HTS Motors in Aircraft Propulsion: Design Considerations

Philippe Masson
Jules Pienkos
Cesar Luongo
FAMU/FSU College of Engineering
Center for Advanced Power Systems

Danielle Soban
Eric Upton
Aerospace System Design Laboratory, GATech

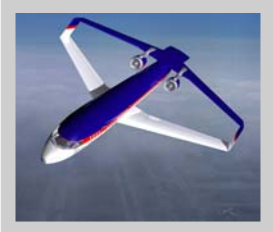
Outline

- Introduction
- Aircraft design
- Electrical propulsion for aircraft
- Scaling model for electrical propulsion
  - HTS motor
  - Cryocooling
- Test case: Cessna 172
- Conclusion

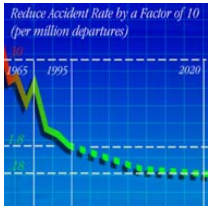
Introduction

- Need to develop environment friendly transportation systems
- Electrical energy is very attractive
- Need to develop new design methods for electrical vehicle

Objective :



Revolutionize Aviation



Increase Safety

Reduce Emissions

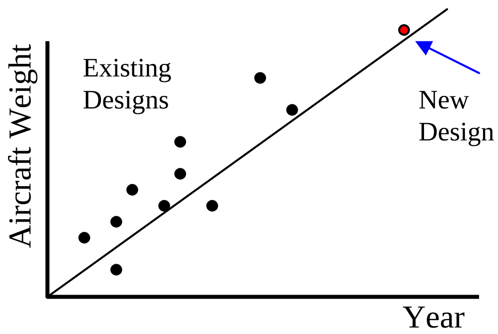
Reduce Noise

Increase Capacity

Increase Mobility

Aircraft Design

Historically, aircraft have been designed using extrapolations of regressed data:



This methodology works well if new designs are similar to prior designs. For example, the evolution of most commercial airliners build upon small improvements over the previous generation of airliners.

Revolutionary designs, however, have no historical database to draw upon, making design by extrapolation impossible.

Modern design methods address the design of revolutionary vehicles through increased reliance on physics-based modeling, made possible through rapid increases in computational capabilities

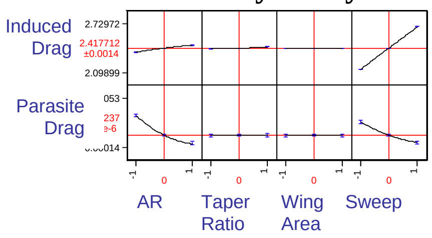
Notional Design

Technologies

Probabilistic and Statistical Techniques

Physics-Based Modeling and Simulation

Sensitivity Analysis



Impact of Technologies

Risk

Uncertainty

Impact of Propulsion Technology

Traditionally, revolutionary advances in propulsion technology have lead to revolutionary leaps in aircraft design

Propulsion Technology	Early Piston/ Propeller	Mature Piston/ Propeller	Early Turbojets	Modern Turbofans
Aircraft Design	Wood/Cloth Biplanes	Monoplanes WWII	First Big Commercial Jets	Current Commercial Jets
Aircraft Capability	Short Distances Small Loads	Effective but Expensive	Expensive Fast Travel	Inexpensive Worldwide Travel

What's Next?

Source: Eric Upton

Source: Eric Upton

Source: Centinnial of Flight.org

Source: Airbus

Electric propulsion technology is one such revolutionary advance, and could herald dramatic changes in the way aircraft are designed.

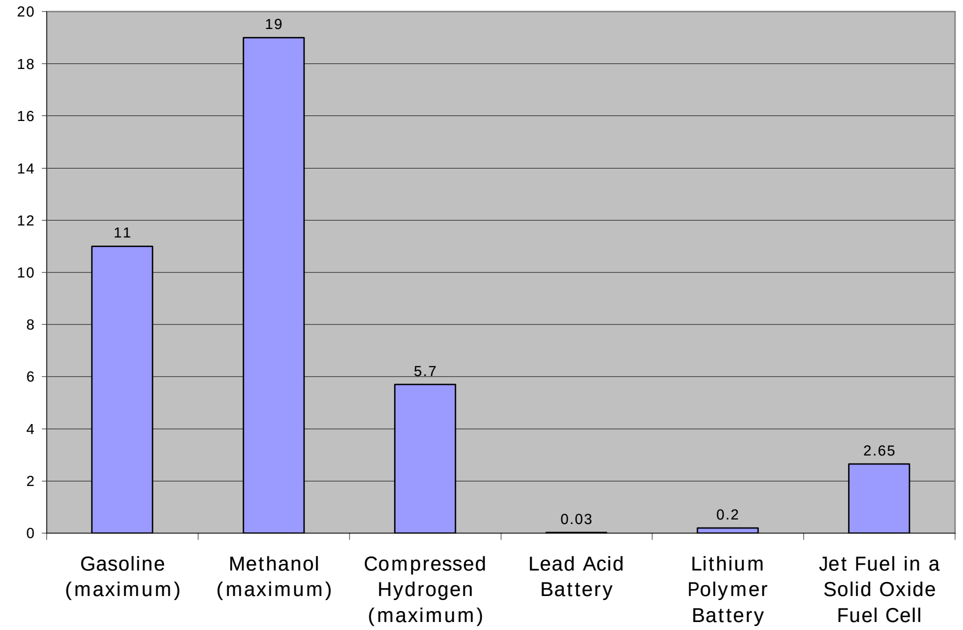
Electric Propulsion for Aircraft

To date, electric propulsion has not been considered feasible for incorporation into aircraft:

- Too heavy
- Too volumetrically inefficient
- Low energy density

Past research has focused heavily on ground-based applications of electric power, with little emphasis placed on reducing weight and volume. More current research, especially in the automotive industry, is paying more attention to these issues, making electric propulsion for aviation a consideration.

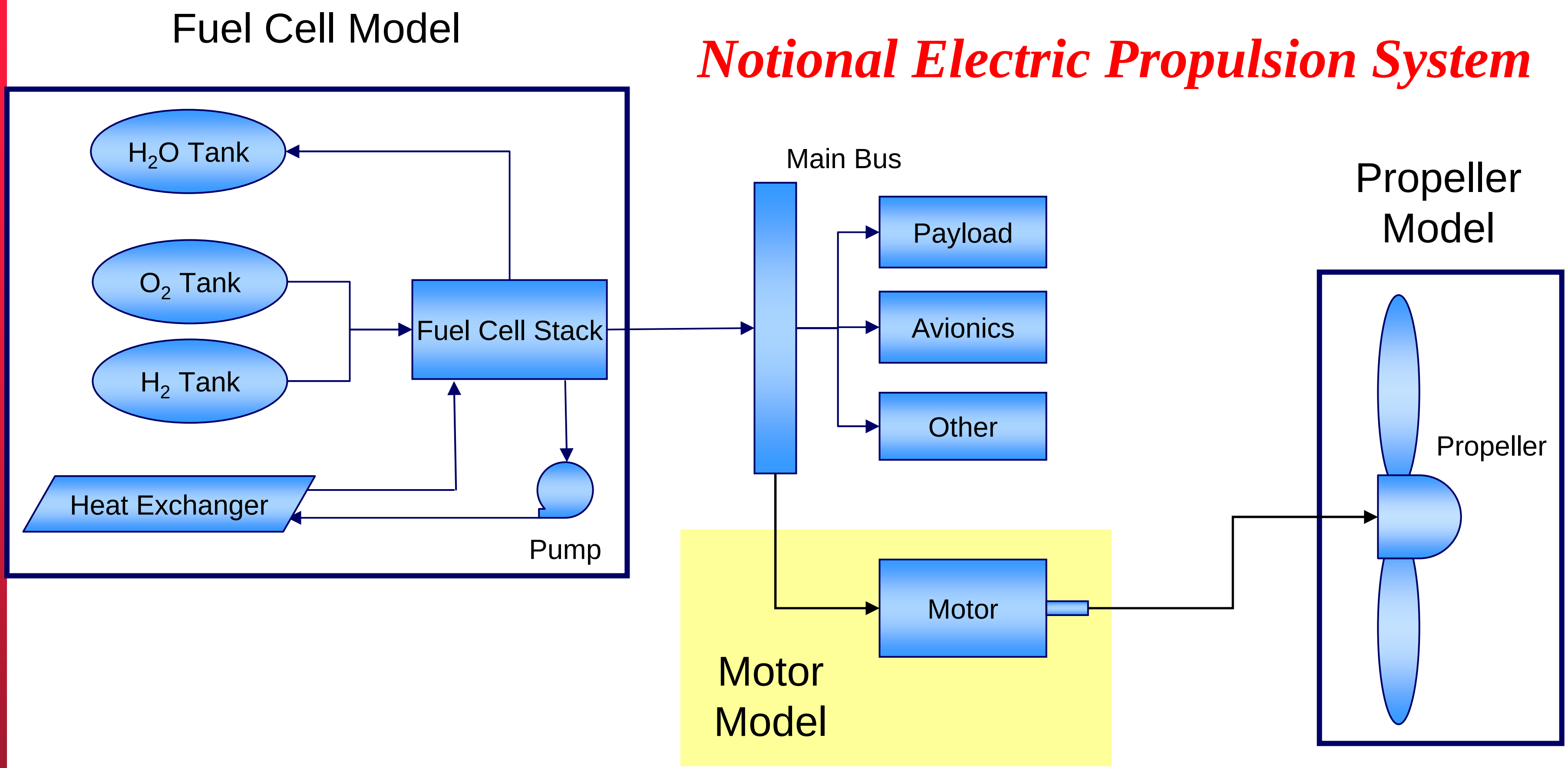
Current Energy Densities for Existing Power Sources (kWh/kg)



Primary advantages of electric propulsion for aircraft include:

- ★ Lower emissions
- ★ Lower noise
- Possible military applications (lower observables)

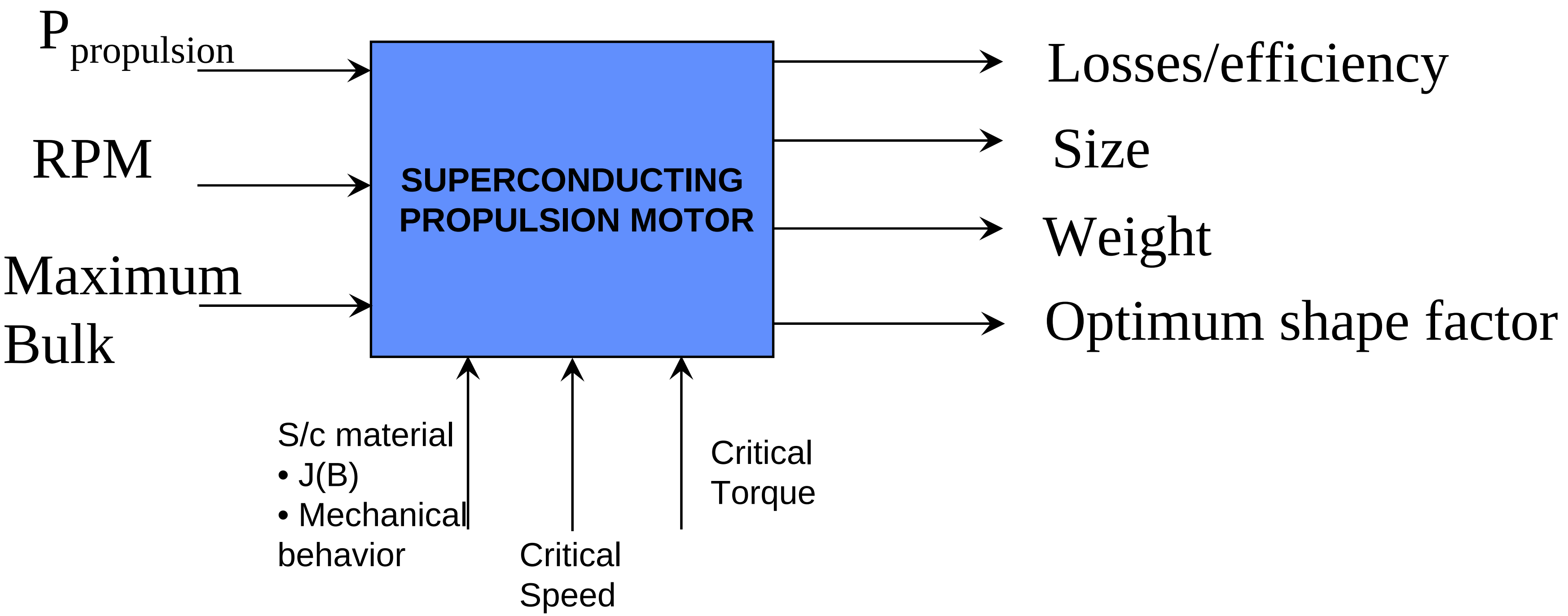
Physics-Based Electric Propulsion Modeling



The electric motor used to translate the power generated by the fuel cells to propulsive power is a key element. Accurate estimates of weight, volume, and power are crucial.

High temperature superconducting motors have the potential to offer significant performance advantages over conventional electric motors.

Electric propulsion motor sizing model



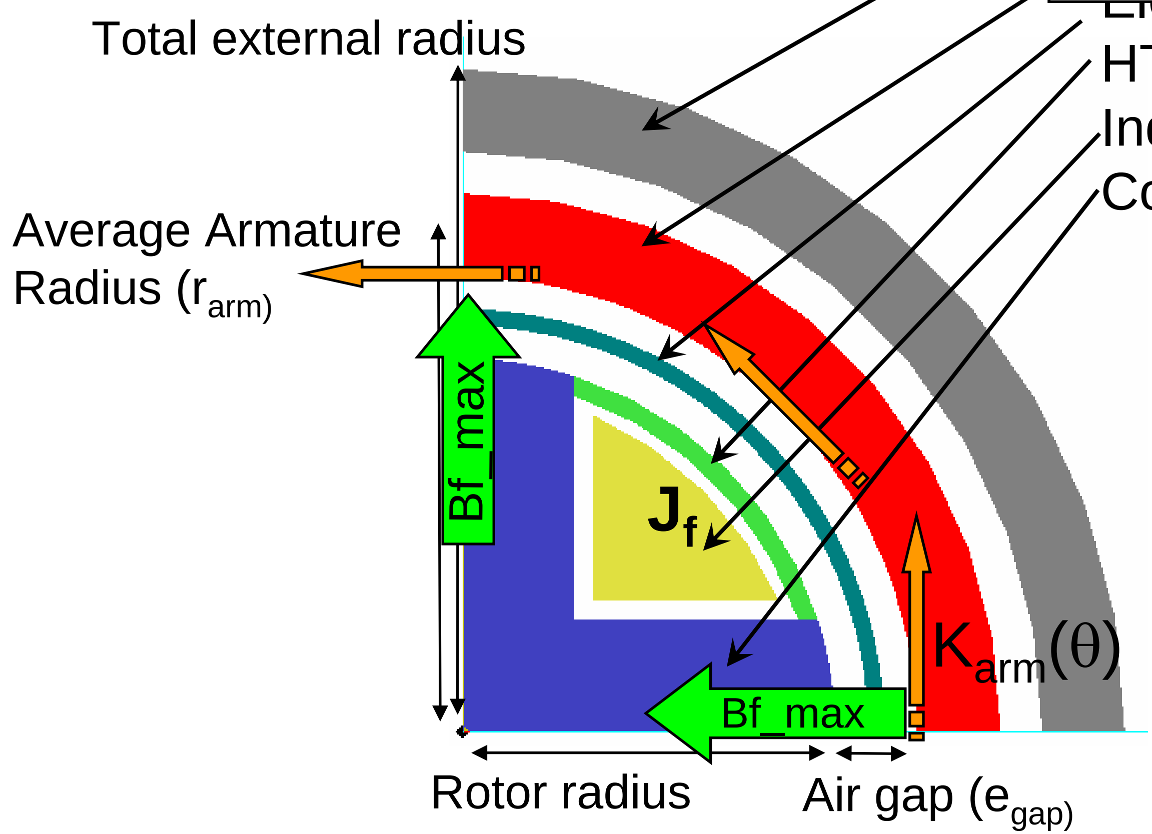
- To be included in an system optimization software
- To be linkable to other model modules

Electric propulsion motor sizing model

- Simplified model implemented in FEA software

$$T = \sqrt{2} B_f K_{arm} \pi r_{arm}^2 L$$

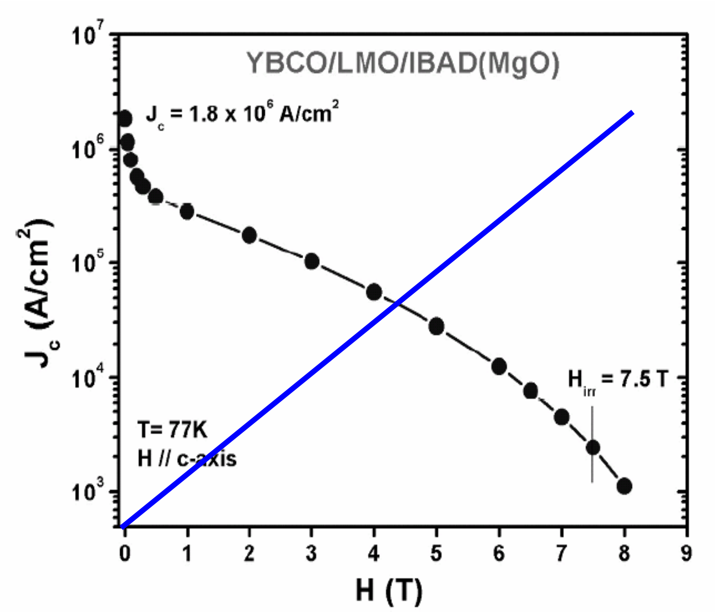
$$P = T \Omega$$

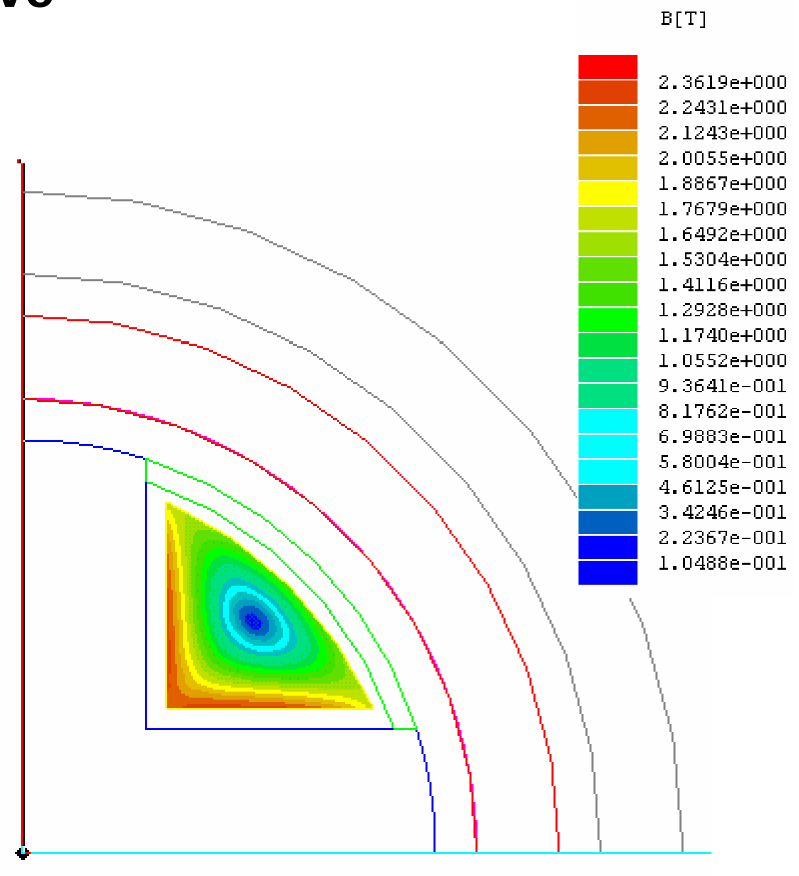


- **Preliminary sizing**
- **Idea of the size**

Determine HTS wire operating point

Jc(B) of the wire and magnet load curve



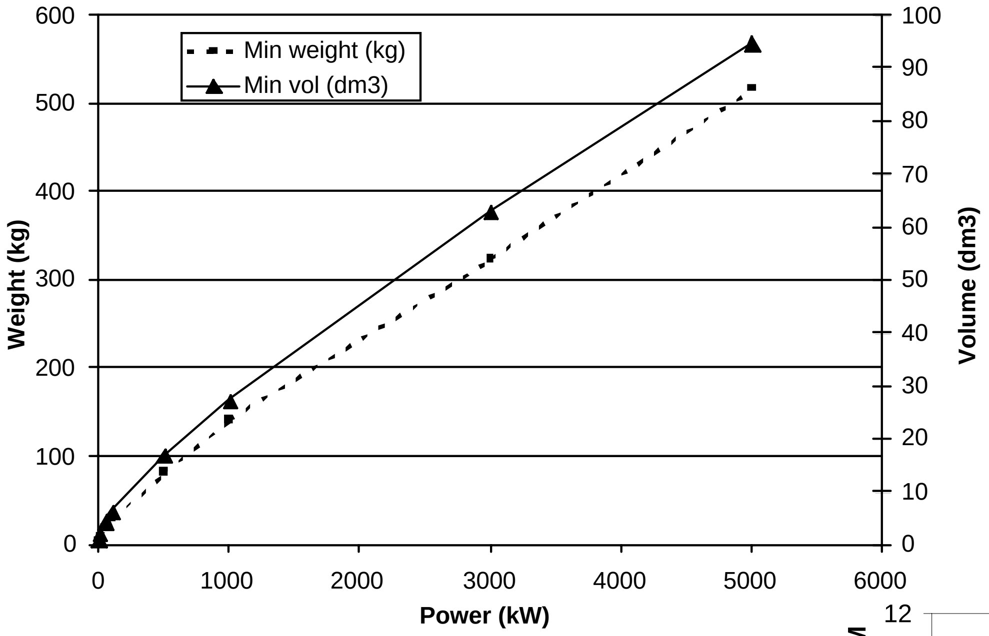


- Characteristic Jc(B) of the wire
- Load curve of the coils
- Operating point of the material at

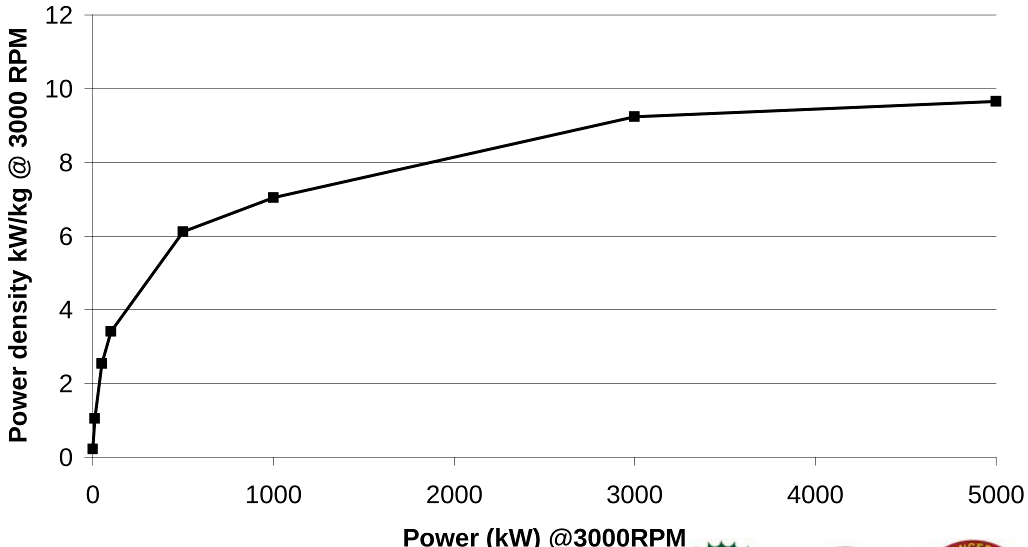
$$\frac{j}{jc} = 0.6 \rightarrow 0.8$$

Ironless field coil, magnetic housing

Electric propulsion motor sizing model



Curves can be fitted by analytical functions



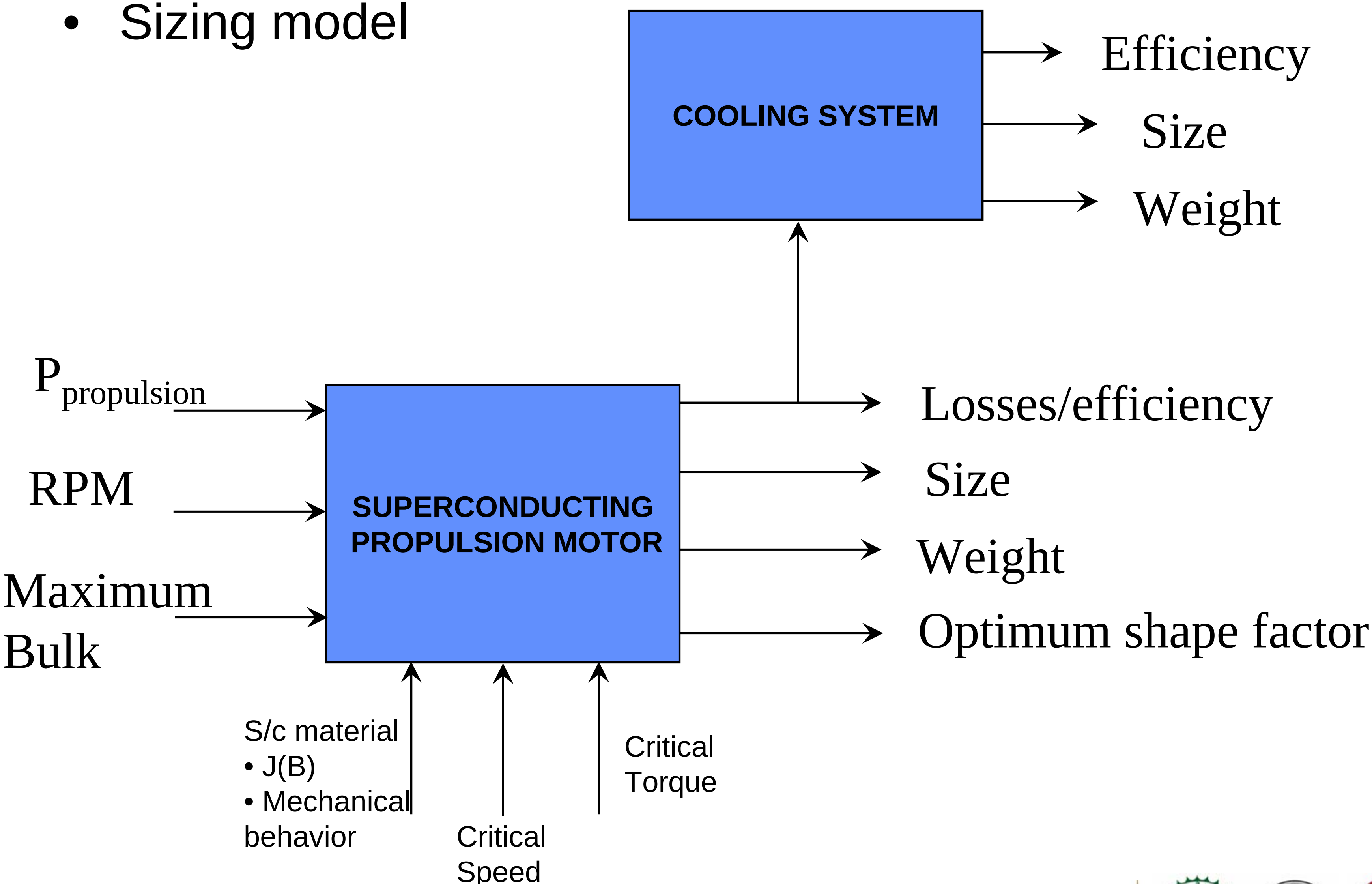
Curves plotted at:

- **Constant operating temperature**
- **Constant shape factor**
- **Constant RPM**

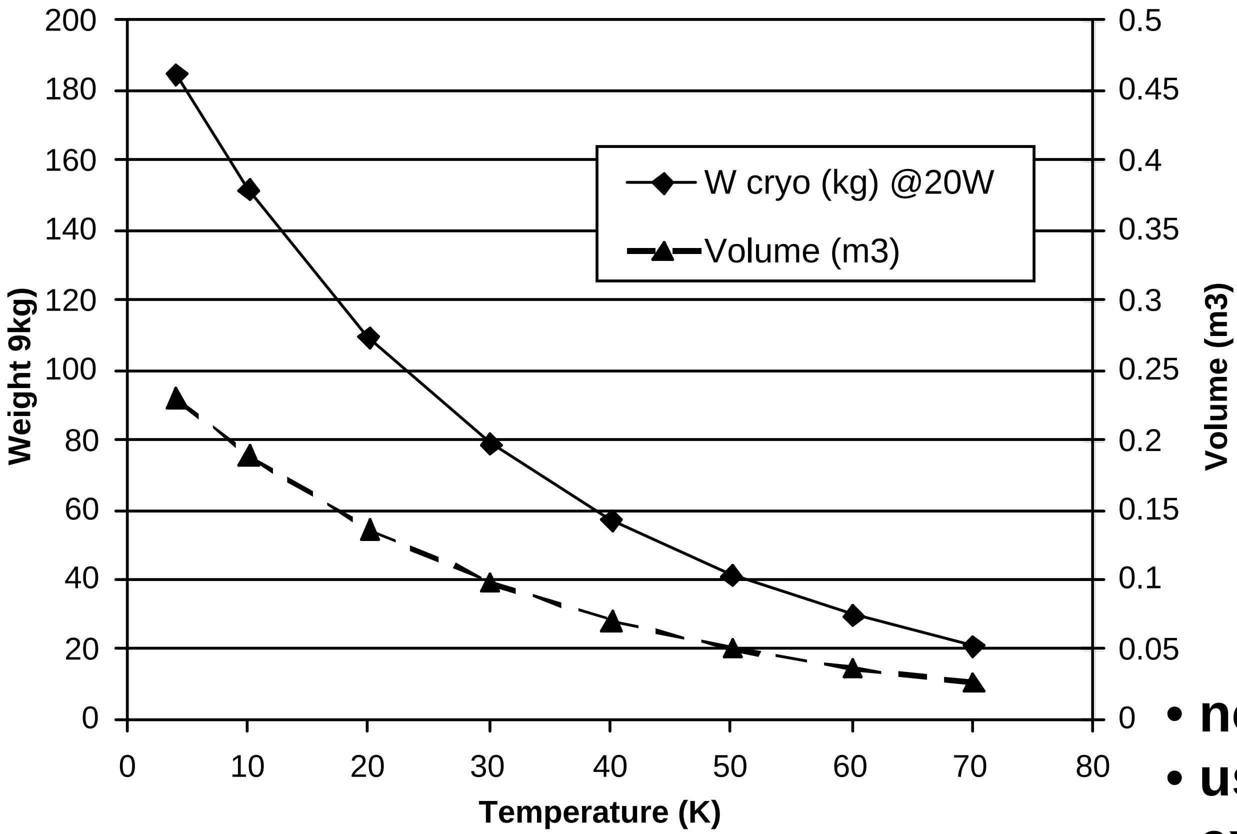
ASDL Georgia Tech

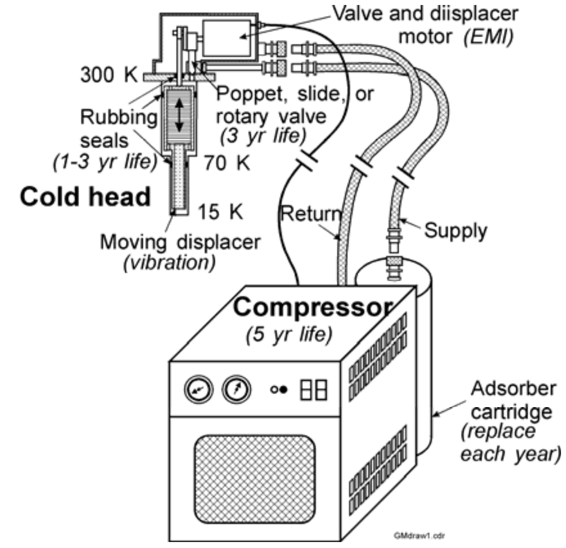
Cooling System sizing model

- Sizing model



Cryocooler Scaling Model





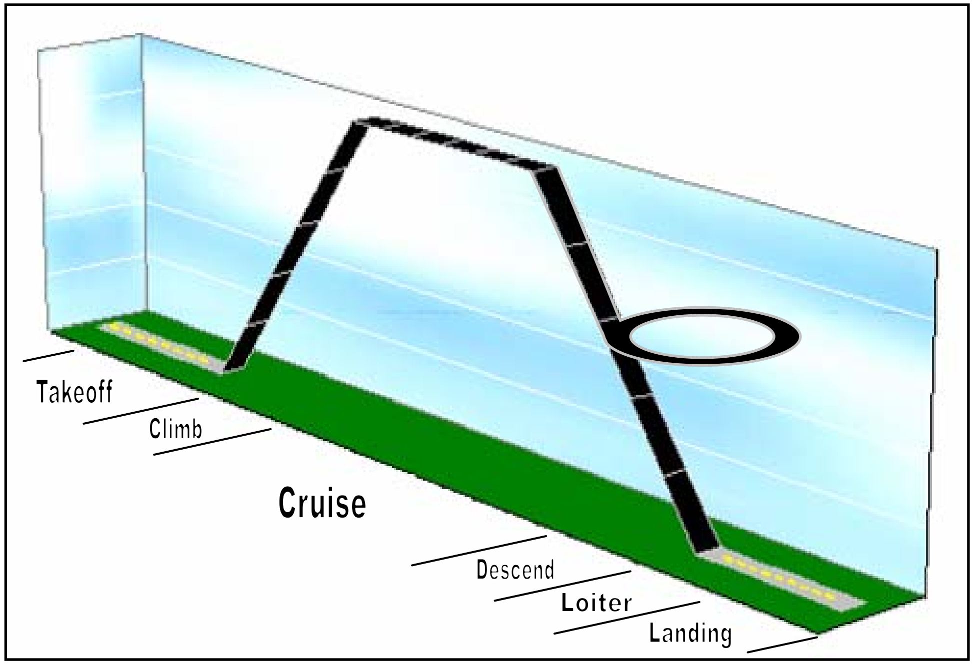
- non weight optimized
- use standard compressor
- expected to improve

Model constructed from actual specifications of commercially available cryocoolers

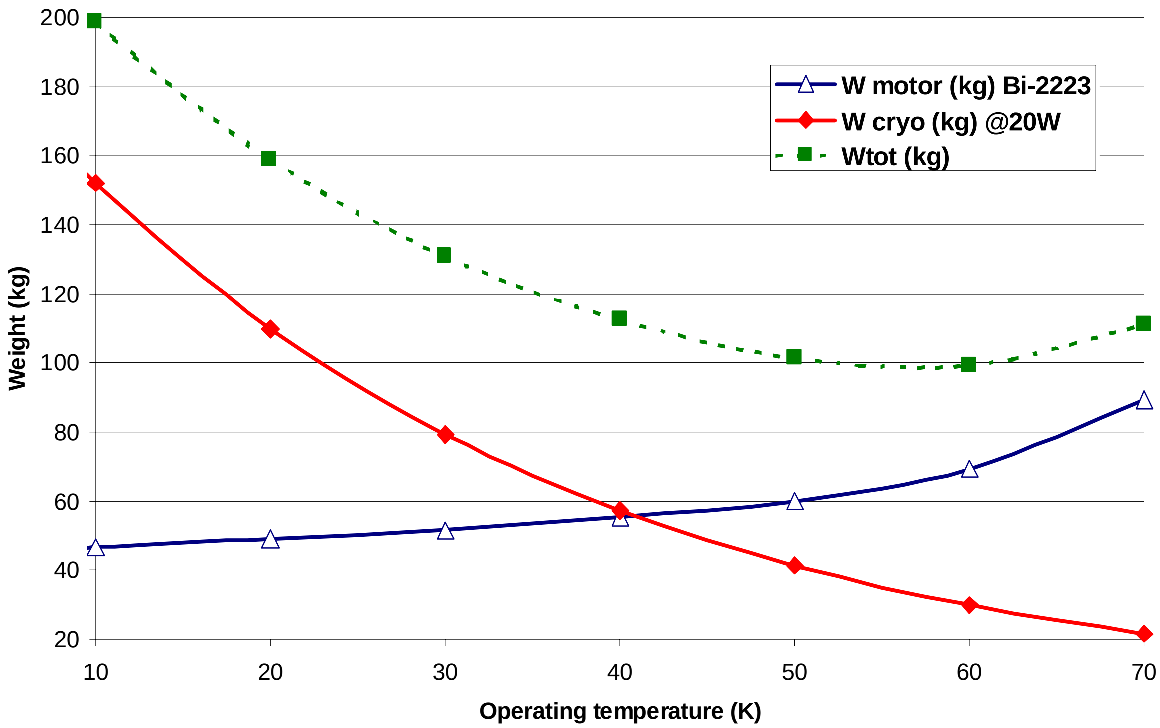
Test Case: Cessna 172

- Mechanically very simple, easy to model
- Perfect target for technology "upgrades"
- Represents a likely size for advances in power generation using fuel cells

Overall Height:	8'11"	2.72m
Overall Length:	27'2"	8.28m
Wing Span:	36'1"	11.0m
Engine Output:	160hp	120kW
Cruise (80% Power):	122kts	226kph
Range (80% power)	:580nm	1074km
Takeoff Gross Weight:	2450lbs	1111kg
Max. Useful Load:	837lbs	380kg



System Approach



In this case:
- 200 HP
- 3000 RPM
- Bi2223/Ag

- Minimum of weight for operation at 55K

Need to optimized the system [HTS motor-cooling apparatus].

Model predict a total active weight of 100kg for the HTS propulsion motor to be compared to 160kg of the conventional engine.

Conclusion

- advances in aircraft technology are often the result of major advances in propulsion technology
- The use of electric motor technology on aircraft could be one such major advance
- The HTS motor is a promising candidate for electric motor application in aircraft