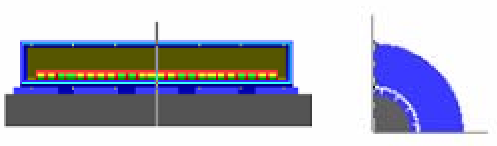
Model



$$\begin{cases} Weight = 1000kg \\ Length = 1m \end{cases}$$



Conventional copper windings
Rare earth permanent magnet



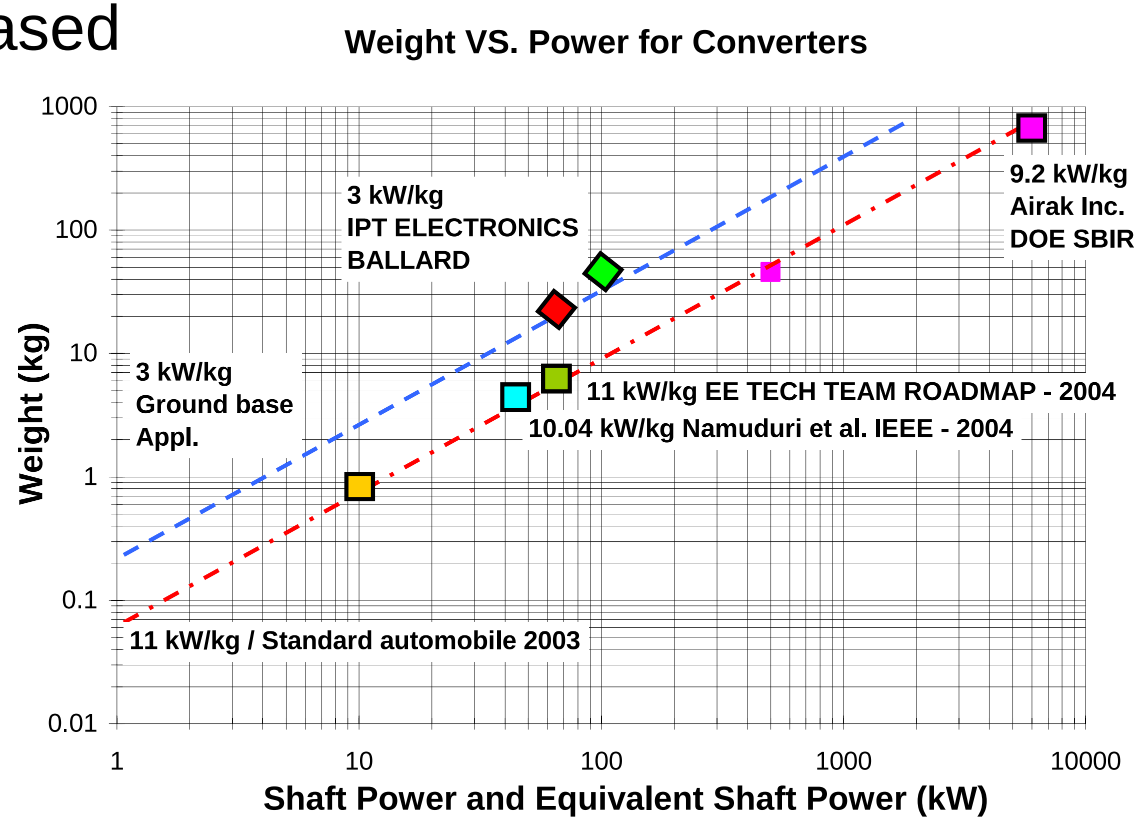
YBCO coated conductors
Operating temperature 77K (LN2)
Rare earth permanent magnet excitation

$$\frac{Volume_{Conventional}}{Volume_{Superconducting}} \approx 5.97$$

$$\frac{Weight_{Conventional}}{Weight_{Superconducting}} \approx 8.77$$

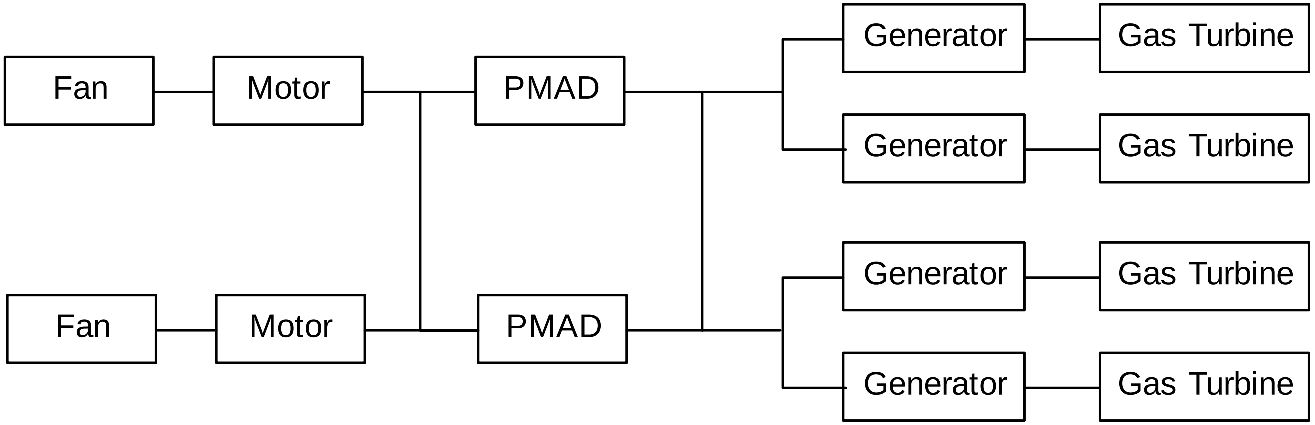
Power Management and Distribution

- 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 UAV (GLOBAL HAWK)

System	Weight (kg)	Volume (dm^3)
Propulsion (motors)	717	2594
PMAD (converters, busses)	690 (220)	690 (220)
Power plant (turbo-generator)	463	460
Total	**1870 (1400)**	**3744 (3274)**

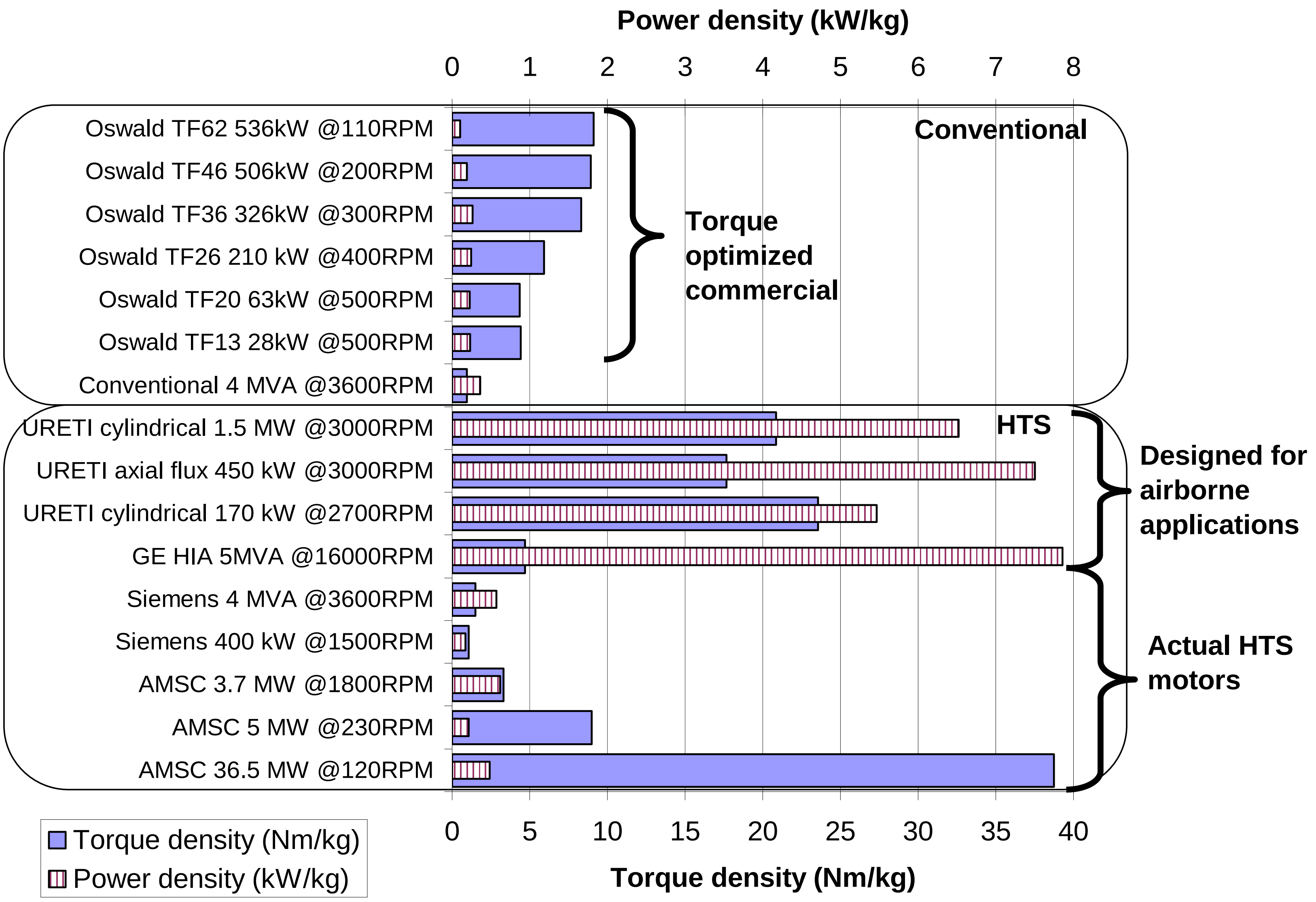
<u>Global Hawk:</u>
Thrust: 8 917 lb.t.
Weight: 1 581 lb = 717 kg
Volume: 2 594 dm3

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

ELECTRIC SYSTEM SIZING FOR ALL-ELECTRIC BOEING 737-200

System	Weight (kg)	Volume (dm^3)
Propulsion (motors)	1346	2149
PMAD (converters, busses)	960 (300)	960 (300)
Power plant (turbo-generator)	920	588
Total	**3226 (2566)**	**3697 (3037)**

Available Technology



Conclusion

- HTS machines can be design to match power density of gas turbine
- 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