A conceptual design and analysis of a 5MW HTS motor for future electric aircraft

CAPTA

MT 26
International Conference on Magnet Technology
Vancouver, Canada | 2019

Presenter: Dinh-Vuong Le*

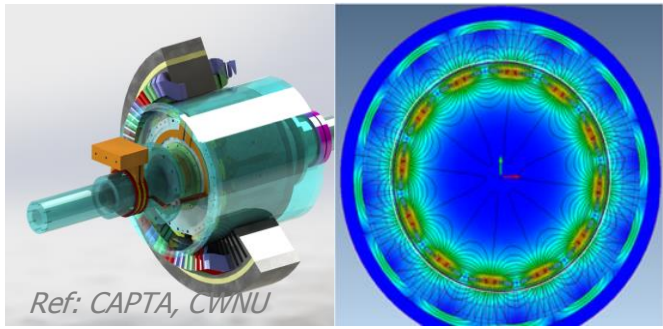
G.-D. Nam, B.-S. Go, S.-J. Lee and M. Park†

Changwon National University
(†capta.paper@gmail.com)

Changwon National University

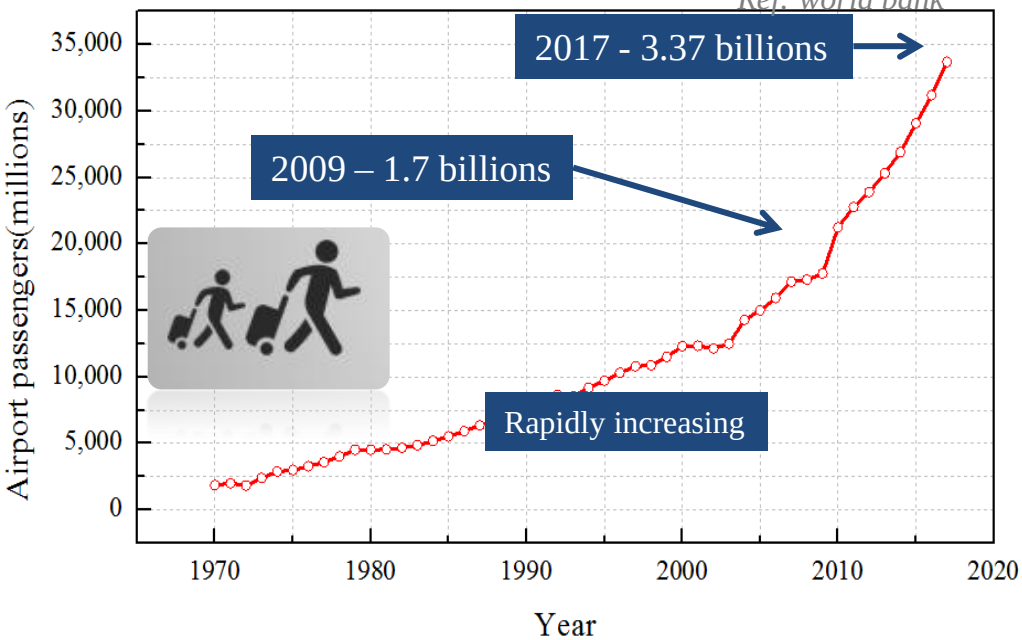
CAPTA
Center for Advanced Power Technology Applications

Contents

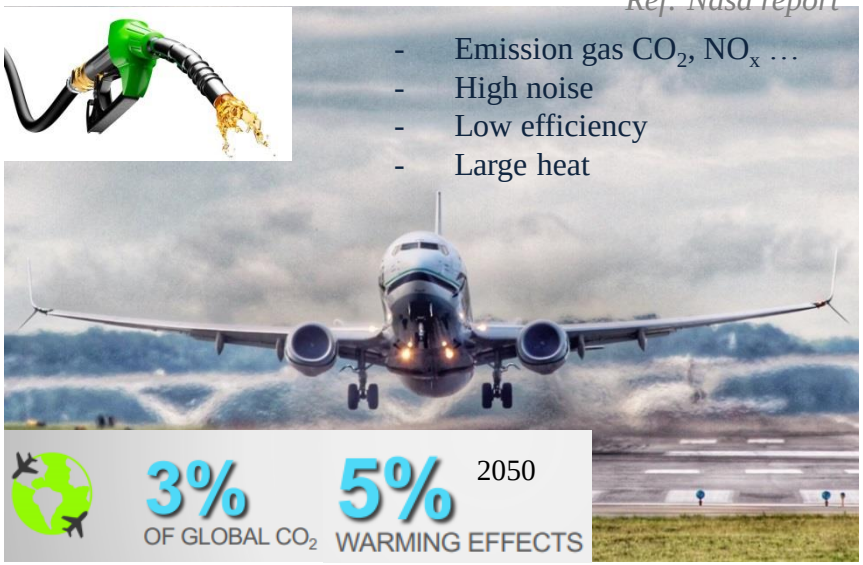


World airport passengers

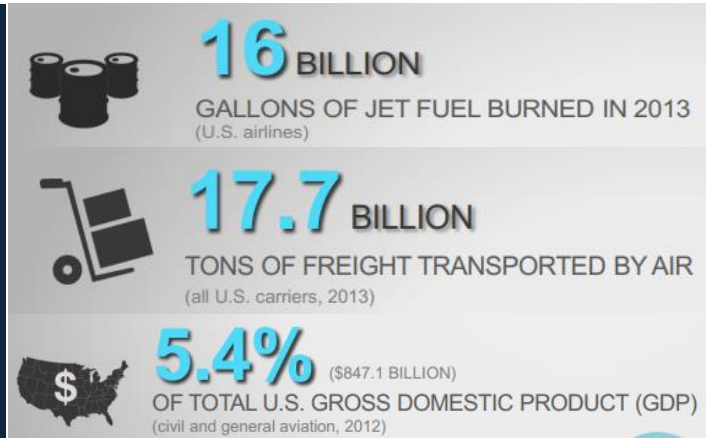
Ref: world bank



Ref: Nasa report



US market

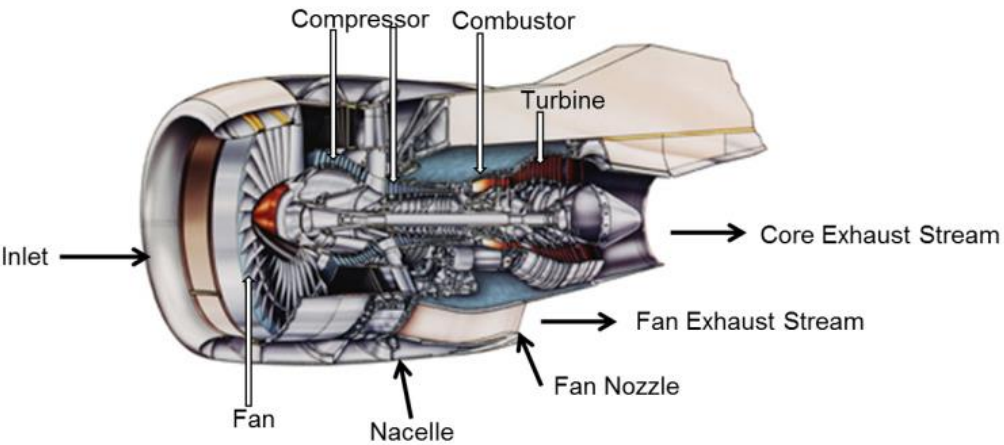


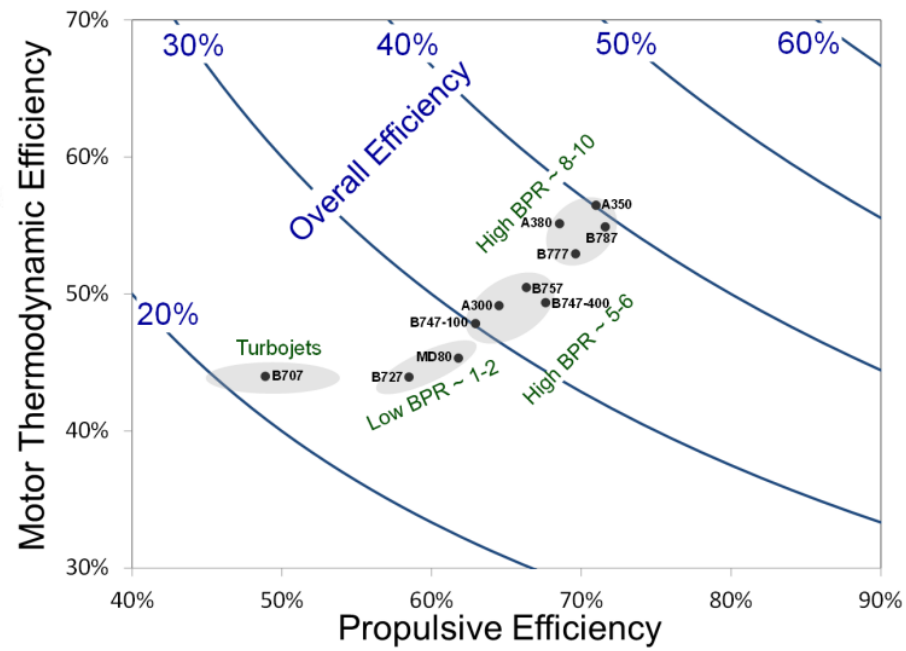
- Airport passengers are increasing rapidly.
- Combustion engine has a large emission gas, noise, and releases large heat → it can cause the significant effects to the Earth.

→ ***Preparing for a revolution in the aviation industry***

Current status of propulsion systems in the aircrafts

Commercial Aircraft Propulsion and Energy Systems Research: Reducing Global Carbon Emissions, NASEM, 2018





Thermopropulsive (overall) efficiency

Thermodynamic efficiency

~ 55%

Propulsive efficiency

~72%

Efficiency of the propulsion system is combined of efficiency of thermodynamic efficiency (burn fuel) and propulsive efficiency (shaft power to thrust by fan/propeller)

State-of-art:

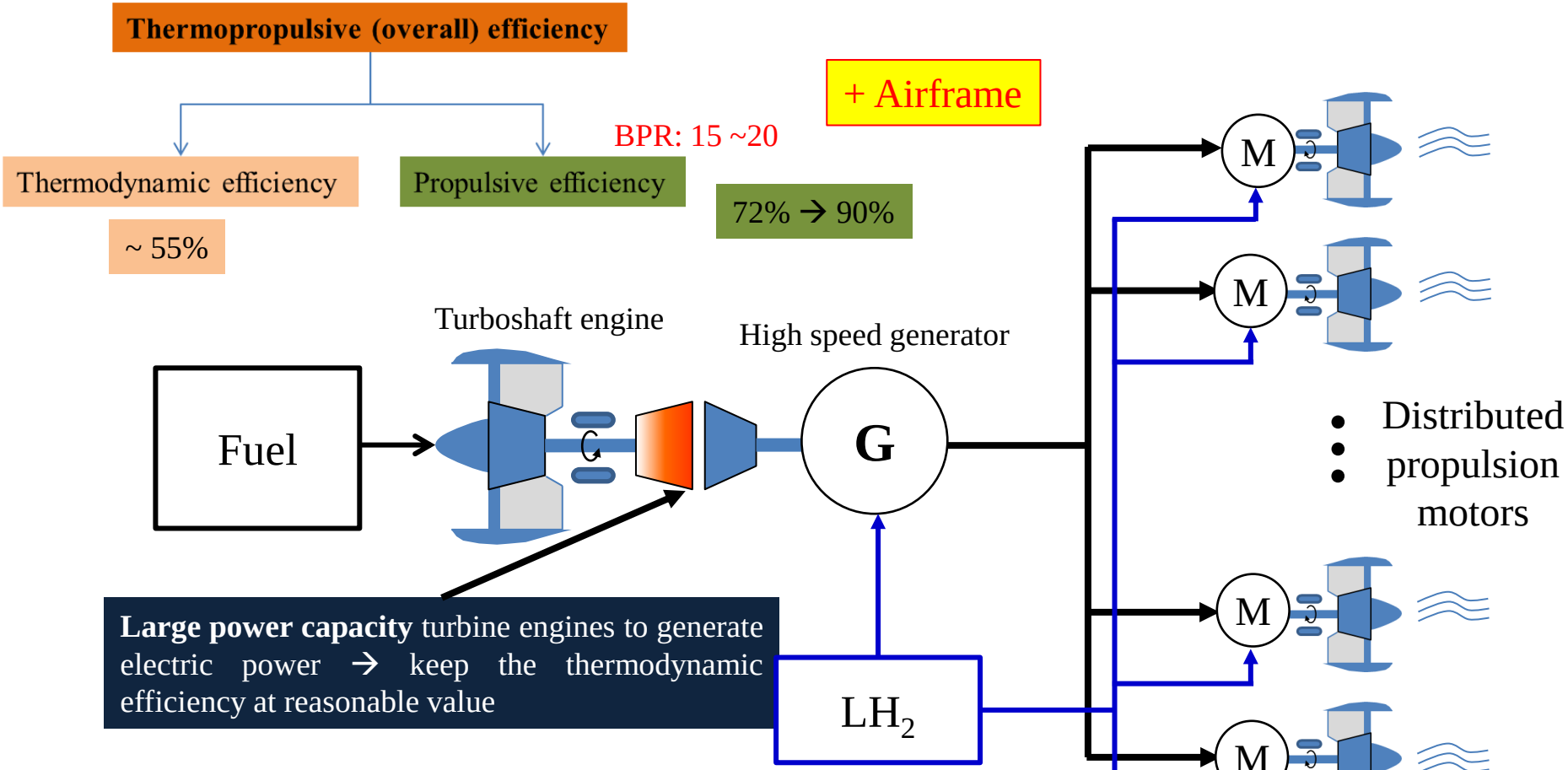
Thermodynamic efficiency: ~ 55%

Propulsive efficiency: ~ 72%

Overall efficiency: ~39.6%

(*Less than a half!*)

Configuration of electric propulsion systems

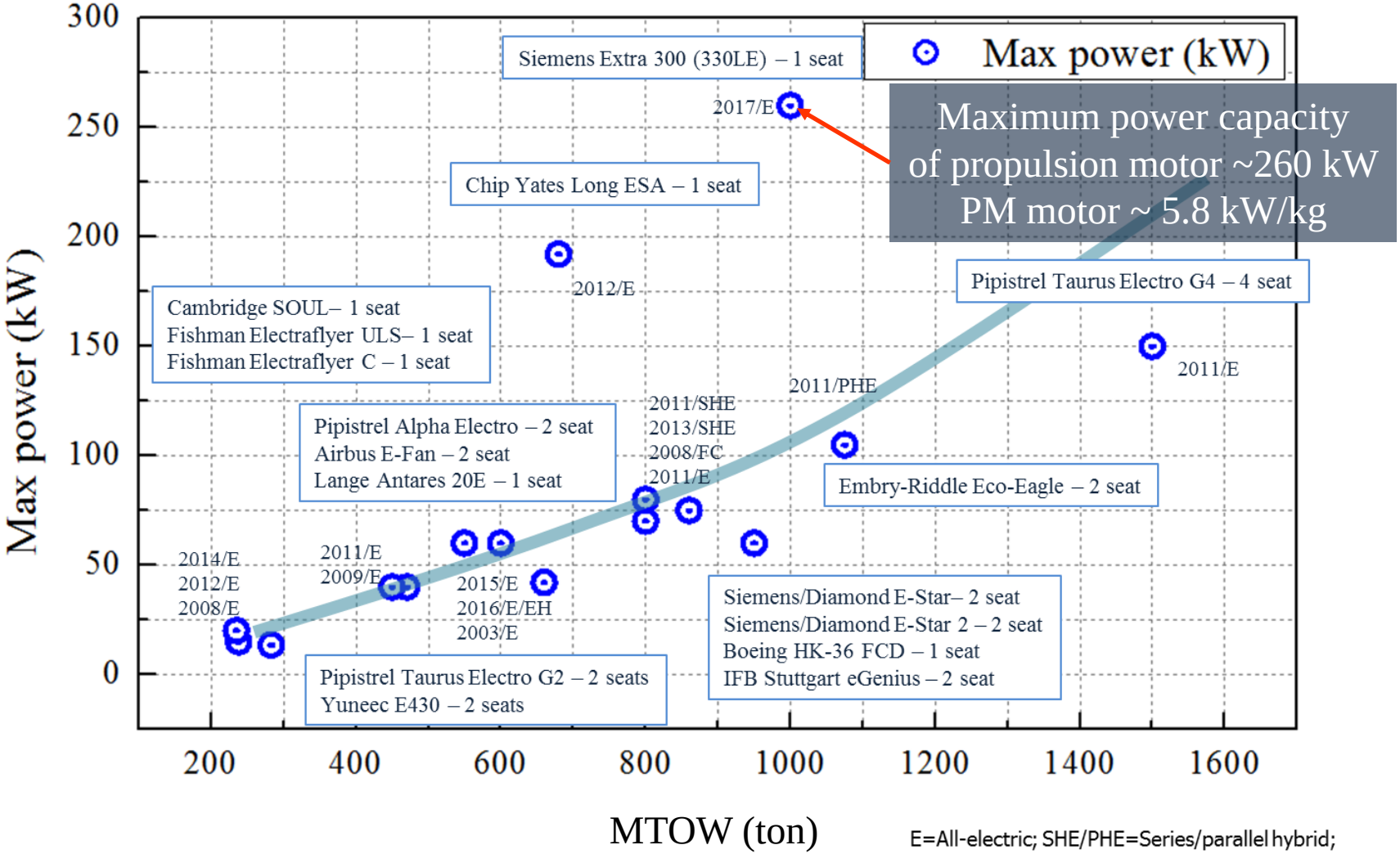


Electric motor has high efficiency that is not depend on the power capacity, relatively.

→ Electric propulsion motor is proposed to overcome the drawback of the small/medium capacity turbine engines.

Electricity production can be configured in other configurations.

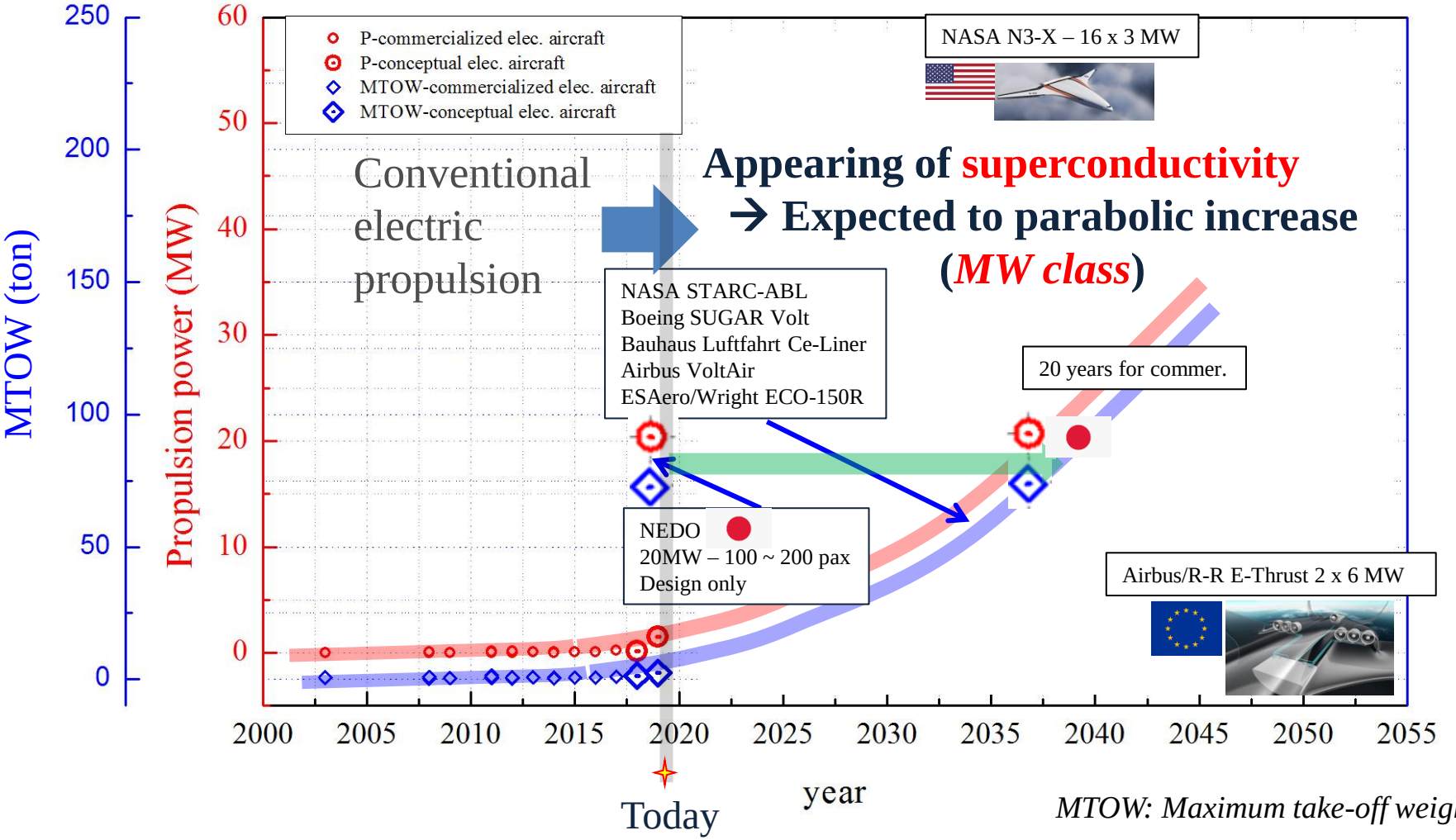
Current status of electric aircraft



E=All-electric; SHE/PHE=Series/parallel hybrid;
TE=Turboelectric; FC=Fuel cell

The power capacity of electric propulsion motor was limited by the disadvantages of the conventional motor (power density)

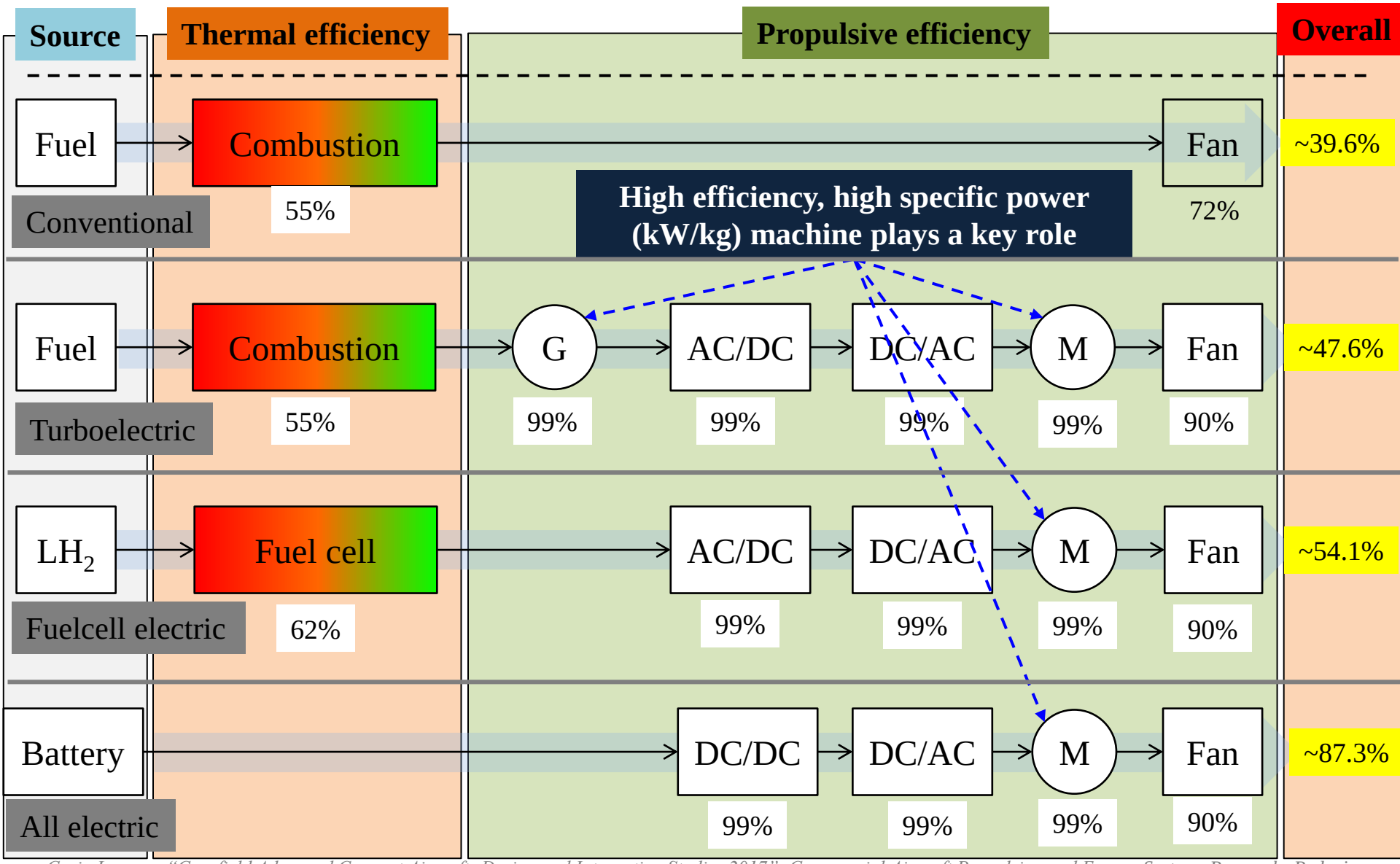
Current status of electric aircraft



MTOW: Maximum take-off weight

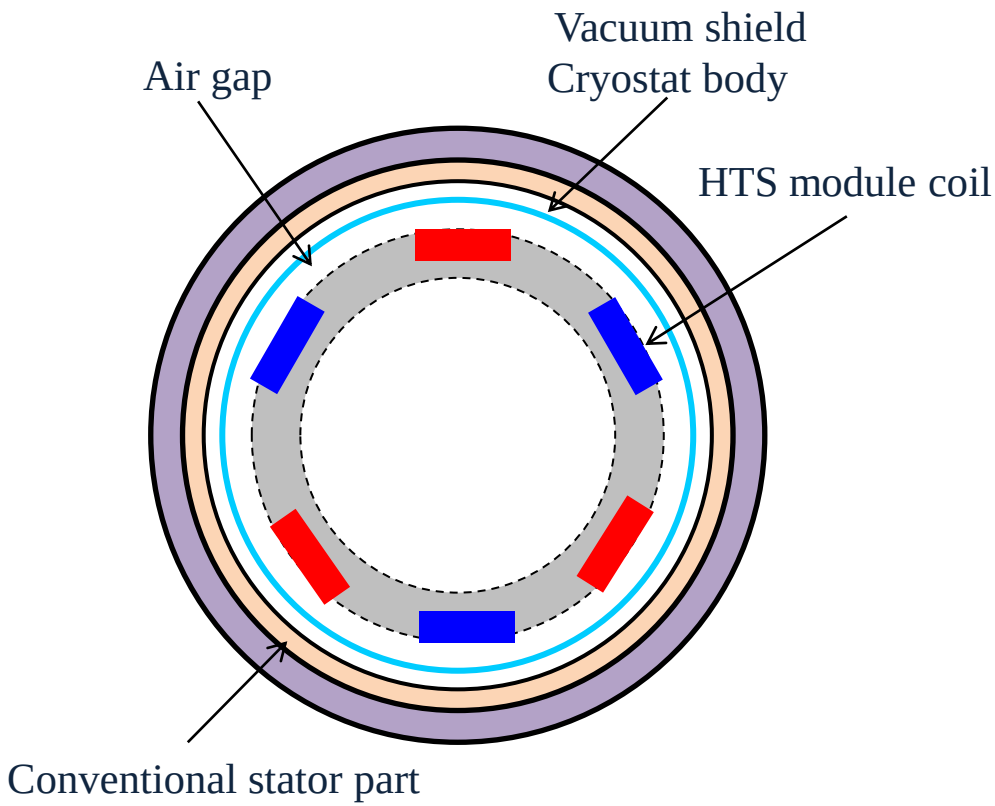
Conventional motor (volume/weight/power density limitation) *is not suitable* for the large electric aircrafts
→ ***Superconductivity opens a new era for the electrical aircrafts***

Propulsion system architecture



Craig Lawson, "Cranfield Advanced Concept Aircraft- Design and Integration Studies 2017"; Commercial Aircraft Propulsion and Energy Systems Research: Reducing Global Carbon Emissions, NASEM, 2018

Configuration of the 5 MW HTS motor



- To analyze the effect of motor parameters on specific power, , the 5 MW HTS motors were designed with five different pole numbers (4, 6, 8, 12, and 16 poles) and two different effective lengths (150 mm and 300 mm). Other parameters were kept at constant.

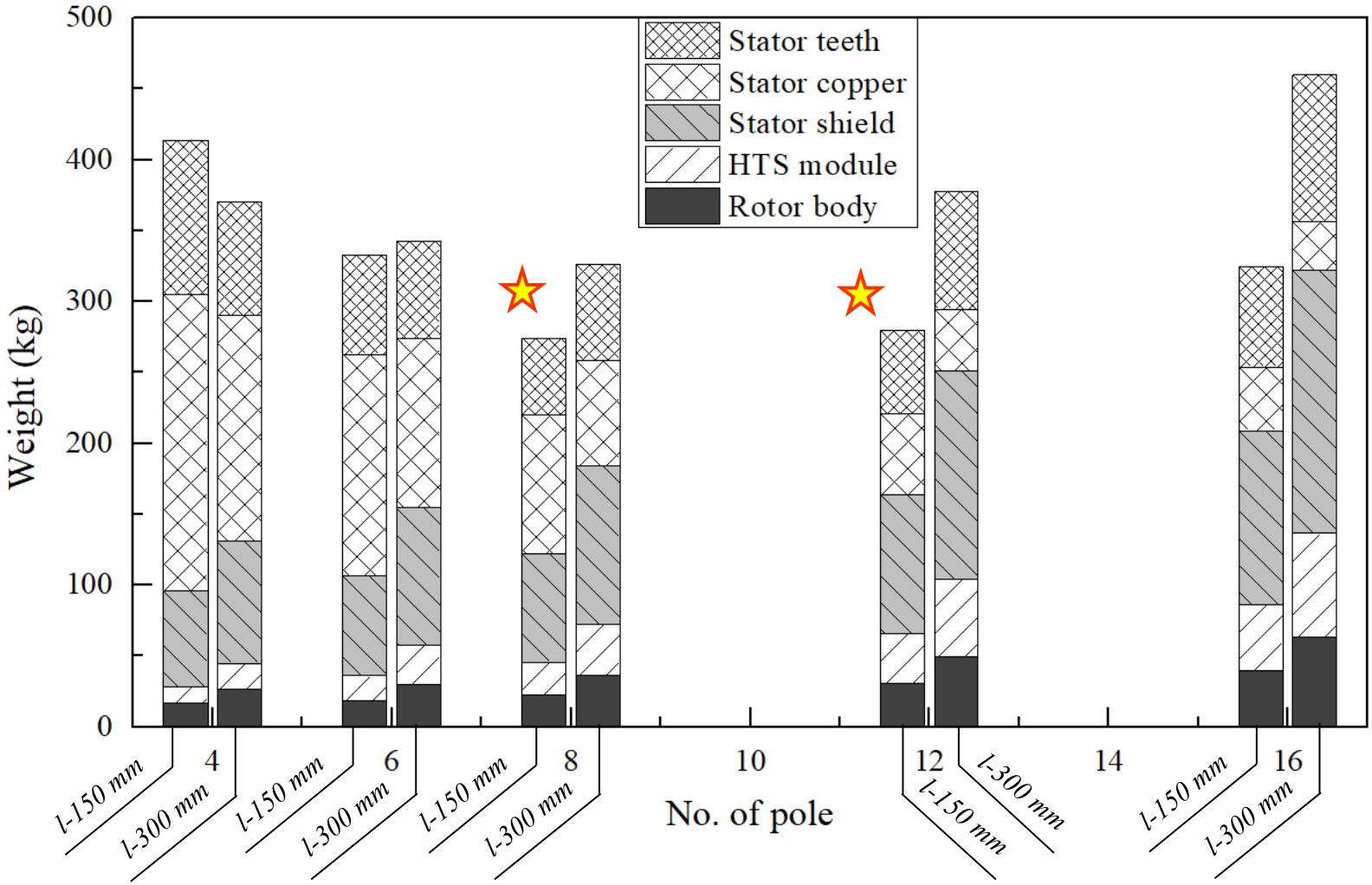
- Parameters of rotor part

PARAMETER	Value
HTS wire thickness	12 mm
Operating temperature	30 K
Operating current	490 A
I_o/I_c ratio	0.7
Minimum bending diameter of the HTS wire	60 mm
Distance between two rotor poles	30 mm
Number of turn/layer of HTS coil	85 turn
Total air gap of the motor	15 mm
Material of the rotor body	Al6061

- Parameters of stator part

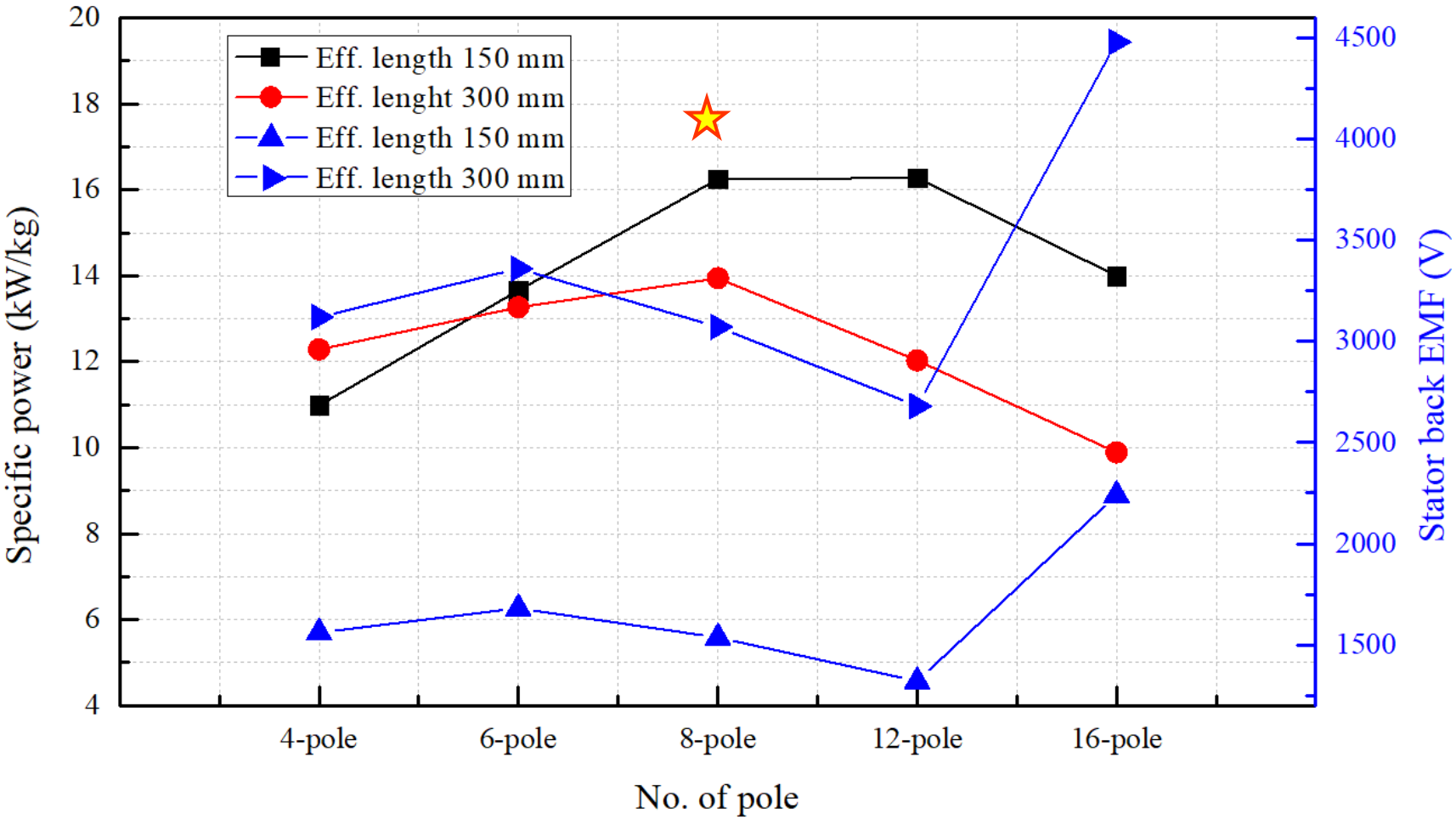
PARAMETER	Value
Number of phase	9
Number of slot/pole	9
Current density	5.8 A/mm^2
Maximum magnetic flux density o utside the stator shield	1.42 T
Stator wire	Copper-Litz
Winding method	Overlap
Material of teeth	M47-26Ga
Material of stator shield	M47-24Ga

Weight comparison of several HTS motor designs



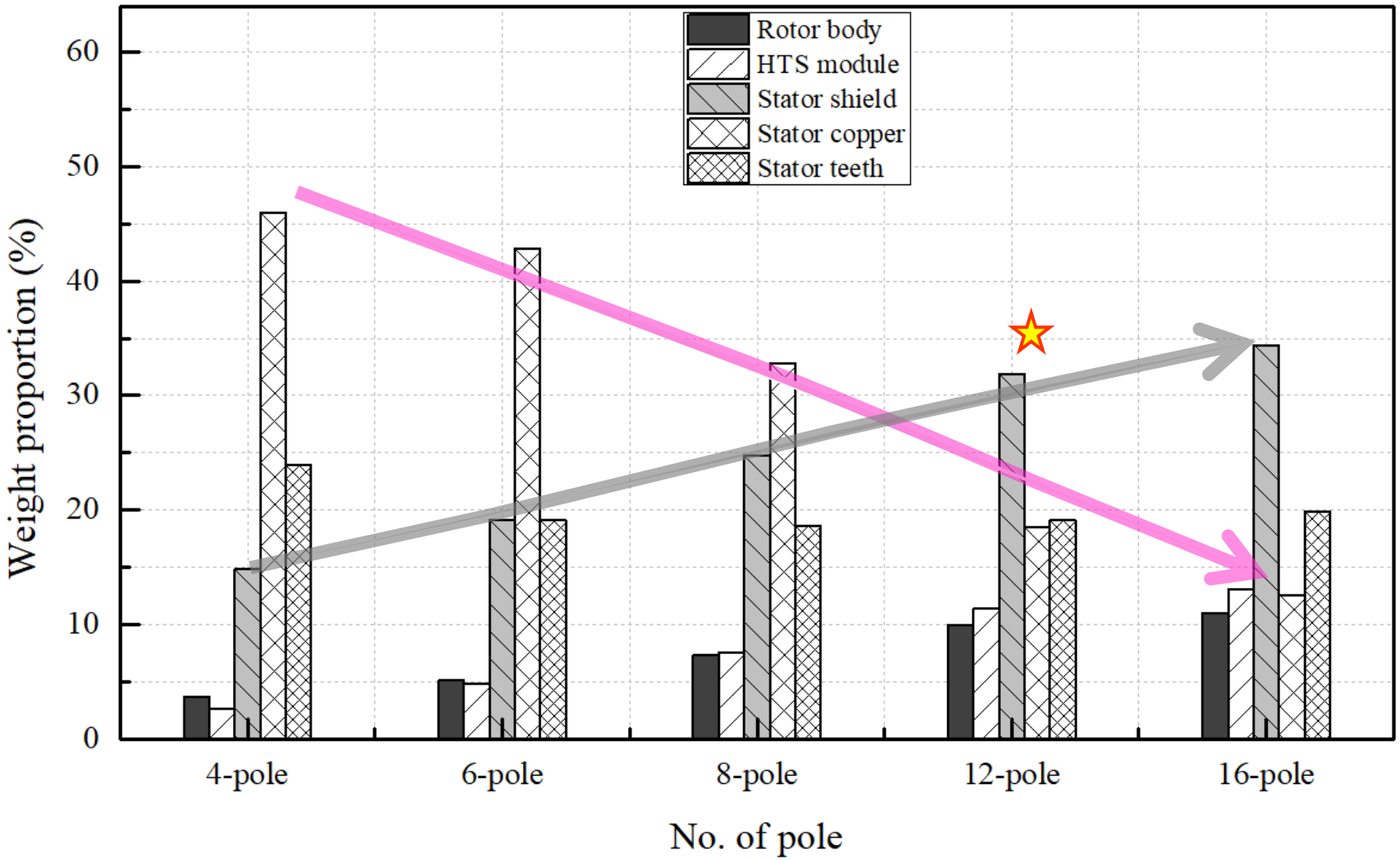
- The design of 8-pole or 12 pole, effective length of 150 mm has lightest weight.

Specific power comparison of several HTS motor designs



- The 12-pole with an effective length of 150 mm produced the highest specific power of 18.04 kW/kg.

Weight comparison of several HTS motor designs

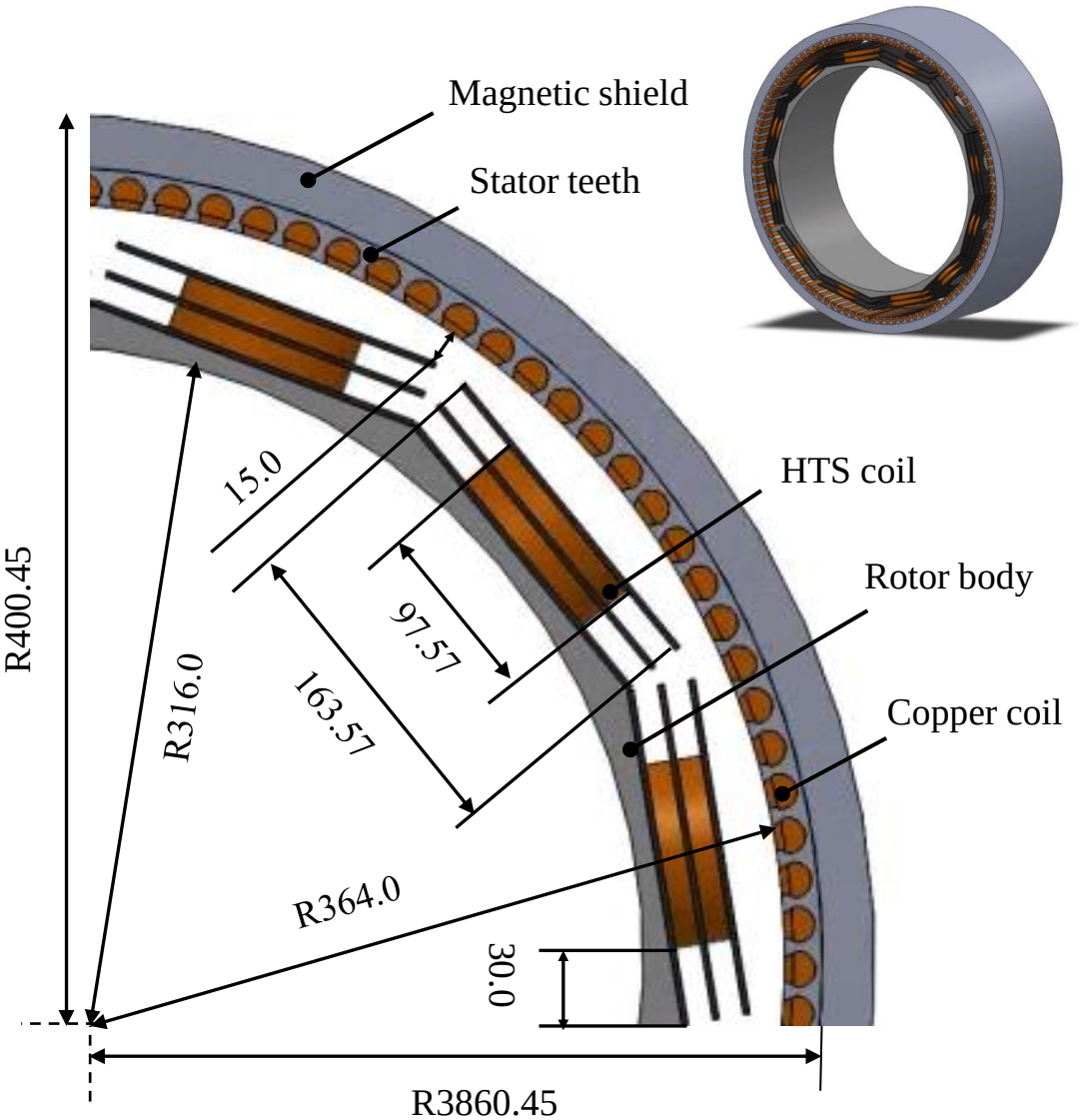


- Weight proportion of copper reduces along with no. of pole (MMF of field coil increase)
- Weight proportion of the stator shield and HTS module increase by increasing of no. of pole & motor diameter

Detailed design of the 5 MW HTS motor

Specifications of the 5 MW HTS motor

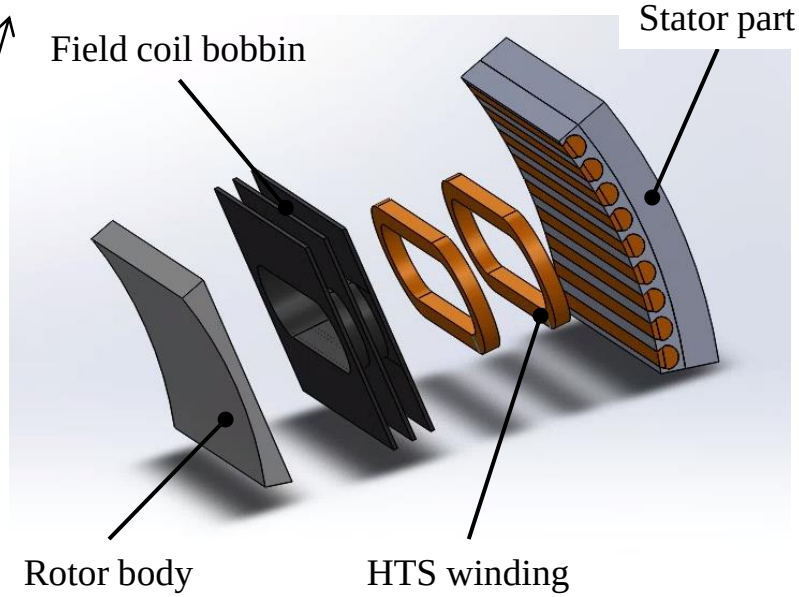
Parameters	Values
No. of pole	12
No. of phase	9
Effective length	150 mm
Rotor inner radius	316.0 mm
Stator outer radius	400.45 mm
Stator inner radius	364.0 mm
Total air gap	15.0 mm
Rotor pole width	163.57 mm
HTS winding width	97.57 mm
Magnetic shield thickness	18.0 mm
Slot depth	8.45 mm
Support width	30.0 mm

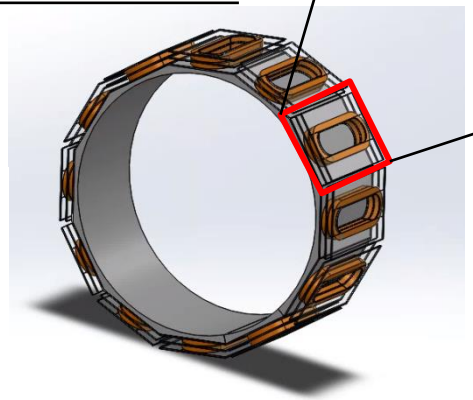


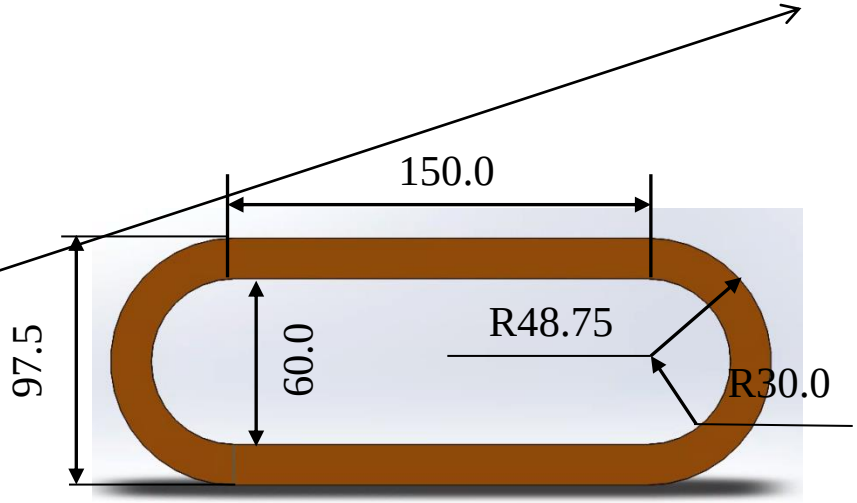
Detailed design of the 5 MW HTS motor

Specifications of the 5 MW HTS motor

Parameters	Values
HTS wire	12 x 0.15 mm
Insulation	No-insulation
Operating temperature	30 K
Operating current	490 A
Rotor body material	Al6061
Stator teeth and shield materials	Iron silicon steel
Stator current density	5.8 A/mm^2



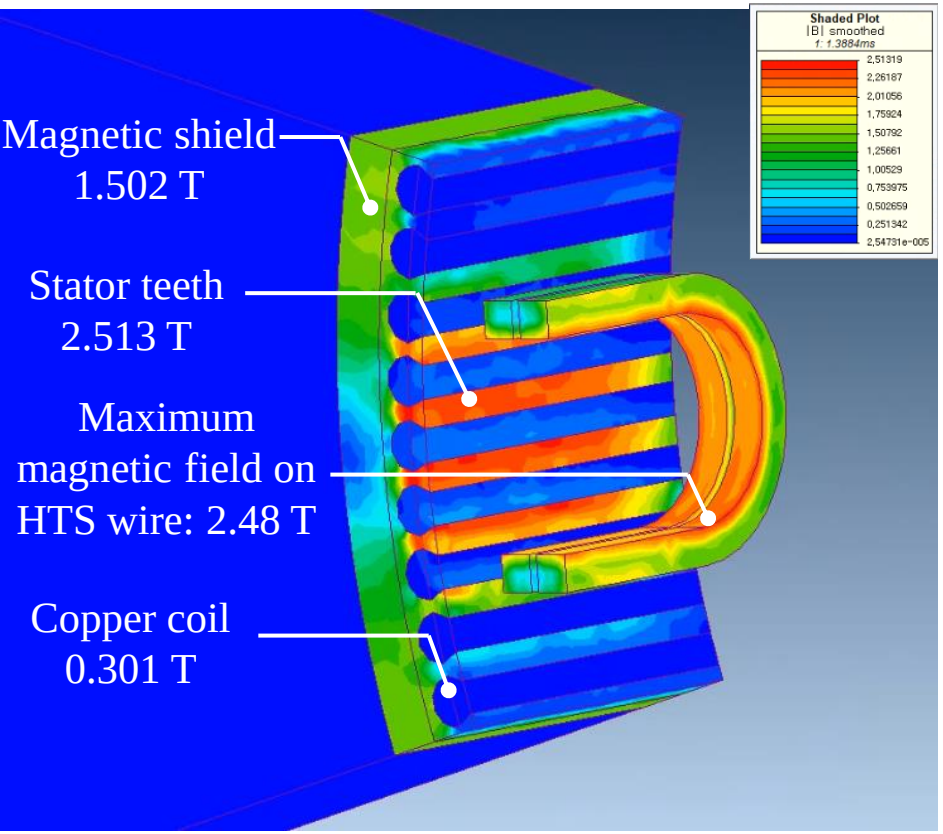




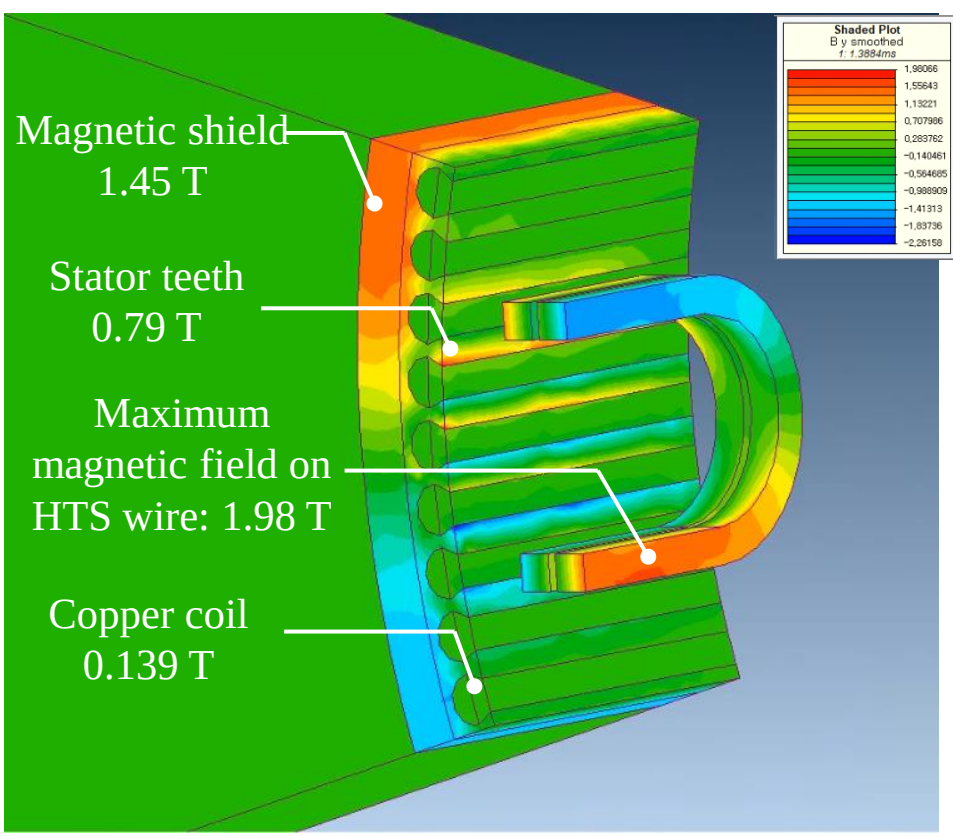
Bending diameter of the HTS wire was selected to 60 mm that is double of minimum values.

Electromagnetic simulation results

Magnetic field distribution at full-load condition



<Magnetic field distribution>



<Perpendicular magnetic field distribution>

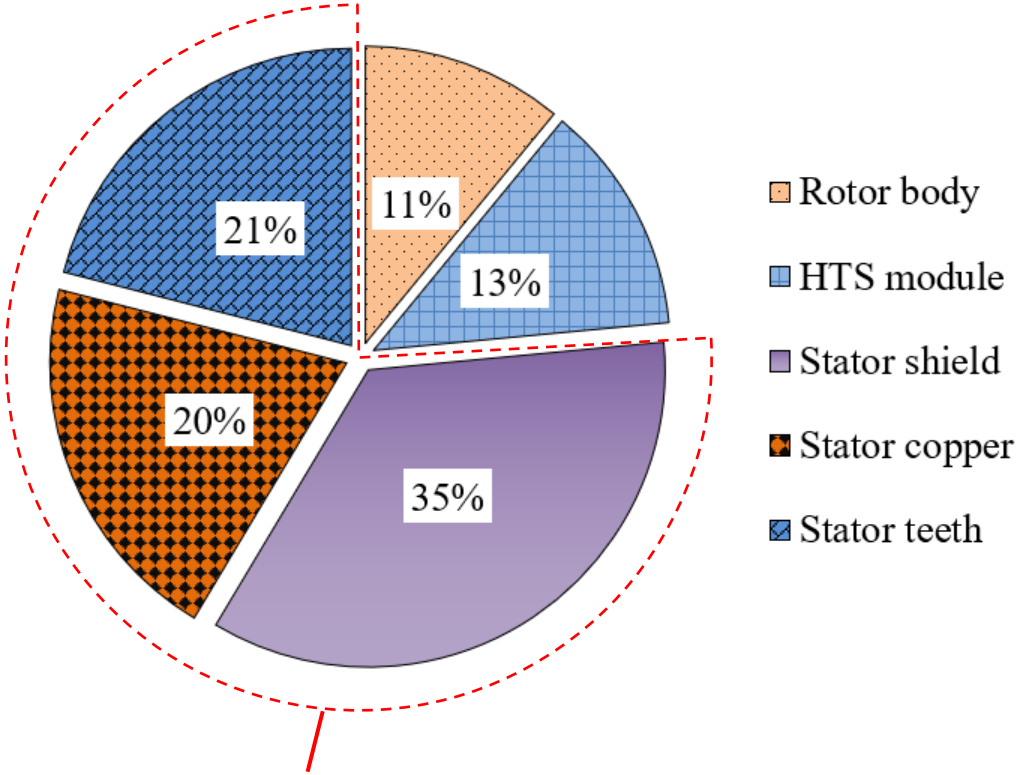
The maximum magnetic field of the motor is 2.513 T at the stator teeth and HTS winding.

The maximum perpendicular magnetic field on the HTS winding is about 1.93 T.

Analysis of the motor weight

Weight of motor components

Parameters	Values
Rotor body	30.629 kg
HTS module	35.1 kg
Stator shield	97.97 kg
Stator teeth	56.94 kg
Copper winding	58.71 kg
Error	10%
Total weight of motor	307.19 kg
Specific power	16.28 kW/kg

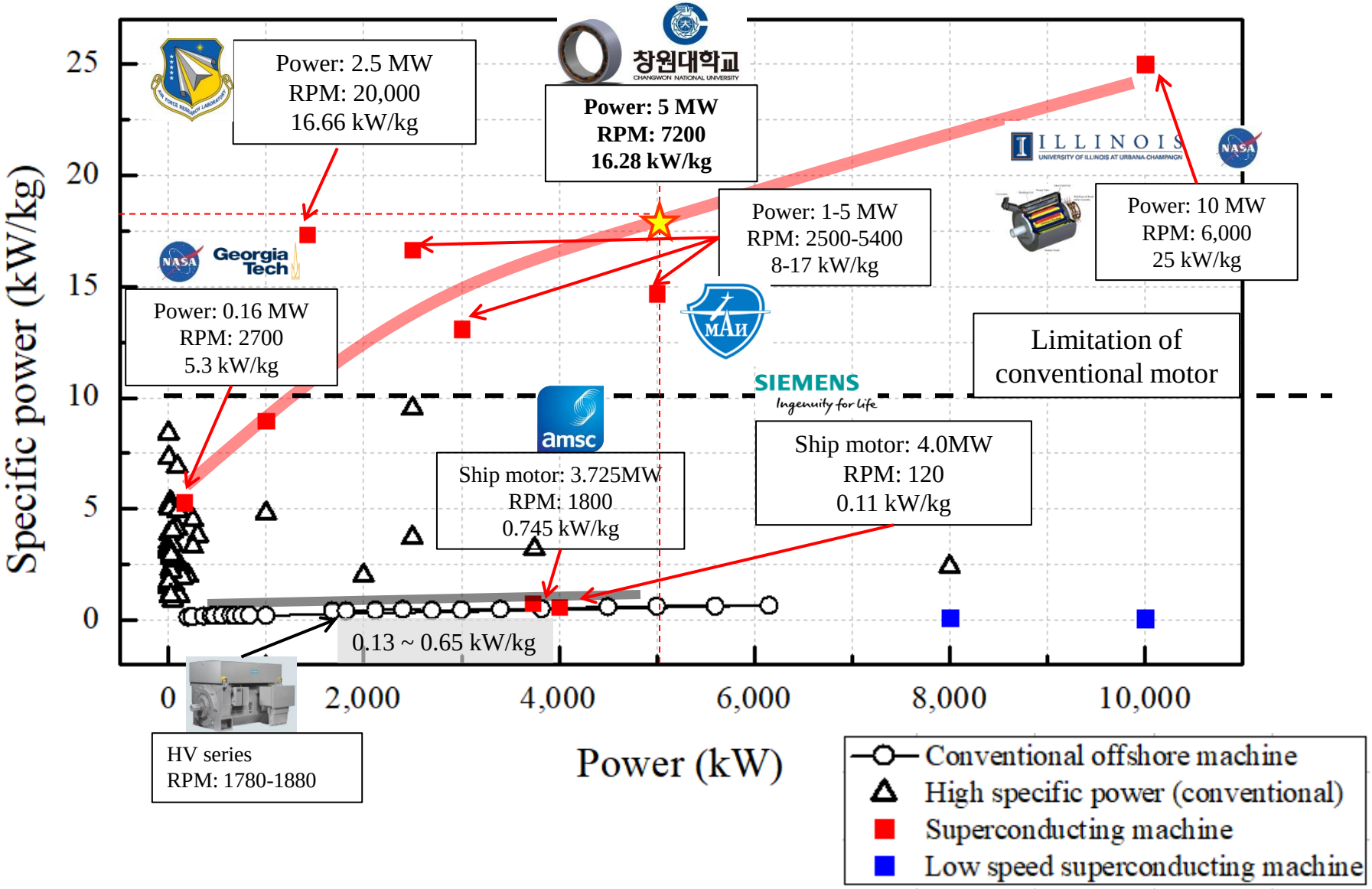


Stator part: 74% of total motor weight

The specific power of the motor is about 16.28 kW/kg (without cooling system).

The stator part accounts for 74% of the total motor weight → it is certain that reducing the weight proportion of the stator part will be a shortcut to greatly improving the specific power of the motor.

Comparison of the specific power



Conclusions

- This paper presents a conceptual design and analysis results of a 5 MW HTS motor for future electric aircraft.
- Several designs for the 5 MW HTS motor were evaluated. Among them, the design of 12-pole, the effective length of 150 mm had the highest specific power of 16.28 kW/kg, which is three times higher than conventional motors.
- The efficiency of 97.37% was achieved. The power loss caused by eddy current loss was significant.
- The weight proportion of the stator part accounts for 74% of the total weight of the motor → Improvement of the stator part will be focused for future work.

Acknowledgement

This work was supported by Korea Electric Power Corporation. This work was supported by the New & Renewable Energy of the Korea Institute of Energy Technology Evaluation and Planning (KETEP) grant funded by the Korea government Ministry of Knowledge Economy (Grant number:R18XA03) (No. 20183010025270)


Thank you for your attention