National Aeronautics and Space Administration

Key Performance Parameter Driven Technology Goals for Electric Machines and Power Systems

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Panel Focus Questions

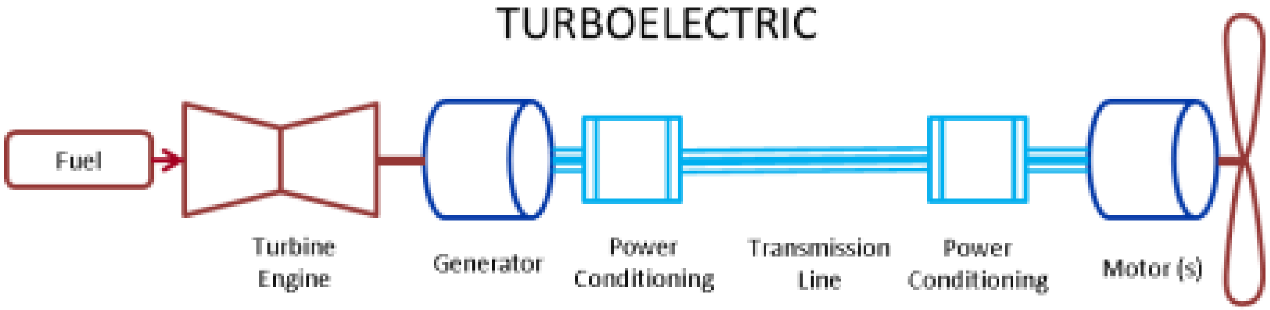
- Feasibility for Large Aircraft
- Near Term Technology Readiness Levels Required
- Suggested Research Priorities

Electric Drive System Feasibility

It is feasible for drive systems to scale up to large aircraft with reasonable TRL advancements through several plausible paths.

Reviewing feasibility of components/subsystems:

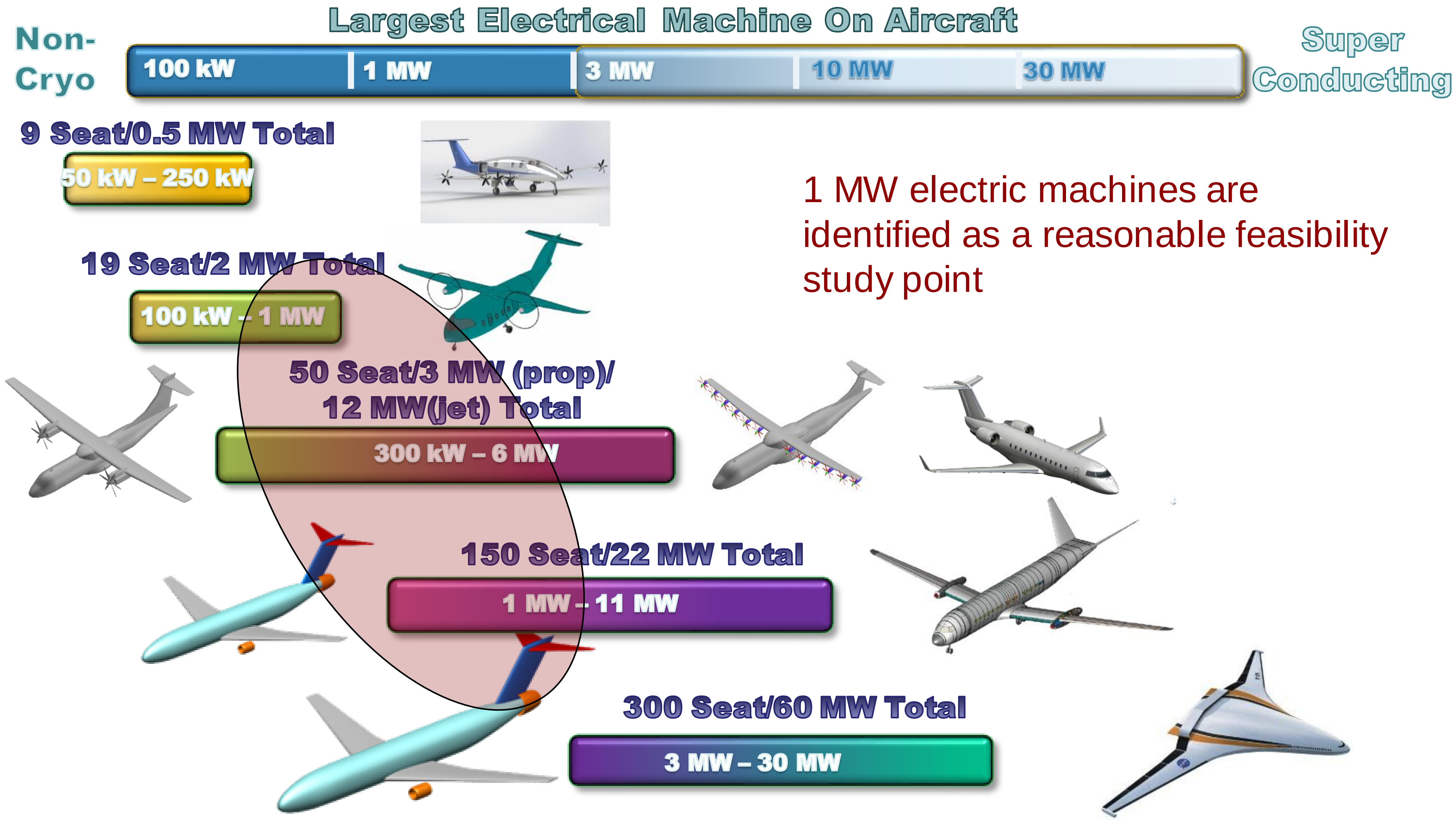
- Electric Machines: Generator & Motor
- Power Conditioning: Converters & Controllers
- Power Distribution: Architecture & Devices



Electric drive system *components* are common to the possible hybrid electric, turboelectric, and electric propulsion aircraft. Electric drive systems are being used now for small aircraft.

Electric Drive Systems tied to Aircraft

System and component feasibility must be discussed in context of vehicle configuration



Largest Electrical Machine On Aircraft

Non-Cryo

100 kW | **1 MW** | **3 MW** | **10 MW** | **30 MW**

Super Conducting

9 Seat/0.5 MW Total

50 kW – 250 kW

19 Seat/2 MW Total

100 kW - 1 MW

50 Seat/3 MW (prop)/ 12 MW(jet) Total

300 kW – 6 MW

150 Seat/22 MW Total

1 MW - 11 MW

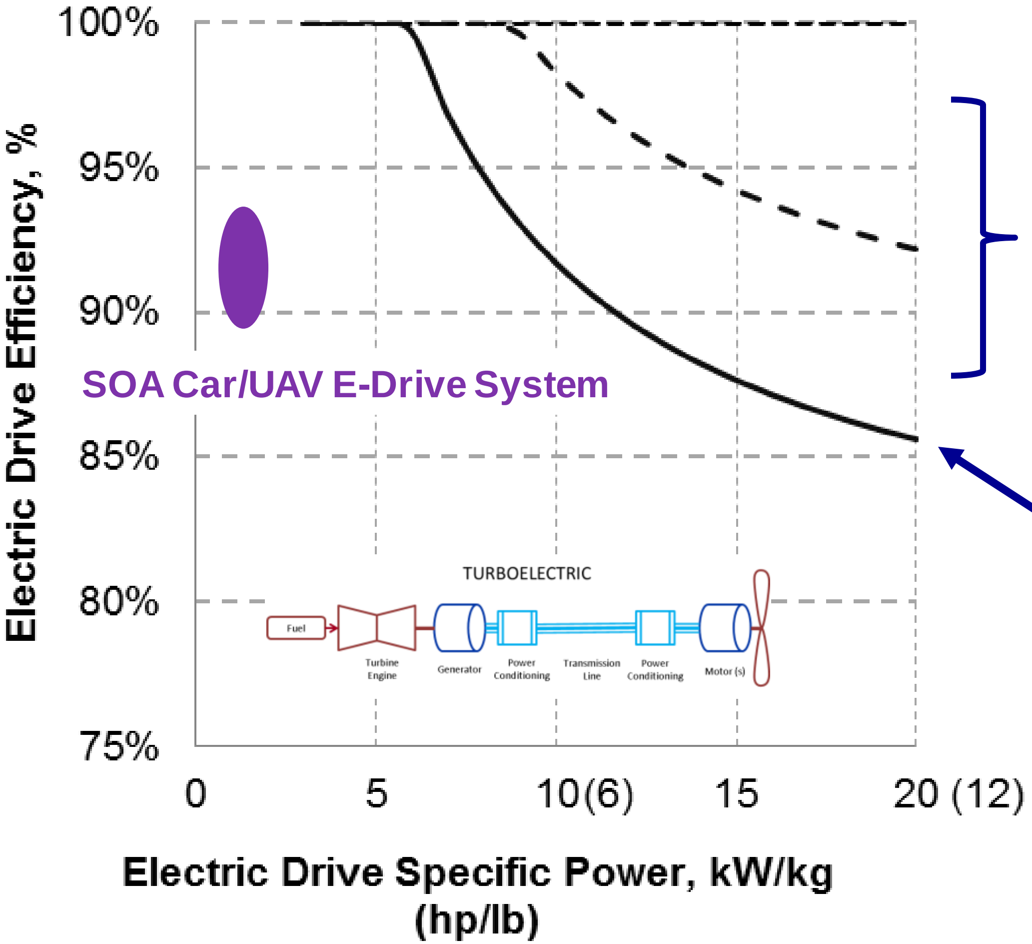
300 Seat/60 MW Total

3 MW – 30 MW

1 MW electric machines are identified as a reasonable feasibility study point

Electric Drive Key Performance Parameters

System studies inform the requirements for aircraft electric drive system



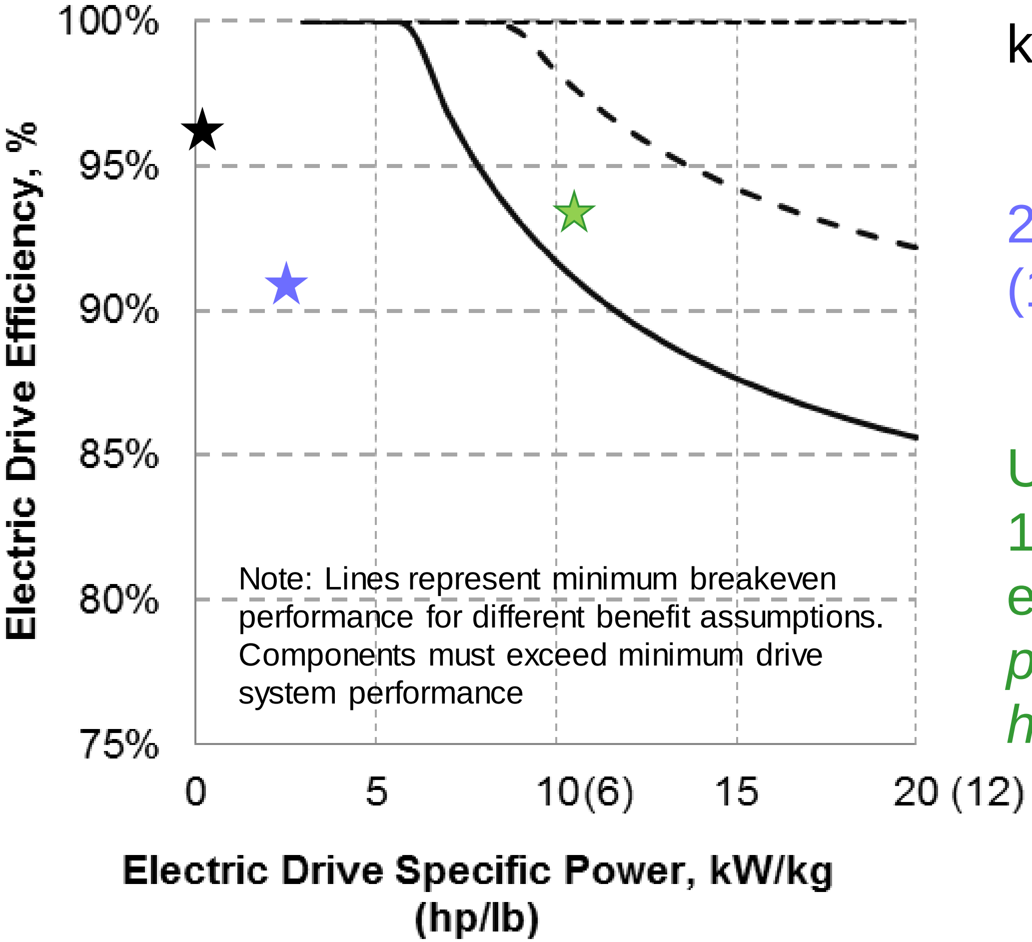
Range of target performance objectives. Each component must meet or exceed system target.

Minimum acceptable system performance based on analysis using by-pass ratio, boundary layer ingestion, and lift/drag benefit potential for small to large transport class aircraft

Jansen et al., Turboelectric Aircraft Drive Key Performance Parameters and Functional Requirements (AIAA 2015-3890)

Electric Machine State of the Art

Typical TRL 9 motors have performance outside target zone



Note: Lines represent minimum breakeven performance for different benefit assumptions. Components must exceed minimum drive system performance

Industrial Motors, 0.5-1MW, ~0.17 kW/kg (0.1 hp/lb), 96% efficiency

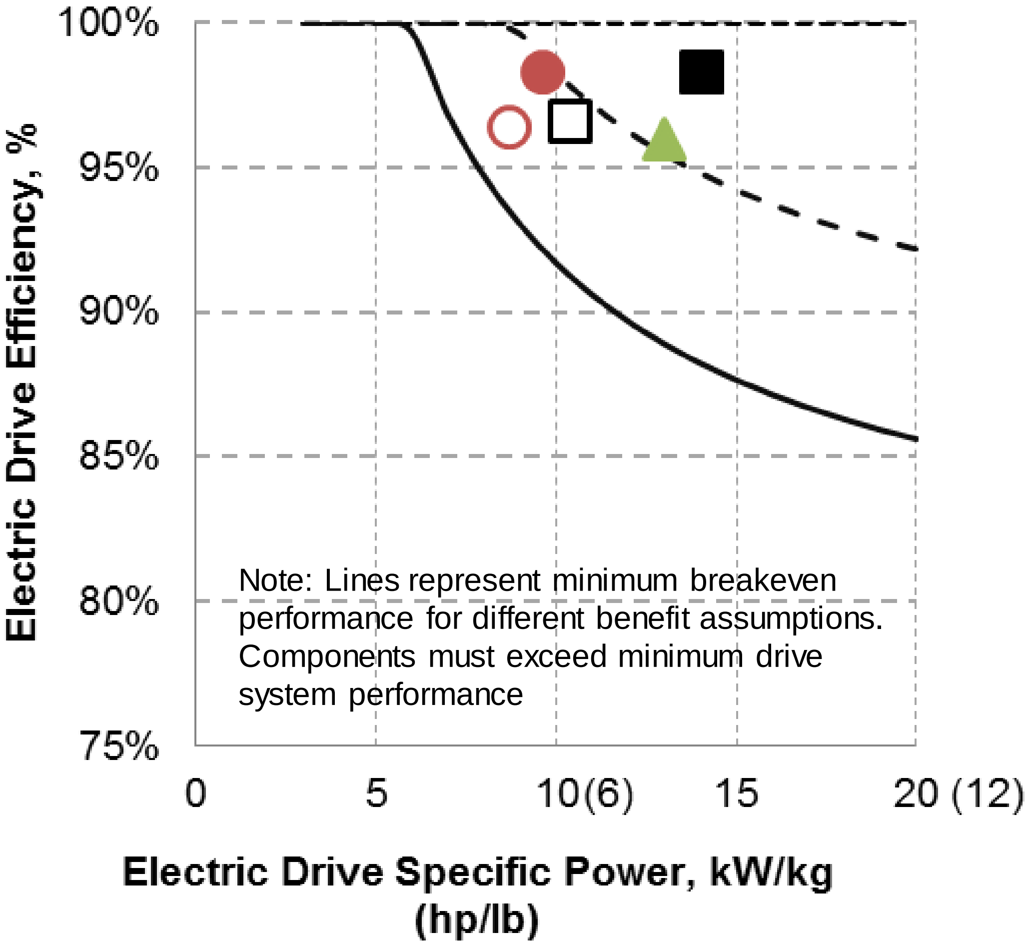
2008 Lexus, 110kW, 2.5kW/kg (1.5 hp/lb), 91% efficiency

UAV (Launchpoint) 100 kW 10.7 kW/kg (6.5hp/lb), 93% efficiency -- *Can this performance be extended to higher power?*

References in backup material

Electric Machine Development Potential

TRL 2-3 Motor design analysis for 1 MW size predicts performance feasibility



Note: Lines represent minimum breakeven performance for different benefit assumptions. Components must exceed minimum drive system performance

Synchronous reluctance motor optimized for SOA materials (open circle), with advanced materials (solid circle)

Interior Permanent Magnet motor optimized for SOA materials (open square), with advanced materials (solid square)

NRA Contract: TRL 4 Demo by 2018 for 1 MW machine with 13 kWkg (8hp/lb), 96% efficiency (triangle)

1 MW analysis by Duffy, Electric Motors for Non-Cryogenic Hybrid Electric Propulsion (AIAA 2015-3891)

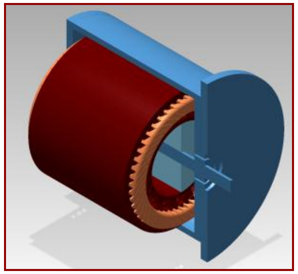
Electric Machine Development Potential

Motor analysis was used to study the performance sensitivity to new materials

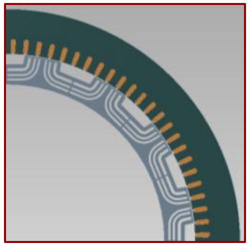
Motor Development Options

Power Level—within class specific power scales with power

Topology—electromagnetic design greatly affects component specific power



Standard PM



Synchronous Reluctance (SRM)

Materials of Construction

Near Term Material Improvements that can improve electric machine performance:

- TRL 6-7: Soft Magnetic Alloys—nanocrystalline structure decreases core losses
- TRL 3-4: Improved Insulation—increases coil packing factor and decreases temperature driven conduction losses

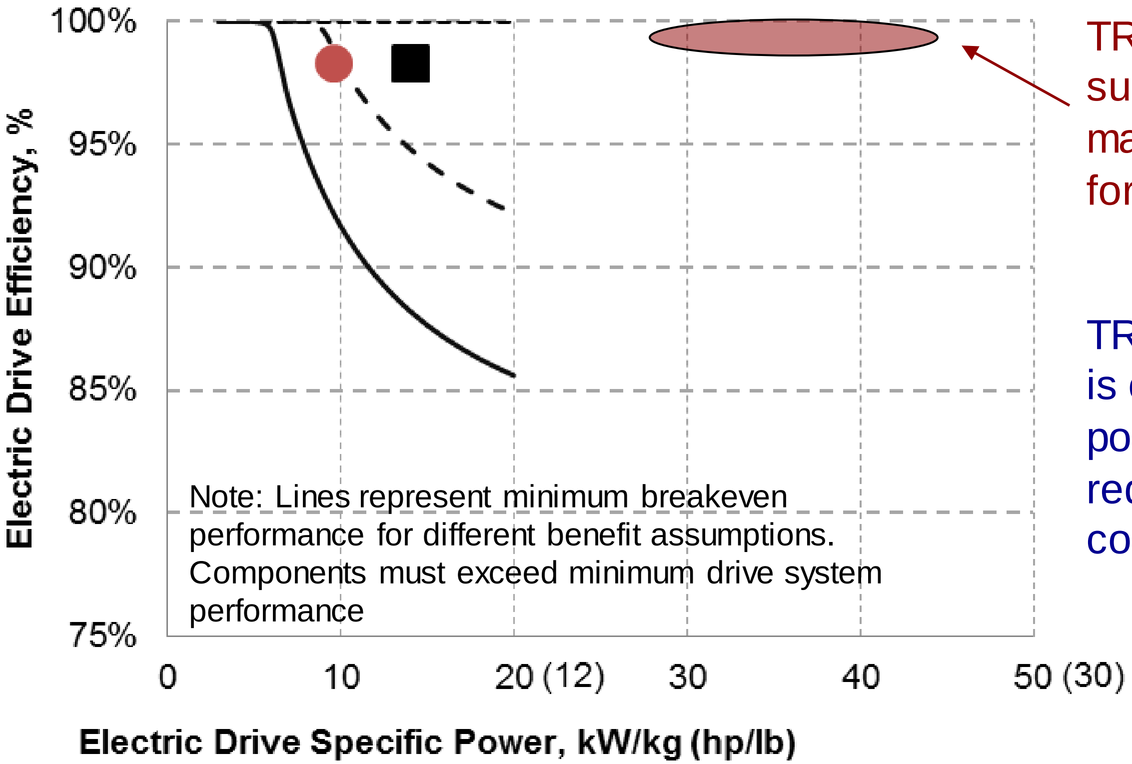
Notable efficiency increases with near-term materials

Farther Term Materials Improvement

- TRL 2-3: Improved Permanent Magnets
- TRL 1-2: Higher electrical conductivity wire

Why Superconducting Electric Machines

Superconducting (infinitely small direct conduction loss) leads to much higher specific power and greatly enhances feasibility for larger aircraft dist. propulsion



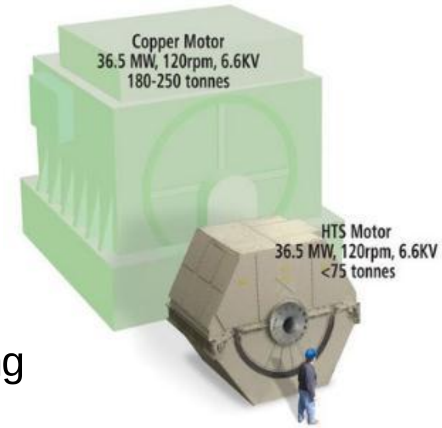
Note: Lines represent minimum breakeven performance for different benefit assumptions. Components must exceed minimum drive system performance

TRL 2-3: Projections for fully superconducting electric machines greatly exceed those for other motor types.

TRL 3-4: Wind turbine industry is considering superconducting power generation for volume reduction and improved component lives

TRL 7: Limited data on specific power, reported values as high as 7 kW/kg*, with flat (not twisted) stator wire

TRL 9: Extensive use of superconducting magnets in medical imaging



*HTS fully superconducting, GE, 2007

Superconducting Electric Machine Potential

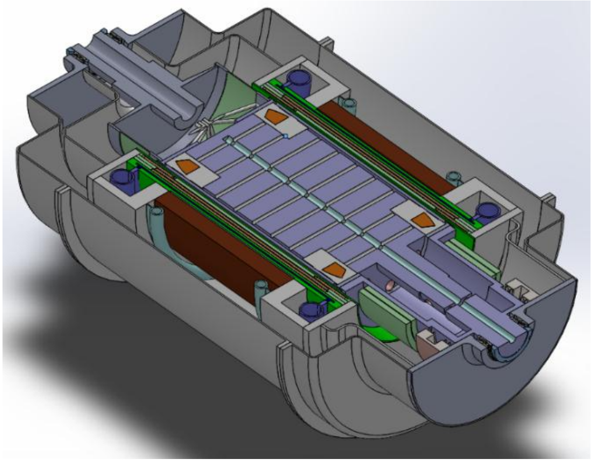
Motor/Generator Designs based on superconducting electric windings have much higher specific power potential

TRL 2-3: Detailed *Concept* Design of 12 MW Fully Superconducting Machine achieving 41 kW/kg (25 hp/lb) assuming practical subcomponent improvement in fine, twisted MgB_2 (Trudell, 2014)

Generator speed	8,000 rpm
Power	12 MW (16,086 hp)
Weight*	288 kg (635 lb)

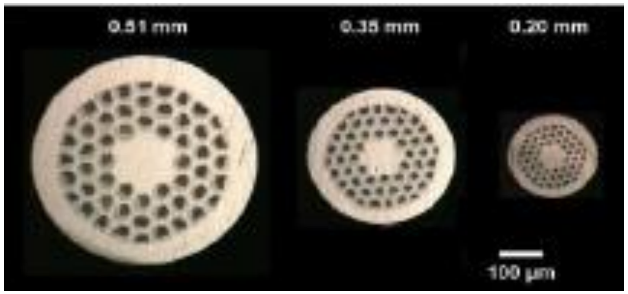
(*SolidWorks design)

Efficiency	99.8 %
Specific Power	**41 kW/kg**
Overall length	0.83 m (32.5”)
Outer diameter	0.52 m (20.6”)



Superconducting Electric Machine Potential

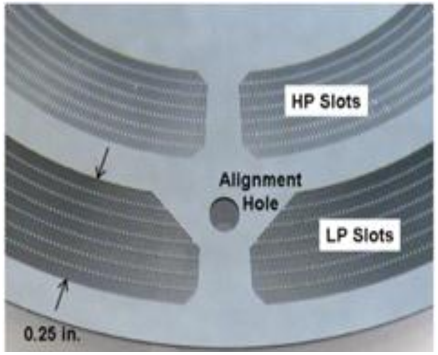
Key Issues in continued superconducting machine development



Power Loss—minimal resistivity losses, but still have losses driven by alternating currents. Strands with filaments as low 10 μm and twist pitch as low as 10 mm per twist have been demonstrated.

Cryogenic thermal management is crucial. Vehicle design can play a roll via fuel selection. Component solution is cyro-cooler development targeting 8 kW/kg based on input power.

Need to continue development of reliable, cryogenic power components.



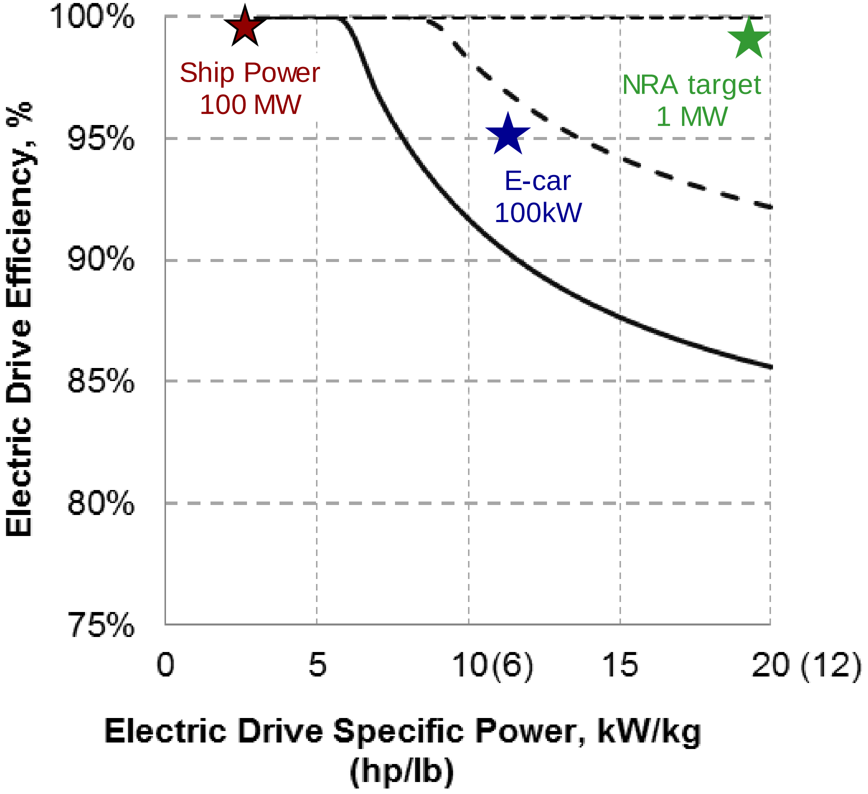
Recuperator plate

Power Conditioning Developments

Industry is advancing development at all component levels

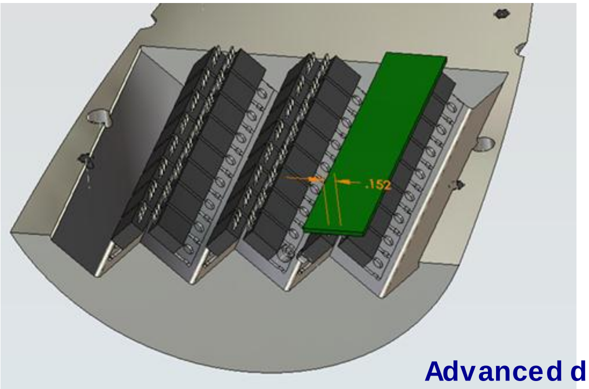
Power Conditioning Electronic Components of interest include:

- Rectifier – convert AC to DC
- Inverter – convert DC to AC
- Motor Controller – control motor speed, for system efficiency integrate with



Power Components are improved by:

- Advance topology
- Sophisticated software control
- Sophisticated thermal management
- Advanced devices

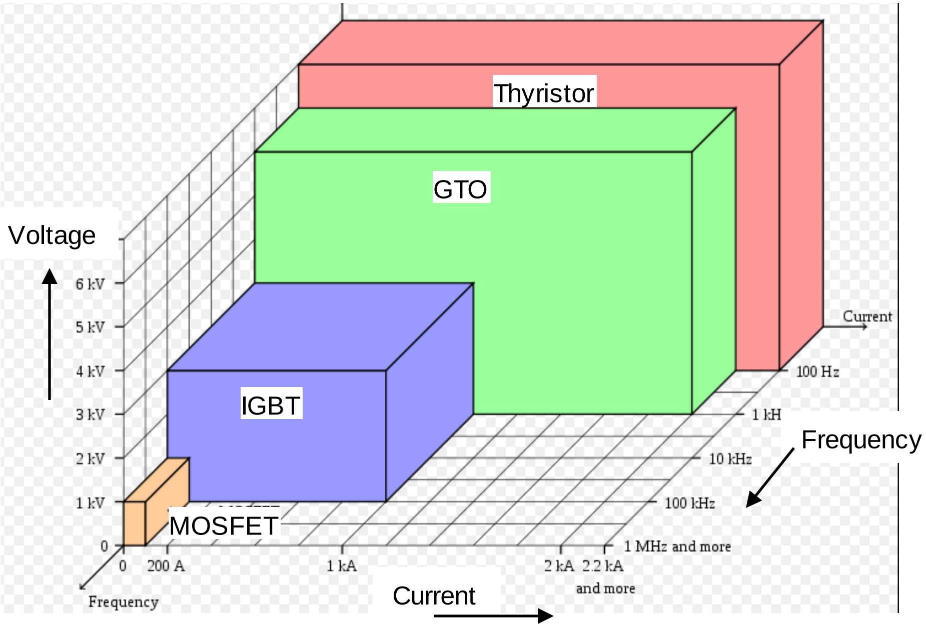


Advanced device packaging for volume and thermal control

Power Device Developments

Power Devices are the building blocks of Power Components

- Different classes of power devices are needed based on the power level needed.
- Advanced component topologies can allow lower power devices to be used in high power applications
- Underlying material advancements are greatly reducing the weight and volume of power conversion devices



Advanced materials are driving device capabilities

- New wide band gap (SiC, GaN) semiconductors have higher current densities, frequency response, and temperature range.
- New soft magnetic and capacitor materials extend voltage and frequency capabilities → increases device efficiency and decreases weight and volume

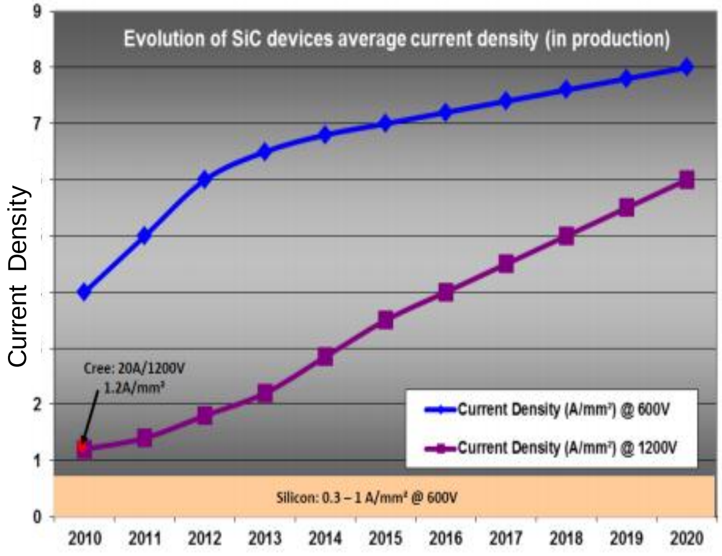
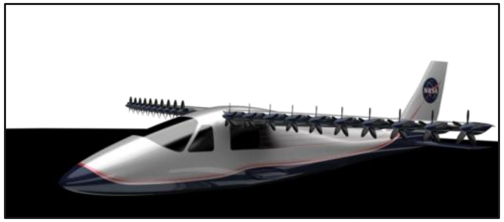


Figure 4. Current Density evolution for SiC (Yole Developpement, 2012)

Power Distribution

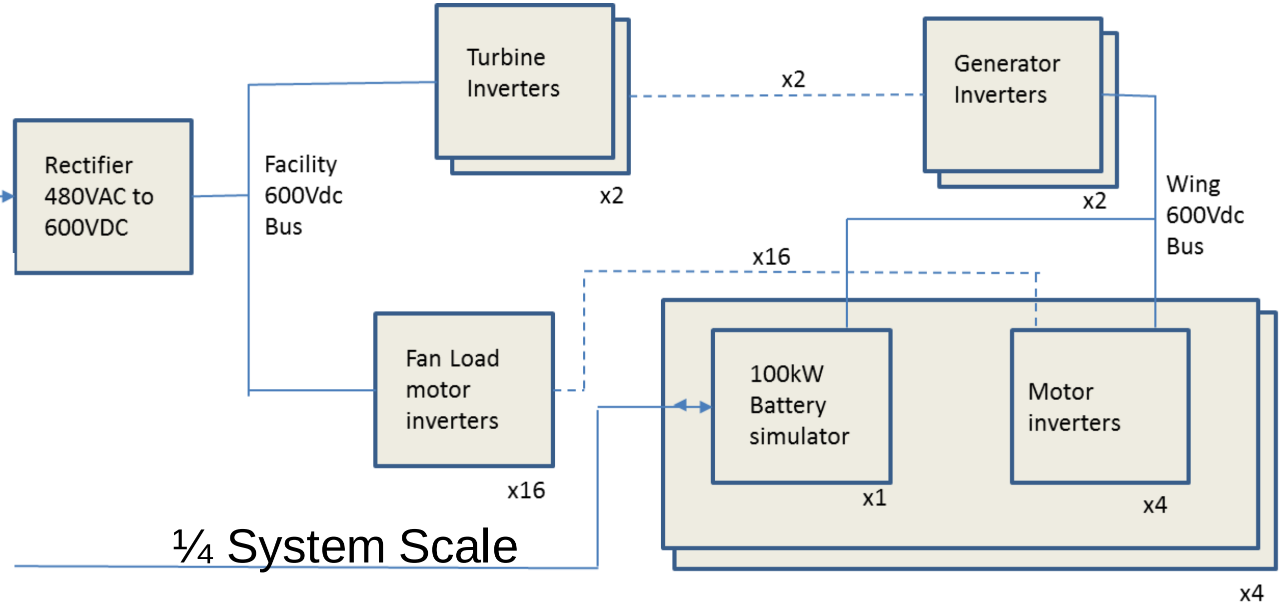
Mass, packaging, and atmospheric pressure induced insulation breakdown represent unique challenges to aircraft distribution grid

Small electric aircraft are establishing the SOA in aircraft distribution

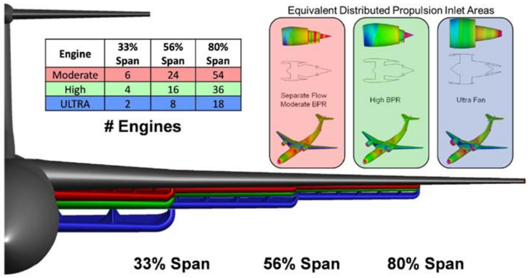


Detailed system analysis/layout to confirm feasibility of 2 MW grid ground test for 16 Ducted Electric Fans and 2 Turbo-generators

480VAC
3 phase



¼ System Scale



Engine	33% Span	56% Span	80% Span
Moderate	6	24	54
High	4	16	36
ULTRA	2	8	18

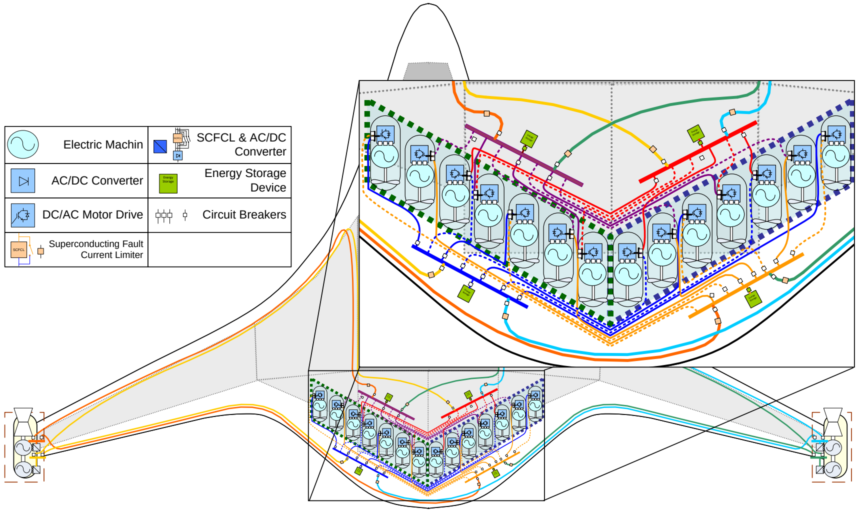
 # Engines

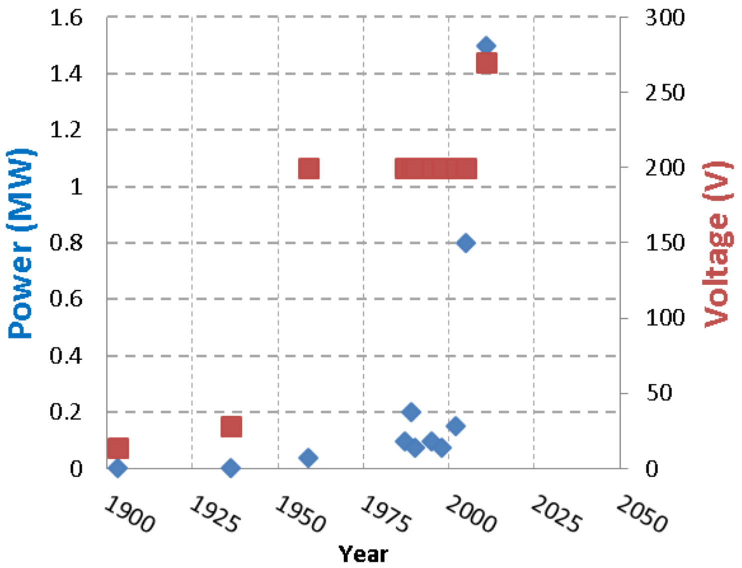
Figure 3: Depiction of OWN Fan Propulsive Areas Distributed Along Various Wing Spans Highlighting the Wide Range of DP Coverage Evaluated Under this Effort.

Power Distribution

Highly distributed power can provide system redundancy but also challenges

- TRL 8-9: Marine and Wind Power Generation are providing some relevant grid, component and standards development
- TRL 5-6: 1MW level aircraft distribution has been demonstrated for non – propulsive loads on aircraft.
- TRL 2-3: High Voltage, advanced AC/DC distribution approaches attractive but requires new technology
- TRL 1-2: Highly conductive transmission lines (superconducting, carbon nanotube, etc.)





Challenges of High Voltage

- Paschen Discharge Curve

  Breakdown voltage across a gap is a function of pressure and gap distance

  Pressure at 40,000 ft greatly reduces breakdown voltage

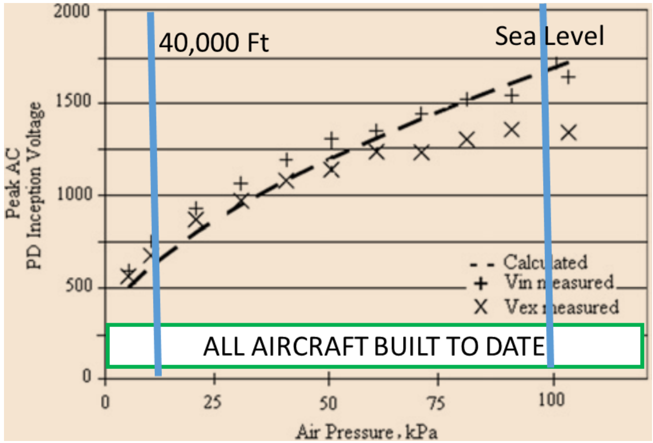
- Electromagnetic Interference

  The aircraft will have multi MW power systems, instrumentation, and people within a very confined space. EMI considerations will be significant.

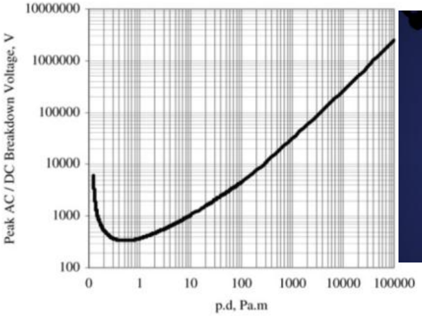
- Standards

  Many elements of a power system need to be coordinated in order to operate successfully as a system

  Definition of voltage, frequency, and interfaces helps facilitate the move to a new voltage.



Partial Discharge Voltage for a representative aircraft cable.



Near-Term Technology Readiness Needs

Going from *FEASIBLE* to *DEMONSTRATED*

TRL 4-5 component demonstration of specific power & efficiency as determined by KPPs

- Demonstrate electric machines, power electronics & power grid at 1 MW level

TRL 6 for subscale power/propulsion ground system verification leading to

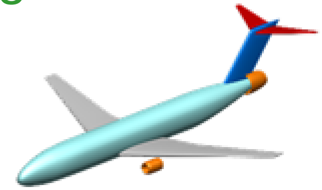
- Higher fidelity vehicle configuration analysis and refined component requirements for high power and high voltage
- Representative aircraft demonstrations

TRL 2-3 for 300 PAX cryogenic turbo electric drive system

- Fully Superconducting machines & distribution represents a feasible solution for revolutionary, large aircraft
- Maintain steady, long-term investment

Research and Development Priorities

Electric Drives Systems must be informed by vehicle and system integration; large aircraft initially must focus on concentrated and less-distributed propulsion



150 Seat/22 MW Total

1 MW – 11 MW

Non-Superconducting Drive Technology

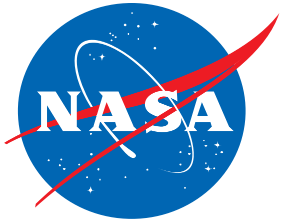
- High Efficiency, Specific Density Electric Machines & Power Electronics
  - emphasis on advanced topologies and materials of construction
- Power protection devices and methodology for high voltage distribution
- Some investment in break-through technology such as revolutionary conductors, self-healing insulation

300 Seat/60 MW Total

3 MW – 30 MW

Cryogenic Superconducting Drive Technology

- Fully Superconducting Electric Machine Technology
  - Fine filament/twisted conductor wire and machine design
- Light, efficient cyro-cooler technology
- Cryogenic power protection devices and methodology for kV distribution
- Some investment in break-through technology such as fine filament/twisted superconductor for higher temperatures (other material systems)


NASA

Panel Focus Questions

Q: For various electric drive system technologies currently under development for aviation and other applications, what is the feasibility that they can be scaled up to meet the requirements of a large commercial transport in terms of key parameters such as power, energy, reliability, and safety?

A: The data presented here shows feasibility with reasonable TRL advancements. The electric drives can be utilized at power appropriate to several plausible transport class vehicles. (Such as concentrated propulsion w/ non-cryogenic motors vs. distributed vehicle configurations with cryogenic, superconducting machines). Energy savings must be addressed at system level. Architecture for distributed can distribute engine-out failures. Component reliability must be determined.

Q: What are the technology readiness levels of technologies needed to realize the next generation or two of electric drive system performance?

A: TRL 4 component and component material demo of power density & efficiency
TRL 6 for subscale power/propulsion ground system verification leading to

- Higher fidelity vehicle configuration analysis and refined component requirements
- Small aircraft flight demonstrations

TRL 2 for 450 PAX cryogenic turbo electric and 150 passenger battery power systems

Panel Focus Questions

Q: What would be the highest priority electric drive research and technology development projects?

- Electric Machines (8-20 kW/kg): Concurrent development and maturation of both non-superconducting and cryogenic superconducting machines will give maximum potential for credible transport class aircraft architectures

  There are no current-industry drivers for performance level aircraft requires

- Power Conditioning & Distribution: Extending 2-4 times SOA in Power Density at MW levels for the higher voltages and higher frequencies of interest
- Electric Machines and Power Electronics: enabled by both clever architectures, advanced topologies and improvements in building block materials

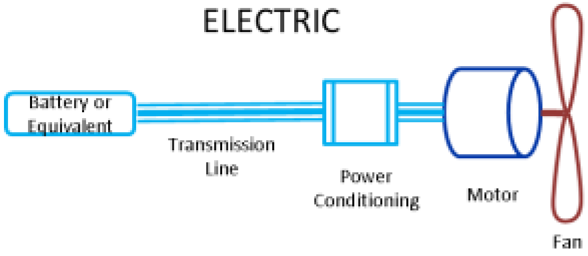
Also

- Deep dive system studies and subsystem validation testing are needed concomitant with drive component development to ensure the correct technical focus
- Performing electric drive system testing will inform higher fidelity vehicle configuration studies.
- Electric drive system characteristics require for flight control development.

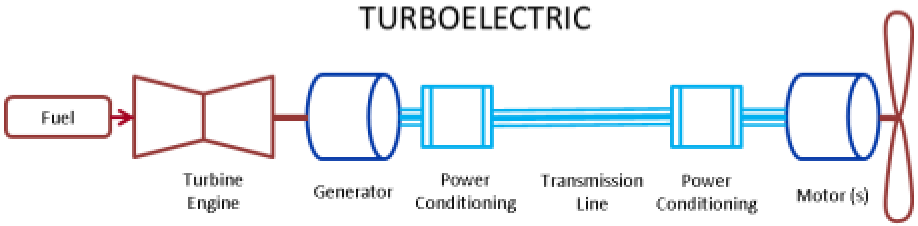
Backup: Electric Drive Definitions

Electric Drive Technology Development Impacts Power Suite. “Hybrid Electric” occasionally used generically for Electrically Augmented Propulsion

Electric – A single power source from stored energy

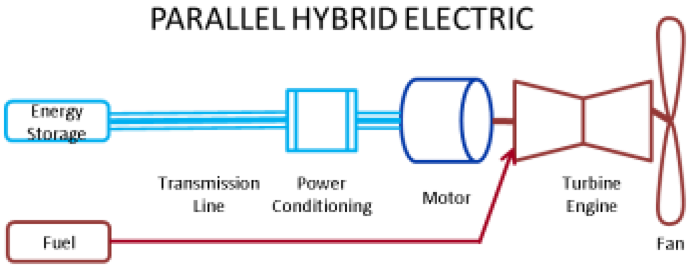


Turbo Electric – A single power source from fuel burning turbine engine and transmitted electrically

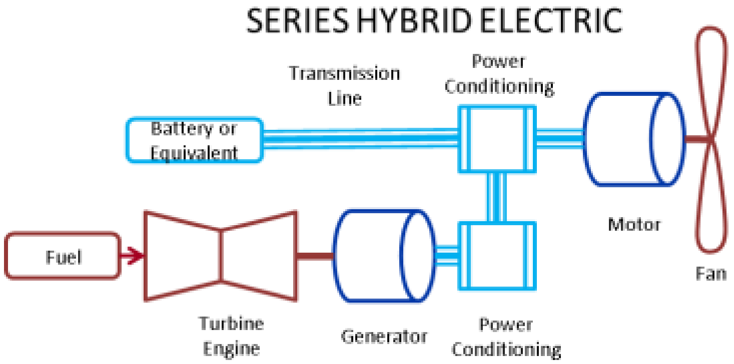


Hybrid Electric – Power is generated from more than one source, such as through turbine shaft power and battery energy storage

Parallel Hybrid Electric – Power sources mix at the point of application



Series Hybrid Electric – Power from all sources are distributed electrically



Series/Parallel Hybrid Electric – Power sources mix at the point of application and can operate independently.

Backup: SOA Drive System & Elec. Machines

	Size Range	Overall System		Motors / Generators		Power Electronics	
Ships	10-120MW			0.48 kW/kg[4]		2.6kW/kg[3]	99%[3]
Trains							
Cars (1) Lexus 600h	50-300kW	1.15kW/kg	91%	1.3kW/kg 2.5	- 91%	11.5kW/kg	
Wind Turbine (8)	Up to 8				96-99		
Industrial (5)	1-500HP 500-575 kW			- 0.17 kW/kg	~96%[2] ~ 96%		
UAV (6, 7)	6 kW 100 kW	1 kW/kg	93%	8.2 10.7 kW/kg	93%		

1) DOE, "Advanced Power Electronics and Electric Motors R&D", May 2013 APE00A, page 5
2) DOE" PREMIUM EFFICIENCY MOTOR SELECTION AND APPLICATION GUIDE", February 2014, page2-4
3) GE Power Conversion Brochure, "MV7000 Reliable, high performance medium voltage drive" 2013
4) Marinlog, "Converteam ships first 36 MW generator for new British aircraft carrier", May, 2011
5) Marathon Electric Motor catalog
6) http://www.launchpnt.com/news/news/bid/105014/LaunchPoint-Develops-High-Specific-Power-Genset-for-UAVs
7) http://www.launchpnt.com/portfolio/transportation/electric-vehicle-propulsion/
8) Blaabjerg and Ma., Future on Power Electronics for Wind Turbine Systems (IEEE J Emerg. Topics Power Elecs., 1(3), Sept. 2013)

Backup: Electric Propulsion Drive State of the Art

Range 7000 nautical miles
40MW- 4160V AC,
turbines& diesel generator sources

117MW- turbines/diesel generator sources

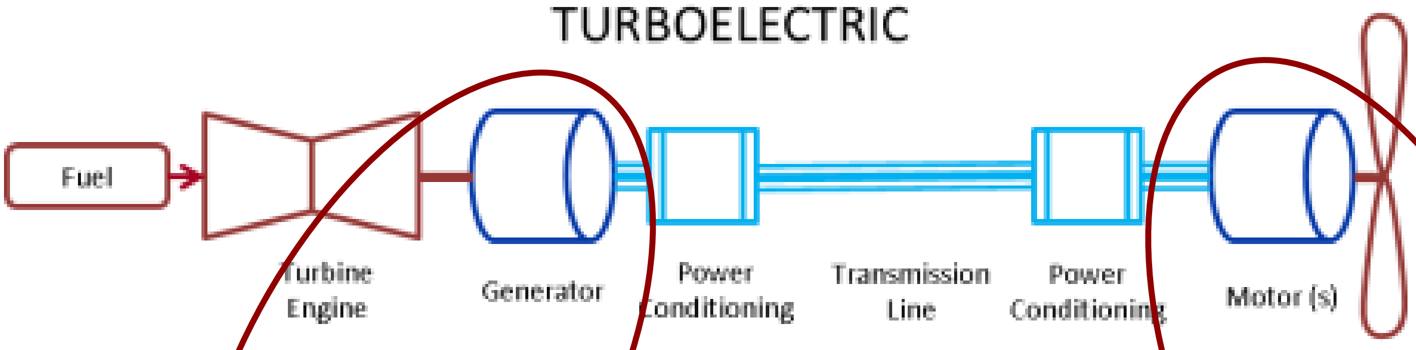
3.2 MW
diesel electric generator source

265 mile range
310kW electric motor
85kW-hr battery
>75,000 units
>1 billion fleet miles

1-2 people
2x30kW motors
Battery powered
1 hour flight time

Electric Drive Definitions

State of the Art Electric Drive System *Sized* for Large Aircraft



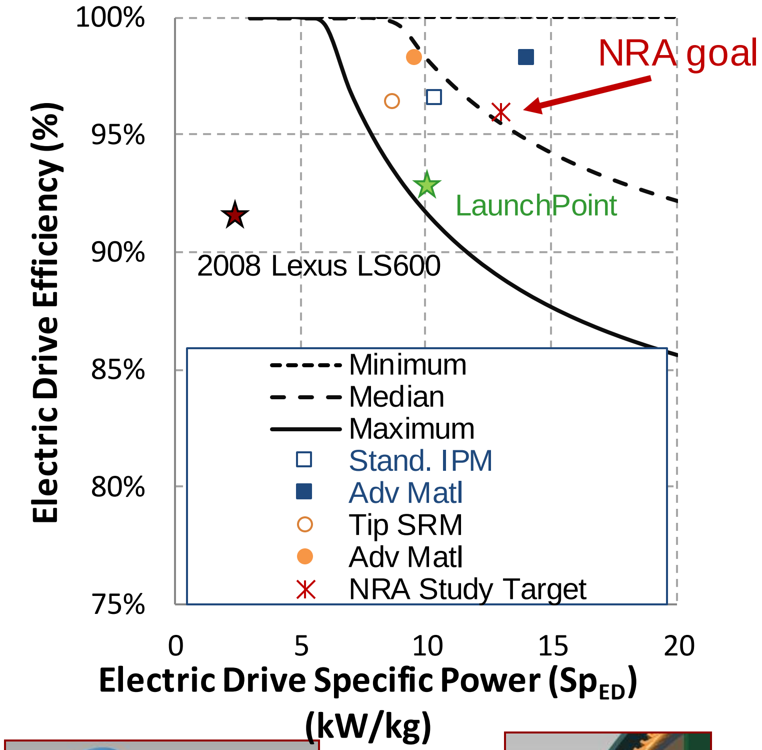
	Generator	Rectifier	Transmission	Inverter	Motor
Relative Wt	38%	11%	2%	11%	38%
Nominal Eff.	97%	98%	99%	98%	97%

Relative weight and efficiency associated with a crude analysis of turboelectric system for large aircraft—does not close with net benefit. Electric Machines are a primary system development driver.

Backup: Electric Machine Development Potential

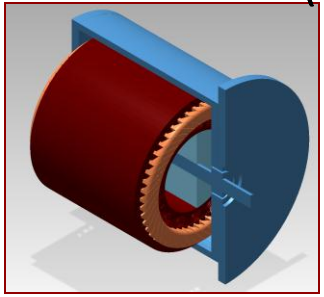
General motor design analysis for multiple topologies optimized for 1 MW size with start-of-art and advanced materials of construction

Drive	**Motor Type**	**Baseline Materials**		**Improved Materials**	
		Power Density kW/kg (HP/lb)	Efficiency	Power Density kW/kg (HP/lb)	Efficiency
Standard	SPM	10.6 (6.4)	95.1%	14.5 (8.8)	97.4%
	IPM	10.4 (6.3)	96.6%	14.0 (8.5)	98.3%
	SRM	4.6 (2.8)	93.5%	4.9 (3.0)	97.1%
	IM	3.5 (2.1)	94.8%	4.9 (3.0)	97.6%
Tip Drive	SPM	9.6 (5.8)	90.9%	12.0 (7.3)	93.3%
	IPM	9.8 (6.0)	96.5%	12.0 (7.3)	97.7%
	SRM	8.7 (5.3)	96.4%	9.6 (5.8)	98.3%

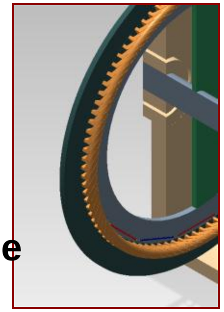


Motors must meet or exceed system goals. Highlighted designs meet preliminary target of 5.8 kW/kg for electromagnetic subsystem weight

Stand. Drive



Tip Drive



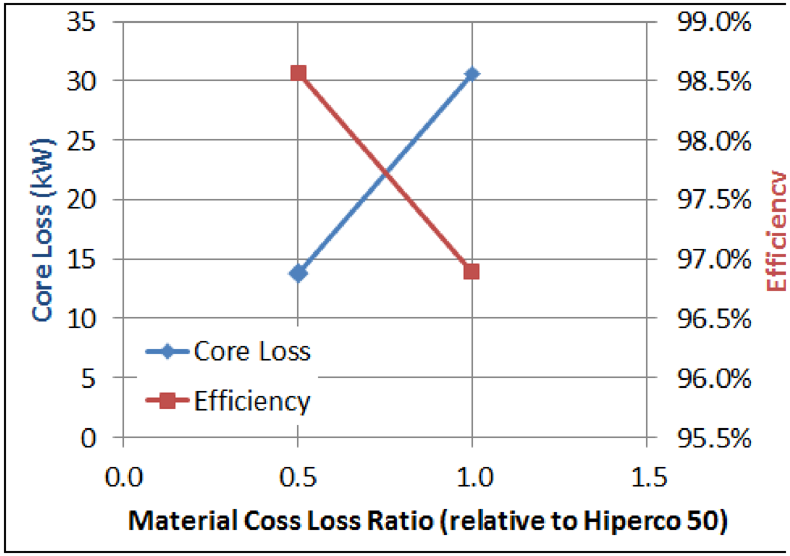
Duffy, Electric Motors for Non-Cryogenic Hybrid Electric Propulsion (AIAA 2015-3891)

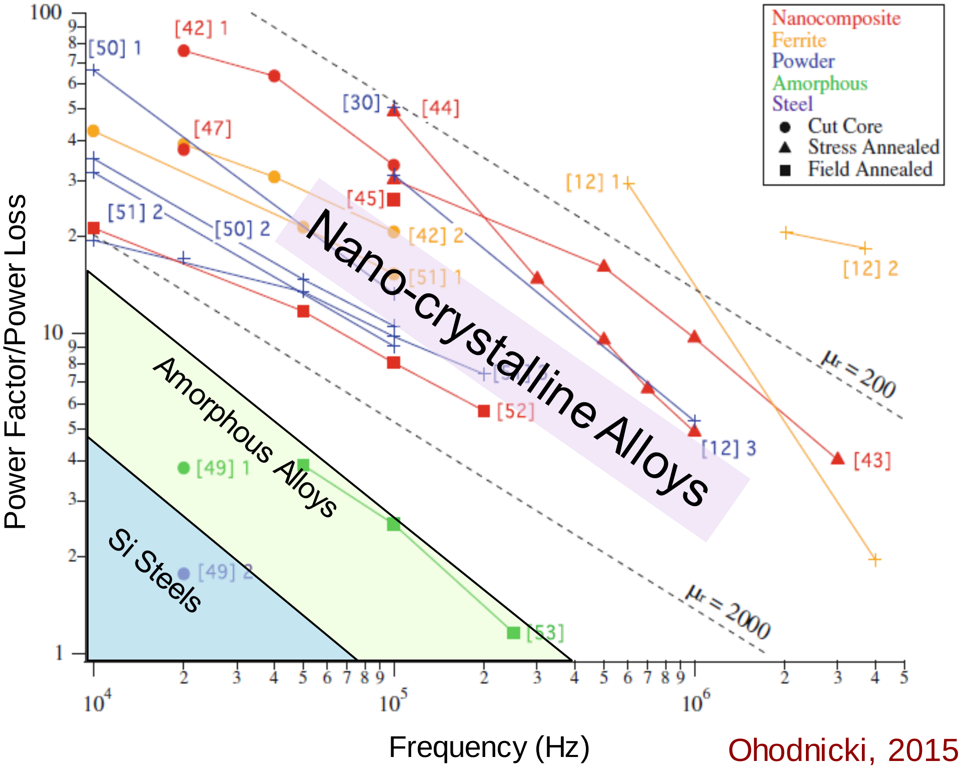
Electric Machine Development Potential

Motor analysis was used to study the performance sensitivity to new materials

Developmental magnetic materials have been shown to increase efficiency in electric machines and power electronics

- Machine (or electronic) efficiency goes up with switching frequency but magnetic losses go up with switching frequency
- Amorphous and nano-crystalline magnetic materials have demonstrated lower power loss losses





Ohodnicki, 2015

Electric Machine Development Potential

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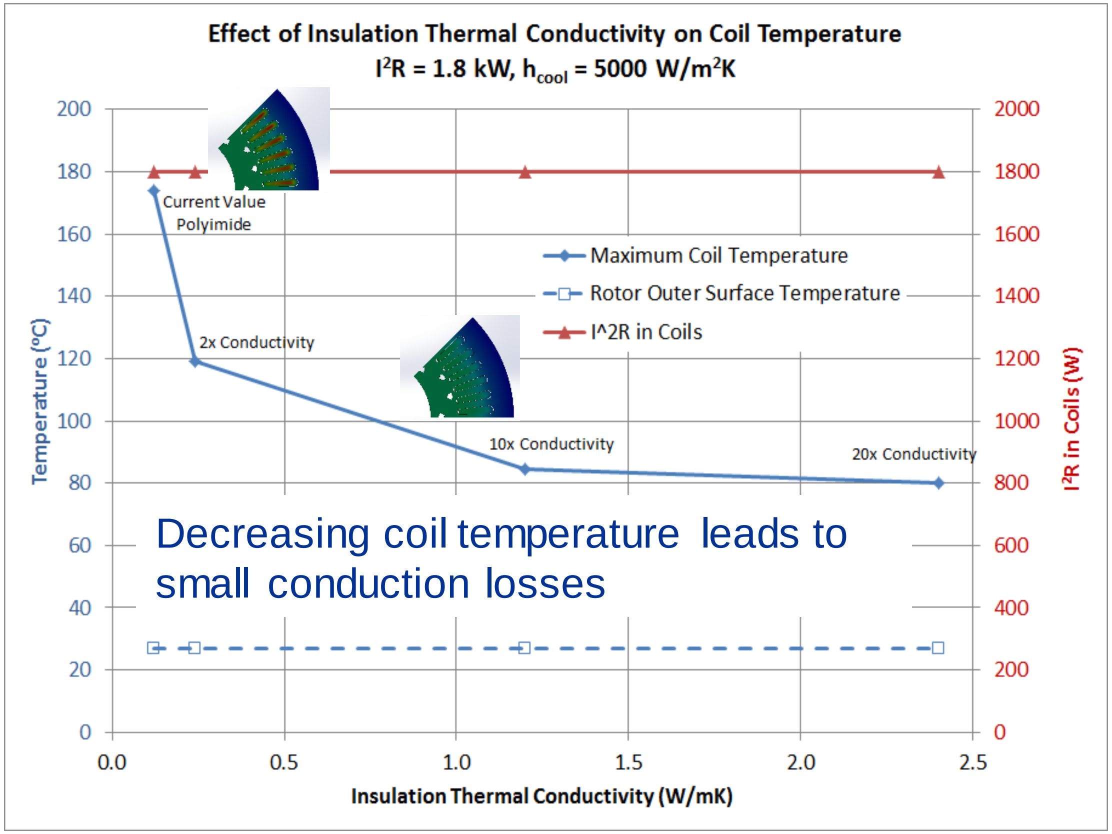
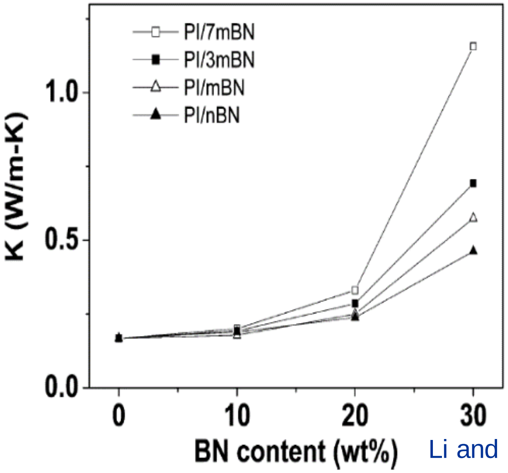


Decreasing coil temperature leads to small conduction losses

- Increasing wire insulation thermal conductivity allows faster heat removal for lower conduction losses.
- Increasing dielectric breakdown voltage allows thinner insulation for tighter coil coupling with volume & electromagnetic benefits



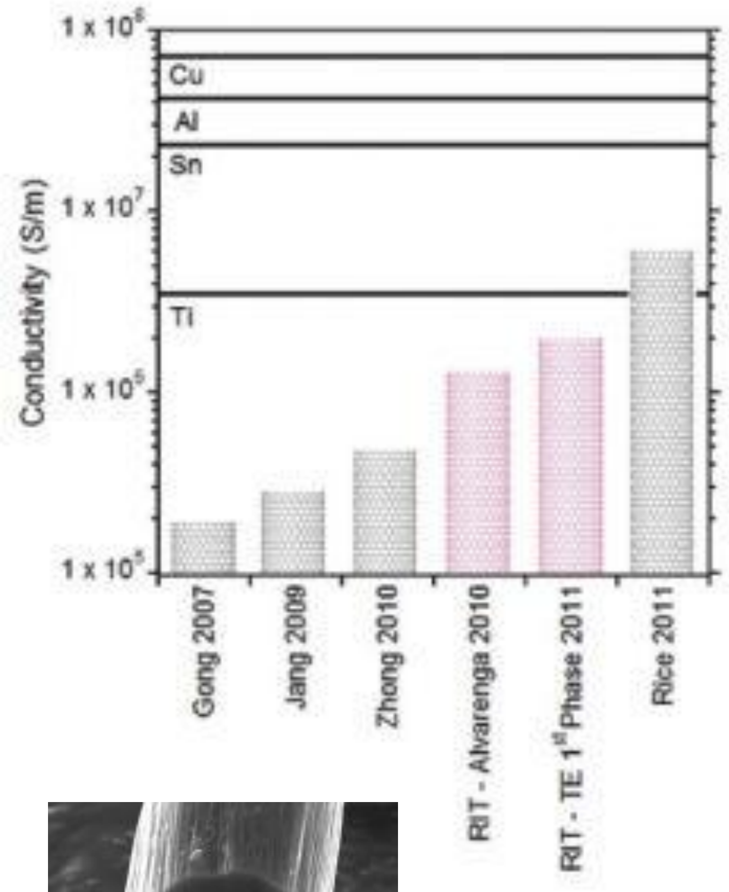
Li and Hsu 2010

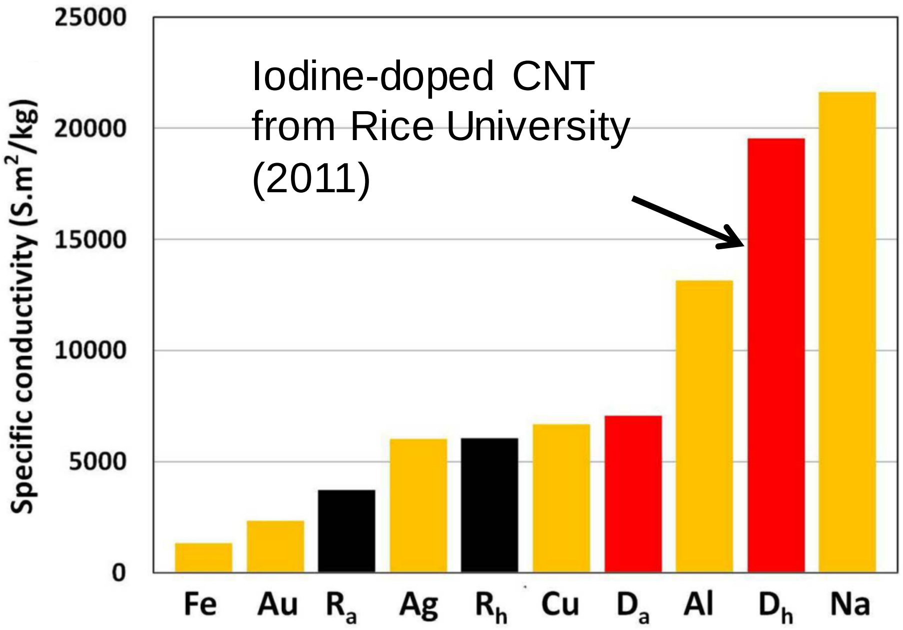
Can Increase Conductivity by

- Polymer chemistry
- nano-composites

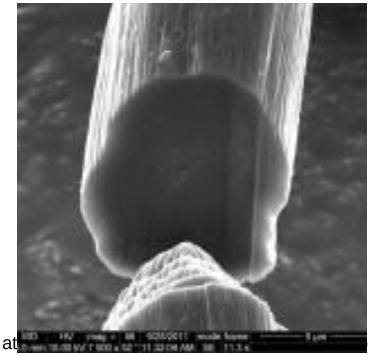
BN has the potential to impact both thermal conduction a electrical resistance

Coils With High Electrical Conductivity





Iodine-doped CNT from Rice University (2011)

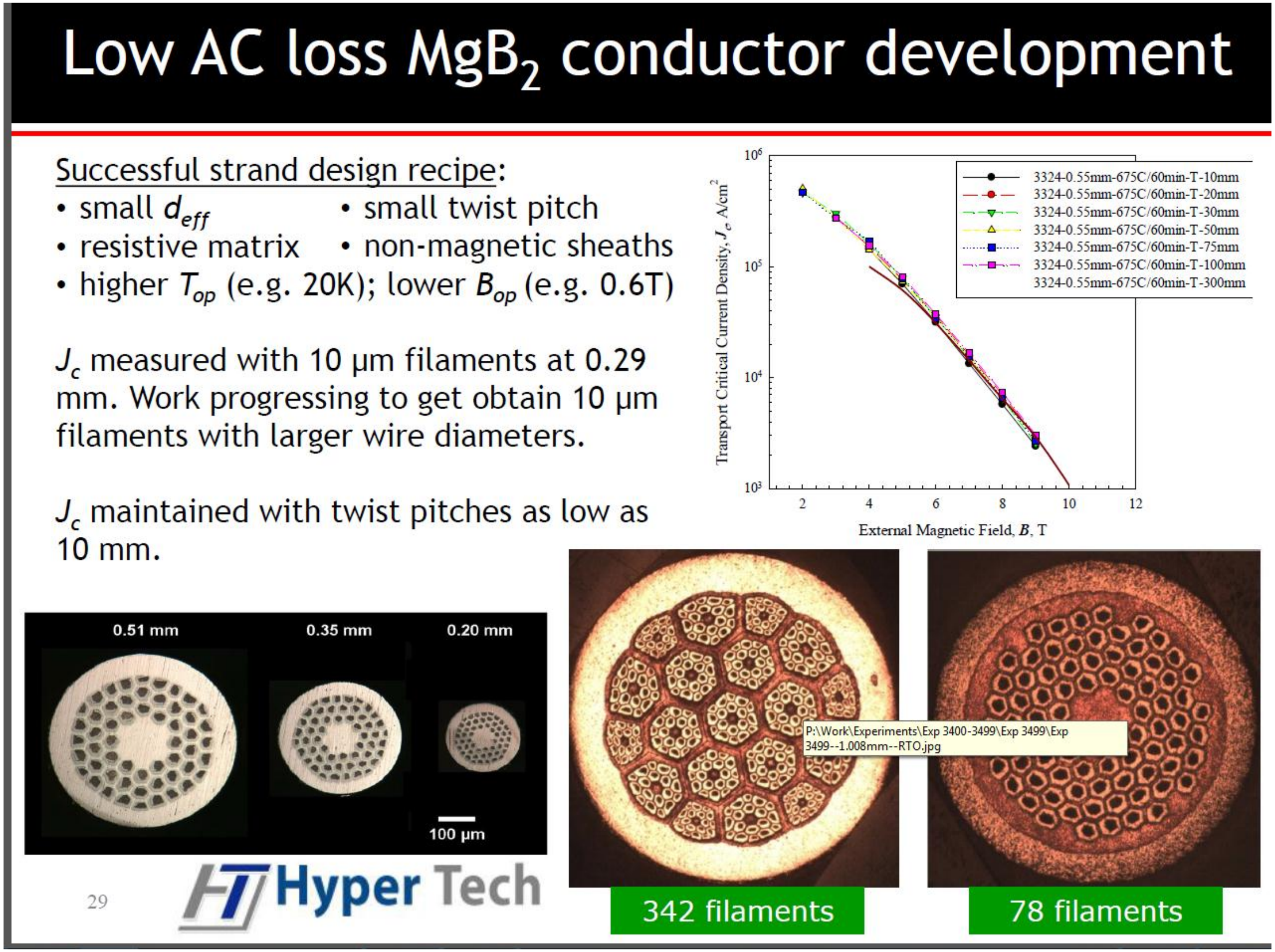


Nat n

2013- carbon nanotube fiber with high specific electrical ampacity by Rice Univ.

Challenge:

- CNT fiber with electrical conductivity greater than Cu
- Fabrication of coils with CNT fiber



Low AC loss MgB_2 conductor development

Successful strand design recipe:

- small d_{eff}
- small twist pitch
- resistive matrix
- non-magnetic sheaths
- higher T_{op} (e.g. 20K); lower B_{op} (e.g. 0.6T)

J_c measured with 10 μm filaments at 0.29 mm. Work progressing to get obtain 10 μm filaments with larger wire diameters.

J_c maintained with twist pitches as low as 10 mm.

P:\Work\Experiments\Exp 3400-3499\Exp 3499\Exp 3499--1.008mm--RTO.jpg

342 filaments

78 filaments

29

From Tomsic, et al, 2015 ASC Presentation, “Development of MgB_2 superconductor wire and coils for practical applications” Cryogenic Engineering Conference (Tucson, June 28-July 2, 2015)

Superconducting Lit

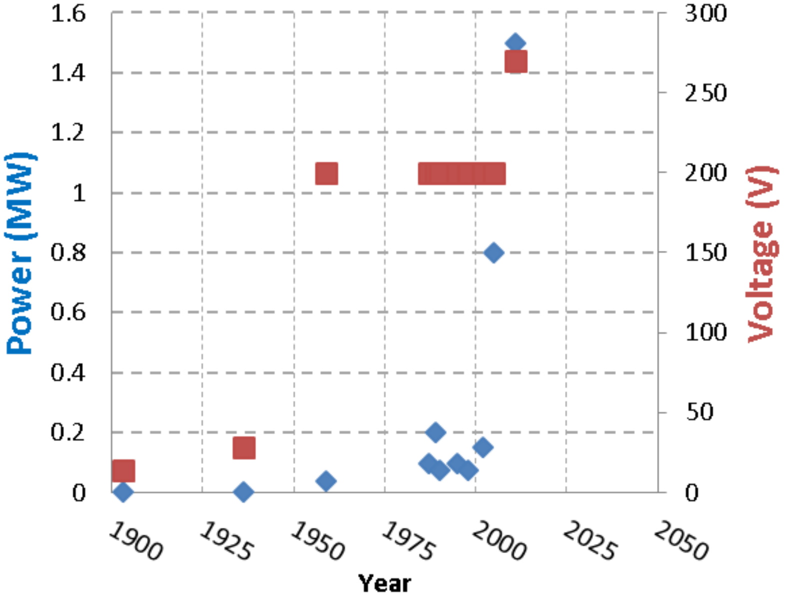
- “*Turboelectric Distributed Propulsion in a Hybrid Wing Body Aircraft*”, J. Felder, G. Brown, H. Kim, J. Chu, ISABE-2011-1340, 20th ISABE Conference, Götenberg, Sweden, 12-16 Sept., 2011
- “*Weights and Efficiencies of Electric Components of a Turboelectric Aircraft Propulsion System*”, G. V. Brown, 49th AIAA Aerospace Sciences Meeting, Orlando FL, January 4-7, 2011
- *“Turboelectric Distributed Propulsion Engine Cycle Analysis for Hybrid-Wing-Body Aircraft”*, J. L. Felder, H. D. Kim, G. V. Brown, 47th AIAA Aerospace Sciences Meeting, Orlando FL, January 5-8, 2009.
- *“Next Generation More-Electric Aircraft: A Potential Application for HTS Superconductors”,* Cesar A. Luongo, Philippe J. Masson, Taewoo Nam, Dimitri Mavris, Hyun D. Kim, Gerald V. Brown, Mark Waters, David Hall, Applied Superconductivity Conference 2008, Chicago, IL

- “*Stability, Transient Response, Control, and Safety of a High-Power Electric Grid for Turboelectric Propulsion of Aircraft*”, Michael Armstrong, Christine Ross, Danny Phillips, and Mark Blackwelder, NASA/CR—2013-217865, 2013
- Two CRs from 2nd RTAPS near publication
- *“Development of a 3D Sizing Model for All-Superconducting Machines for Turbo-Electric Aircraft Propulsion”*, Philippe J. Masson, Kevin Ratelle, Pierre-Adrien Delobel, Antonio Lipardi, and Clement Lorin, VOL. 23, NO. 3, JUNE 2013
- *“Numerical Analysis of the Impact of Elliptical Fields on Magnetization Losses”*, Clement Lorin and Philippe J. Masson, IEEE TRANSACTIONS ON APPLIED SUPERCONDUCTIVITY, VOL. 23, NO. 3, JUNE 2013
- *“Scaling Law for Hysteresis Losses in Round Superconductors Magnetized by Alternating, Rotating or Elliptical Magnetic Fields”*, Clément Lorin, Denis Netter, and Philippe J. Masson, IEEE TRANSACTIONS ON APPLIED SUPERCONDUCTIVITY, VOL. 25, NO. 1, FEBRUARY 2015
- *“Design of Fully Superconducting Machines for Turbo-Electric Propulsion in Transportation Airplane”*, P.J. Masson, L. Makong, Y. Nyanteh, R. Seuxet, A. Colle, A. Masoudi, IEEE TRANSACTIONS ON APPLIED SUPERCONDUCTIVITY, in preparation
- *“3D Modeling of Straight Uncoupled Multifilamentary Superconductors Subjected to Elliptical Field”*, L. Makong, J. leclerc, P. J. Masson, in preparation
- *“Impact of magnetic matrix material on AC losses in multi-filamentary superconducting wires”*, J. Leclerc, L. Makong, P. J. Masson, SUPERCONDUCTORS SCIENCE AND TECHNOLOGY, in preparation

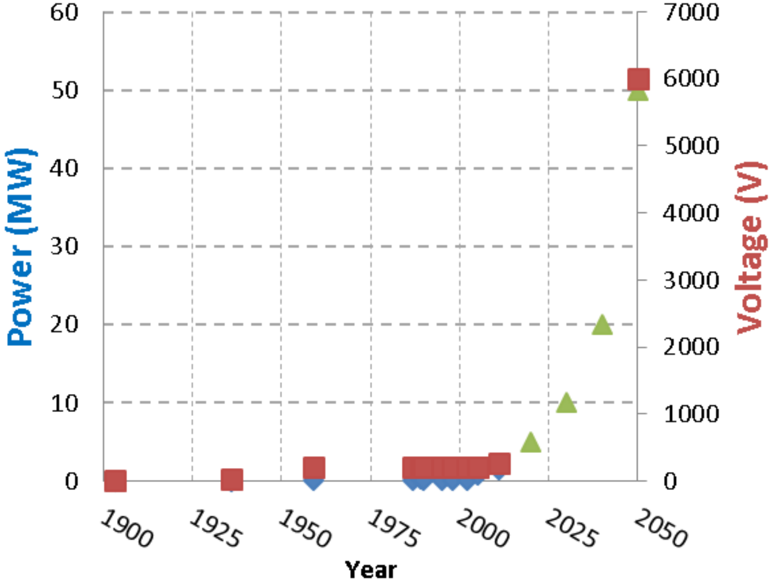
Aircraft Power/Voltage Through Time

- 1900 to 2015

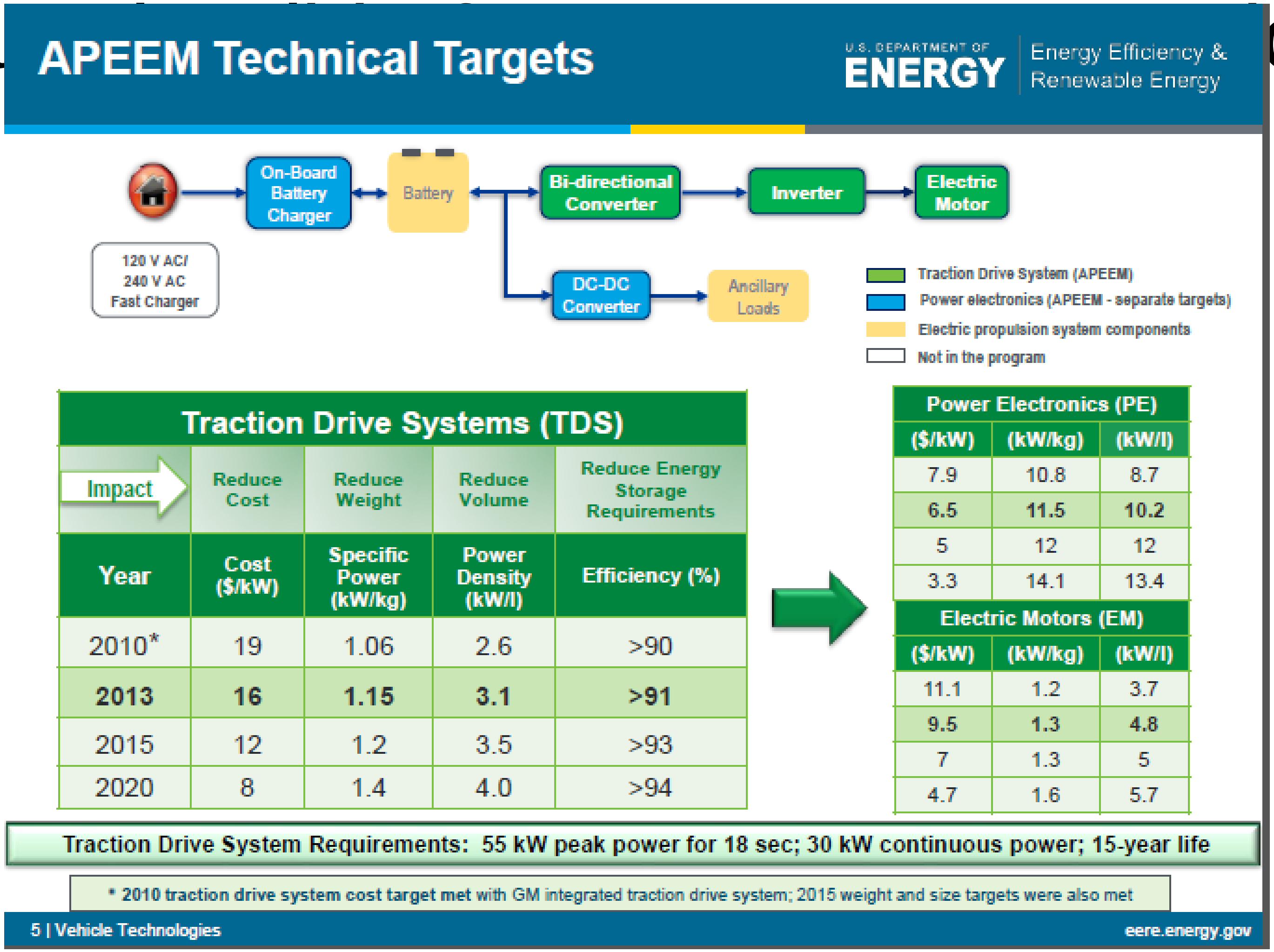
Power Increased from a few watts to 1.5MW



- 2015 to 2050 (AATT)
  - Power Increased from 1.5MW to 50MW
  - What will the voltage be?



Exa on



APEEM Technical Targets

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

🟩 Traction Drive System (APEEM)
🟦 Power electronics (APEEM - separate targets)
🟨 Electric propulsion system components
☐ Not in the program

Traction Drive Systems (TDS)

Impact	Reduce Cost	Reduce Weight	Reduce Volume	Reduce Energy Storage Requirements
Year	**Cost ($/kW)**	**Specific Power (kW/kg)**	**Power Density (kW/l)**	**Efficiency (%)**
2010*	19	1.06	2.6	>90
2013	**16**	**1.15**	**3.1**	**>91**
2015	12	1.2	3.5	>93
2020	8	1.4	4.0	>94

Power Electronics (PE)

($/kW)	(kW/kg)	(kW/l)
7.9	10.8	8.7
6.5	**11.5**	**10.2**
5	12	12
3.3	14.1	13.4

Electric Motors (EM)

($/kW)	(kW/kg)	(kW/l)
11.1	1.2	3.7
9.5	**1.3**	**4.8**
7	1.3	5
4.7	1.6	5.7

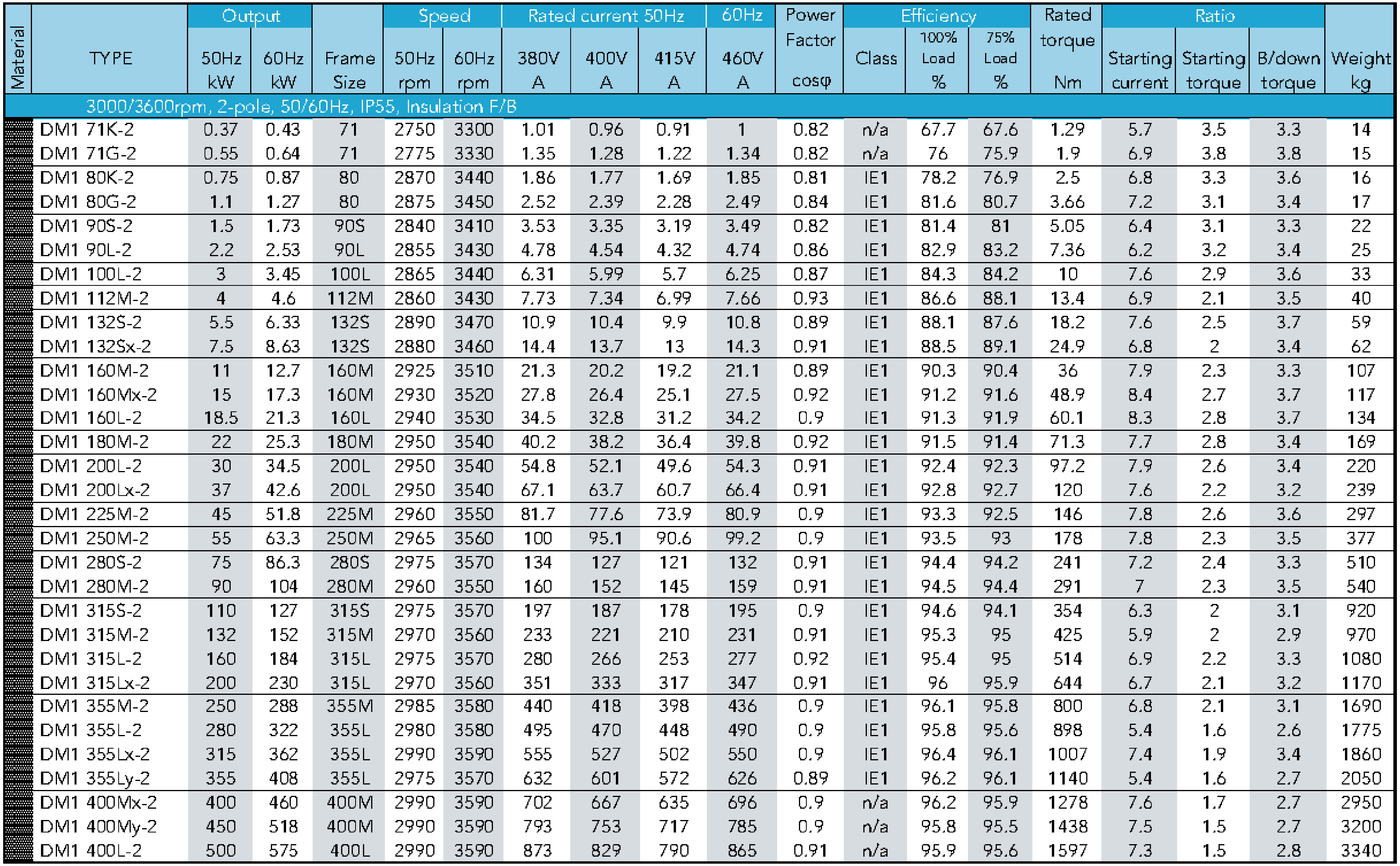
Traction Drive System Requirements: 55 kW peak power for 18 sec; 30 kW continuous power; 15-year life

* 2010 traction drive system cost target met with GM integrated traction drive system; 2015 weight and size targets were also met

5 | Vehicle Technologies

eere.energy.gov

Backup: Marathon Electric Industrial Motors



Material	TYPE	Output		Frame Size	Speed		Rated current 50Hz			60Hz	Power Factor cosφ	Efficiency			Rated torque Nm	Ratio			Weight kg
		50Hz kW	60Hz kW		50Hz rpm	60Hz rpm	380V A	400V A	415V A	460V A		Class	100% Load %	75% Load %		Starting current	Starting torque	B/down torque	
	3000/3600rpm, 2-pole, 50/60Hz, IP55, Insulation F/B																		
	DM1 71K-2	0.37	0.43	71	2750	3300	1.01	0.96	0.91	1	0.82	n/a	67.7	67.6	1.29	5.7	3.5	3.3	14
	DM1 71G-2	0.55	0.64	71	2775	3330	1.35	1.28	1.22	1.34	0.82	n/a	76	75.9	1.9	6.9	3.8	3.8	15
	DM1 80K-2	0.75	0.87	80	2870	3440	1.86	1.77	1.69	1.85	0.81	IE1	78.2	76.9	2.5	6.8	3.3	3.6	16
	DM1 80G-2	1.1	1.27	80	2875	3450	2.52	2.39	2.28	2.49	0.84	IE1	81.6	80.7	3.66	7.2	3.1	3.4	17
	DM1 90S-2	1.5	1.73	90S	2840	3410	3.53	3.35	3.19	3.49	0.82	IE1	81.4	81	5.05	6.4	3.1	3.3	22
	DM1 90L-2	2.2	2.53	90L	2855	3430	4.78	4.54	4.32	4.74	0.86	IE1	82.9	83.2	7.36	6.2	3.2	3.4	25
	DM1 100L-2	3	3.45	100L	2865	3440	6.31	5.99	5.7	6.25	0.87	IE1	84.3	84.2	10	7.6	2.9	3.6	33
	DM1 112M-2	4	4.6	112M	2860	3430	7.73	7.34	6.99	7.66	0.93	IE1	86.6	88.1	13.4	6.9	2.1	3.5	40
	DM1 132S-2	5.5	6.33	132S	2890	3470	10.9	10.4	9.9	10.8	0.89	IE1	88.1	87.6	18.2	7.6	2.5	3.7	59
	DM1 132Sx-2	7.5	8.63	132S	2880	3460	14.4	13.7	13	14.3	0.91	IE1	88.5	89.1	24.9	6.8	2	3.4	62
	DM1 160M-2	11	12.7	160M	2925	3510	21.3	20.2	19.2	21.1	0.89	IE1	90.3	90.4	36	7.9	2.3	3.3	107
	DM1 160Mx-2	15	17.3	160M	2930	3520	27.8	26.4	25.1	27.5	0.92	IE1	91.2	91.6	48.9	8.4	2.7	3.7	117
	DM1 160L-2	18.5	21.3	160L	2940	3530	34.5	32.8	31.2	34.2	0.9	IE1	91.3	91.9	60.1	8.3	2.8	3.7	134
	DM1 180M-2	22	25.3	180M	2950	3540	40.2	38.2	36.4	39.8	0.92	IE1	91.5	91.4	71.3	7.7	2.8	3.4	169
	DM1 200L-2	30	34.5	200L	2950	3540	54.8	52.1	49.6	54.3	0.91	IE1	92.4	92.3	97.2	7.9	2.6	3.4	220
	DM1 200Lx-2	37	42.6	200L	2950	3540	67.1	63.7	60.7	66.4	0.91	IE1	92.8	92.7	120	7.6	2.2	3.2	239
	DM1 225M-2	45	51.8	225M	2960	3550	81.7	77.6	73.9	80.9	0.9	IE1	93.3	92.5	146	7.8	2.6	3.6	297
	DM1 250M-2	55	63.3	250M	2965	3560	100	95.1	90.6	99.2	0.9	IE1	93.5	93	178	7.8	2.3	3.5	377
	DM1 280S-2	75	86.3	280S	2975	3570	134	127	121	132	0.91	IE1	94.4	94.2	241	7.2	2.4	3.3	510
	DM1 280M-2	90	104	280M	2960	3550	160	152	145	159	0.91	IE1	94.5	94.4	291	7	2.3	3.5	540
	DM1 315S-2	110	127	315S	2975	3570	197	187	178	195	0.9	IE1	94.6	94.1	354	6.3	2	3.1	920
	DM1 315M-2	132	152	315M	2970	3560	233	221	210	231	0.91	IE1	95.3	95	425	5.9	2	2.9	970
	DM1 315L-2	160	184	315L	2975	3570	280	266	253	277	0.92	IE1	95.4	95	514	6.9	2.2	3.3	1080
	DM1 315Lx-2	200	230	315L	2970	3560	351	333	317	347	0.91	IE1	96	95.9	644	6.7	2.1	3.2	1170
	DM1 355M-2	250	288	355M	2985	3580	440	418	398	436	0.9	IE1	96.1	95.8	800	6.8	2.1	3.1	1690
	DM1 355L-2	280	322	355L	2980	3580	495	470	448	490	0.9	IE1	95.8	95.6	898	5.4	1.6	2.6	1775
	DM1 355Lx-2	315	362	355L	2990	3590	555	527	502	550	0.9	IE1	96.4	96.1	1007	7.4	1.9	3.4	1860
	DM1 355Ly-2	355	408	355L	2975	3570	632	601	572	626	0.89	IE1	96.2	96.1	1140	5.4	1.6	2.7	2050
	DM1 400Mx-2	400	460	400M	2990	3590	702	667	635	696	0.9	n/a	96.2	95.9	1278	7.6	1.7	2.7	2950
	DM1 400My-2	450	518	400M	2990	3590	793	753	717	785	0.9	n/a	95.8	95.5	1438	7.5	1.5	2.7	3200
	DM1 400L-2	500	575	400L	2990	3590	873	829	790	865	0.91	n/a	95.9	95.6	1597	7.3	1.5	2.8	3340