Technology Roadmap for Large Electrical Machines

IEEE

GRAINGER
Center for Electric Machinery and Electromechanics

NASA
National Aeronautics
and Space Administration

Part I: Prior to break-out session

Existing Drive System & Elec. Machines

	Size Range	Overall System		Electric Machines		Power Electronics	
		Sp. Power	Eff.	Sp. Power	Eff.	Sp. Power	Eff.
Ships	10-120MW			0.48 kW/kg[1]		2.6kW/kg[2]	99%[2]
Trains							
Cars Lexus 600h[3]	50-300kW	1.15kW/kg	91%	1.3kW/kg 2.5	- 91%	11.5kW/kg	
Wind Turbine[4]	Up to 8 MW				96-99		
Industrial	1-500HP[5] 500-575 kW[6]			- 0.17 kW/kg[6]	~96%[5] ~96%[6]		
UAV[7,8]	6 kW 100 kW	1 kW/kg	93%	8.2 10.7 kW/kg	93%		
ThinGap Motors[9]	3.9 kW			4 kW/kg			
Honeywell[10]	1 MW			5 kW/kg			
OSU Lab Demo[11]	10 kW			11 kW/kg	98%		
Siemens[12]	300 kW			6.5 kW/kg			
Airbus[13]				4 kW/kg			

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Aviation Electric Drive Goals

Other Groups	Size Range	Electric Machines		Power Electronics	
		Sp. Power	Eff.	Sp. Power	Eff.
OSU 3 yr Goal[11]	300 kW	15 kW/kg			
OSU 5 yr Goal[11]	2 MW	15 kW/kg		23 kW/kg	99%
Airbus 15 yr Target[13]		10-15 kW/kg			
McLaren[14]	250 kW			50 kW/kg	
NASA NRA Targets[15]	1 MW	13.2 kW/kg	96%	19 kW/kg	99%

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Possible Opportunity for Insertion

Single-aisle Turbo-electric AiRCraft - Aft Boundary Layer[16]

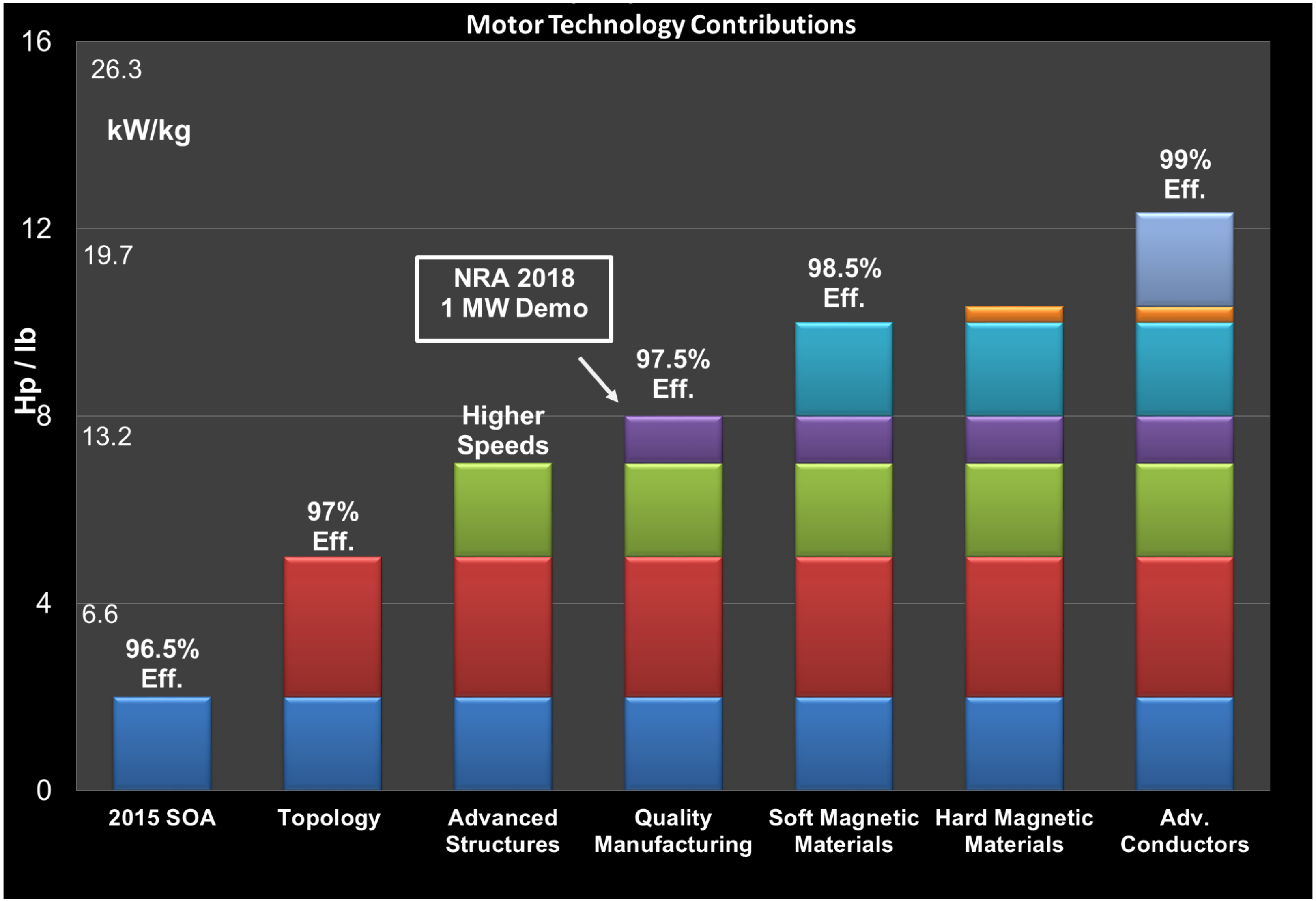
Compared to baseline aircraft with equivalent N+3 technology
7% fuel (& energy) reduction for 900 nm mission
12% fuel (& energy) reduction for 3500 nm mission

- **2.6 MW motor (2 x 1.45 MW generators)**
- **Assuming 90% electric drive system efficiency**
- **~45% boundary layer ingestion accounting for ~70% momentum deficit**

Electric Motor	8 hp/lb	96%	3500 hp	437 lbs
Inverter	10 hp/lb	98%	3500 hp	350 lbs
Generator 2	8 hp/lb	96%	2@1937 hp	484 lbs
Cable 2 x 93' @ 750 V / 1926 amps	3.85 kg/m	99.6%	1.44 MW	482 lbs
Circuit Protection	0.5 * Cable Wt			240 lbs
Thermal Management System (ROM)	0.68 kW(th)/kg	279 kw(th)		906 lbs
Total Electrical + TMS				2921 lbs

Passengers: 154
Range: 3500 nm
Cruise Speed: Mach 0.7

Advance Technology Opportunities



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Part II: Post break-out session

(incorporating input from session at workshop)

Conventional Electrical Machines

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Workshop Goals:

- Technology road map state of the art 10 years from now
- Technology investments required to meet the goals
- Recommendations courses or educational investments university level

Strawman Roadmap: 10 yrs

1-10 MW electric machines with

- 30% improvement in torque/unit volume
- 2-3 kHz fundamental frequencies
- Increased application of non-typical topologies: ~expect 10% power density improvement from asymmetric topology

Technology Investment: Fundamental Issues & Opportunities

- Machine Frequency (tip speed & fund. feq.)
- Mechanical/electromagnetic optimization of air gap vs steel saturation
- Scalability (& Modularity?)
- Simultaneous optimization: electrical, mechanical, & thermal loading
- Bearing
- Magnetic material mechanical strength
- Adv. Metallic conductors (CNTs, etc.)
- Adv. structural composites (CNTs, ect.)
- thermal management
- Does the application require power density or torque density?

Categories To Address

- Define the achievable limits (pareto-optimal limit, entitlement) of machine metrics
- Invigorating Topologies
- Asymmetric Machines
- Beyond 3-phase Machines
- Maximizing
  - Efficiency/Thermal Loading
  - Electrical Loading
  - Mechanical Loading
  - Magnetic Loading
- Bearing performance
- Power factor
- Thermal Management (current density)

- Designing for Prognostic Analysis / Fault Tolerance
- Balance of speed vs cooling schemes
- Consider efficiency profile and not just single number

Need from Other Breakouts

- Power Electronics for High Power as Well as High Frequency
- Expanded property ranges for soft & hard magnetic to higher frequencies and temperature
- Insulation for high voltage & high altitude
- Adv. Metallic conductors (CNTs, etc.)
- Adv. structural composites (CNTs, ect.)

Crucial Investments

- pareto-optimal limit of novel machine topologies
- Integral design of heat management (a la power electronics)

Education

Want to encourage

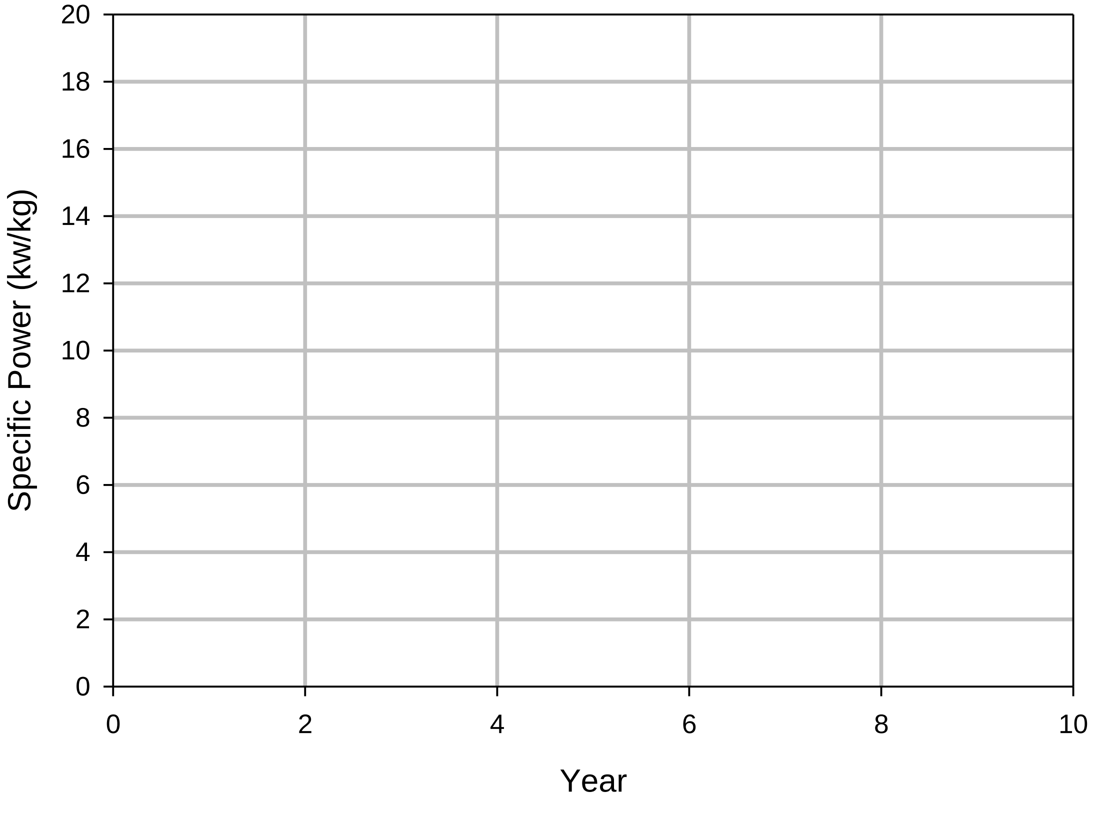
- Machine fundamentals at undergraduate level
- Machine design at graduate level

Trends

- What technologies are being pursued?
  - Structural materials, manufacturing changes, thermal management
- Where would machine power density be if current projects are successful?
- How large can Halbach /ring designs grow?
- Do Doubly Fed designs offer system level improvements?

Chart

- Estimated improvement in machine power density & efficiency over a rough timeline



Technology Opportunities & Gaps

- Highlight key points from previous chart
- Recommend coursework and training opportunities

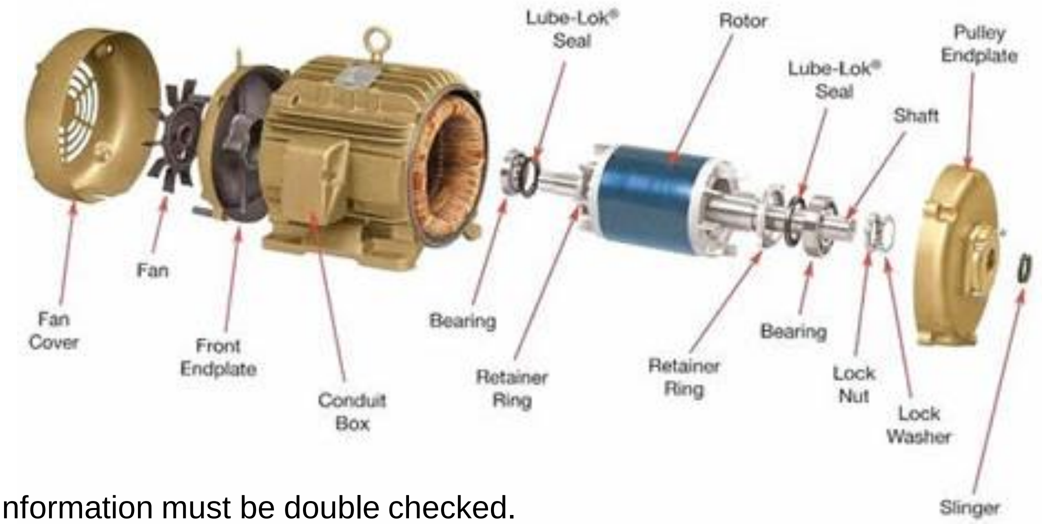
Opportunities for Mass Reduction

1/20 hp Shaded Pole - General Categories		
Item	grams	% of Total
Casing (stator, fan, front and back plates)	692	35.4%
Stator Laminations	664	34.0%
Rotor + Shaft	438	22.4%
Windings	160	8.2%
Total	1954	

3 hp 3-Phase - General Categories		
Item	kg	% of Total
Casing (stator, fan, front and back plates)	12.715	43.7%
Stator Laminations	7.518	25.9%
Rotor + Shaft	6.6	22.7%
Windings	2.242	7.7%
Total	29.075	

Prius Motor Mass Distribution		
Item	kg	% of Total
Casing	14.1	38.3%
Stator Laminations	10.36	28.1%
Rotor + Shaft	6.7	18.2%
Windings	4.93	13.4%
Magnets	0.77	2.1%
Total	36.86	

- **Mass fractions are consistent over a wide range of motor types and power.**
- **Casing is the largest single element in all motors. (~40%)**
- **Stator Laminations are second (~30%)**
- **Rotor + shaft are third (~20%)**
- **Neither the windings (10%) nor the magnets (2%) are major contributors to mass**



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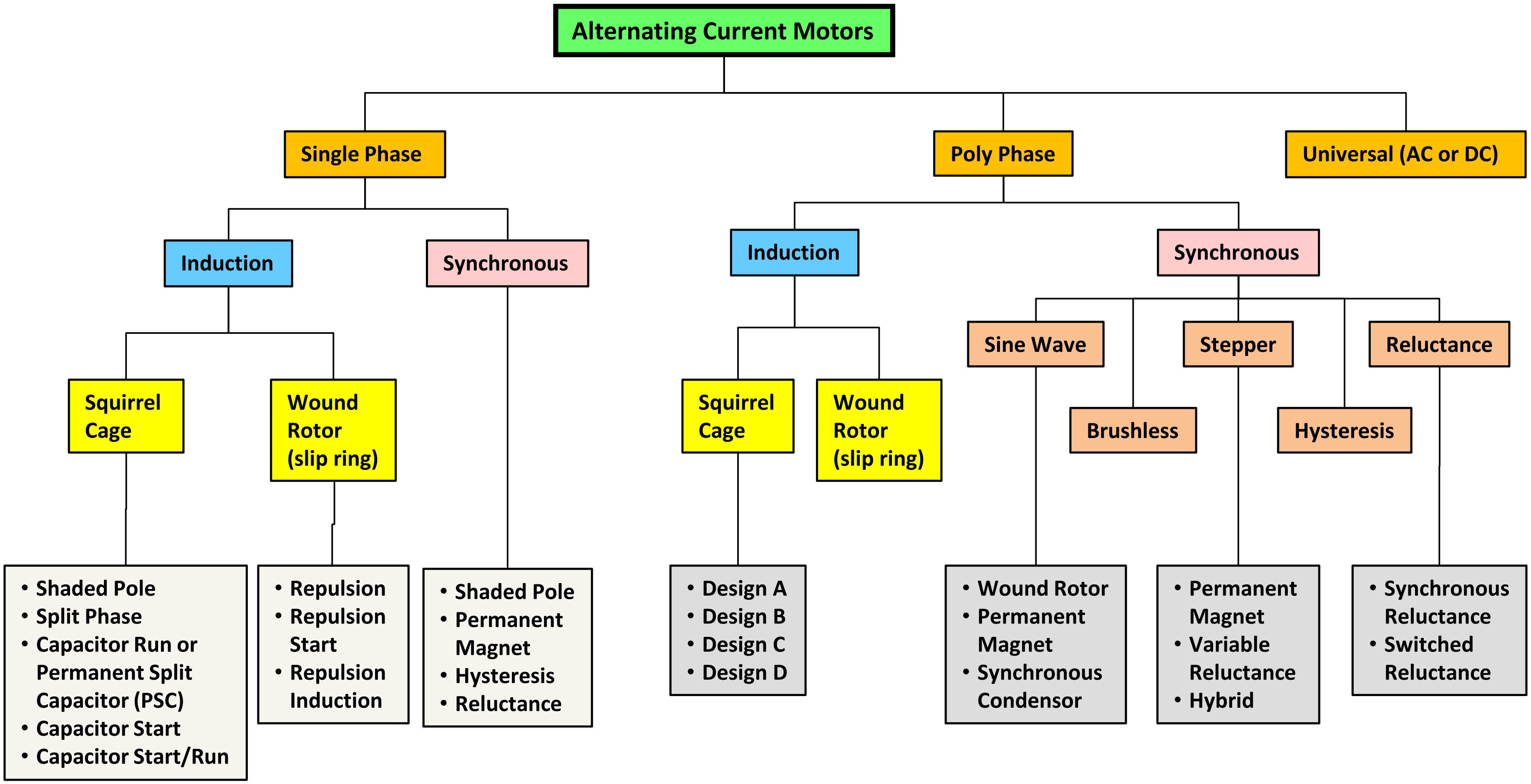

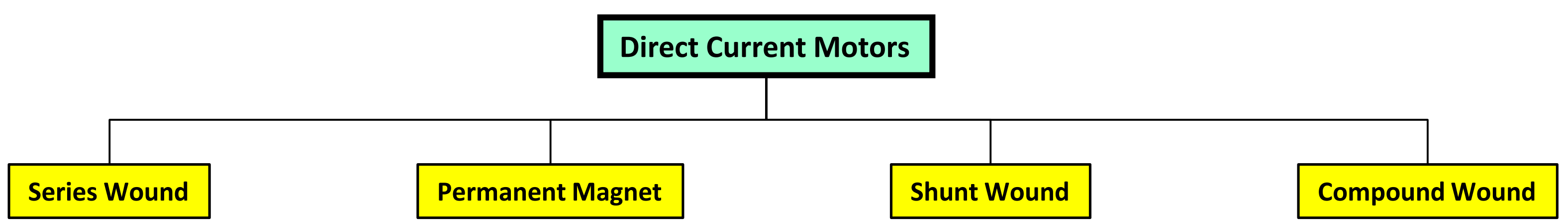

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Resources

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