Challenges of Megawatt Scale Electric Aircraft Propulsion

Andrew Woodworth, PhD.
Hybrid Electric Aircraft Materials Technical Lead
Materials Chemistry and Physics Branch/ Materials and Structures Division,
NASA Glenn Research Center

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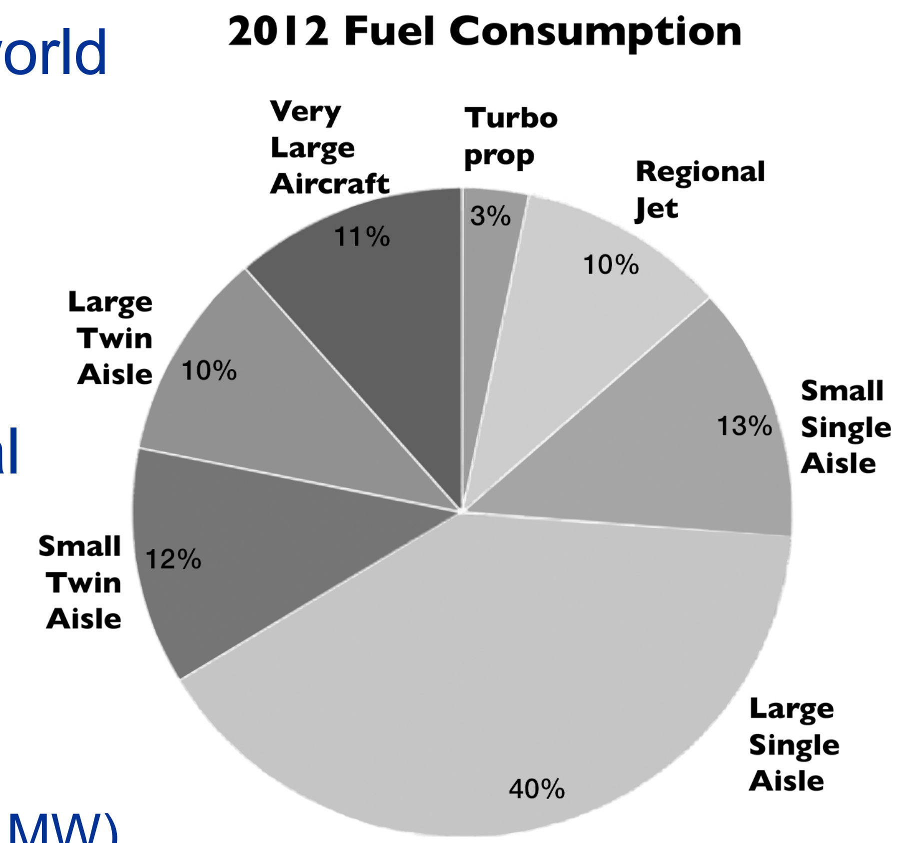
SS23 EMI and Insulation Related Challenges and Solutions for WBG based Power Electronic Systems

Megawatt-Scale Electric Aircraft Propulsion

- Narrow body single isle aircraft most utilized in the world
  - Rely on MW scale propulsion systems
  - Target entry into service of 2035
- National Academies of Sciences, E., and Medicine. *Commercial aircraft propulsion and energy systems research: reducing global carbon emissions*: National Academies Press, 2016
  - Parallel Hybrid 3 kW/kg (end to end)
    - Series hybrid not well covered
  - Turboelectric and all electric: 6.5 kW/kg (end to end)
  - Efficiency is important (1% inefficiency is 10 kW of heat per MW)
- Electrifying in any configuration requires
  - The system to run at ~1 kV
  - Efficient components (size of the thermal management system)

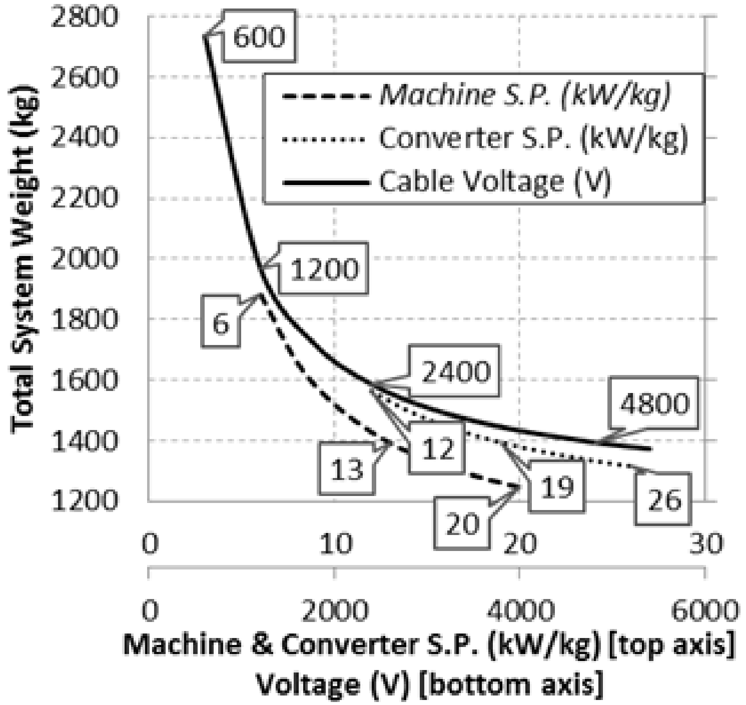


Haran, K. *Electrified Aircraft Propulsion: Powering the Future of Air Transportation*: Cambridge University Press, 2021.

NASA Sponsored Research

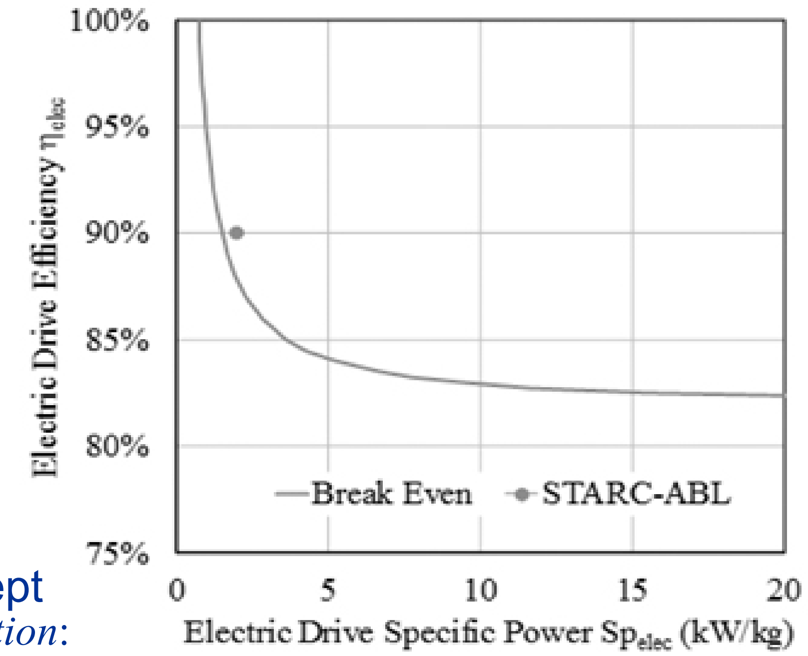
1 MW motor goals

	Specific Power (kW/kg)	Specific Power (hp/lb)	Efficiency (%)
NRA Goal	13.2	8.0	96.0



1 MW inverter goals

	Specific Power (kW/kg)	Specific Power (HP/lb)	Efficiency (%)
Minimum	12	7.3	98.0
Goal	19	11.6	99.0
Stretch	25	15.2	99.5



Metrics developed for NASA's STARC-ABL partial turbo electric concept

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Electric Powertrain Flight Demonstration

STATEMENT OF OBJECTIVES

Flight Demonstration of MW-Class Powertrain Systems for Commercial Transports

NASA Armstrong Flight Research Center

January 25, 2021

Table 2 – Technical Performance Measures of the Flight Demonstrations

Technical Performance Measures (TPMs)	Full Success	Minimum Success
Total power level of hybrid electric power system	1.5MW	500kW
Power level of electrical components	1MW	250kW
Operating voltage of integrated system	1000V	500V
Altitude capability of integrated system	>30,000 ft.	>10,000ft
Specific power of integrated electrical power system	1.25 kW/kg	0.5 kW/kg
End to end loss of integrated electrical power system	20%	25%
Environmental / airworthiness	Flight test	Flight test

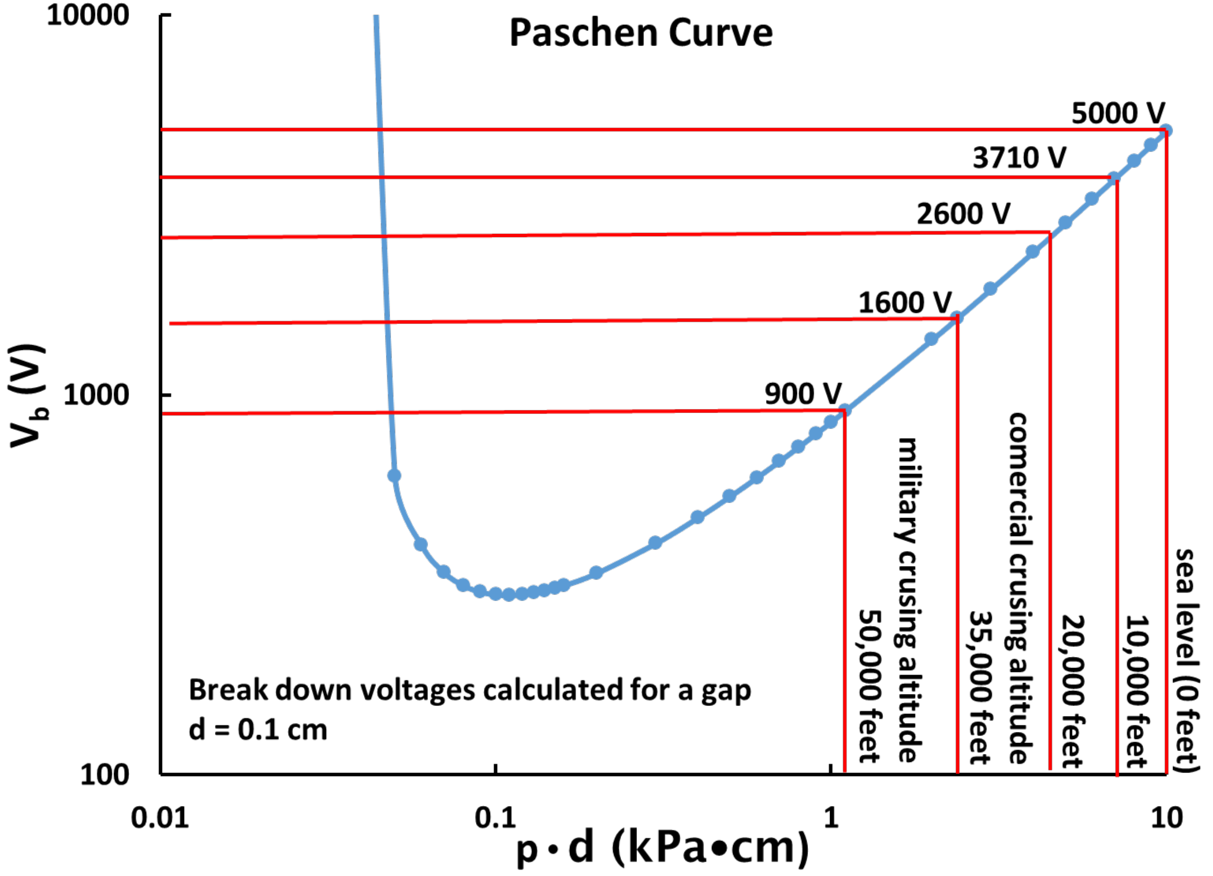
It all comes down to mass!

Need for new electrical insulators

- Central to all electrical components
- Needs to be light weight
- Specific power density requires less over design (~less mass)
- High reliability application
- Organic polymers can handle the task but…
  - Low thermal conductivity
  - Low thermal limits (usually the lifetime limiter of an electric system)
  - Partial discharge (PD) quickly degrades the material (issue for altitude operation)
  - Inorganic solutions (e,g, mica) are more robust but cost in mass and size and are not flexible
- IEC standard 60034 for rotating electric machine insulation

Insulation development is needed

HV at altitude consideration

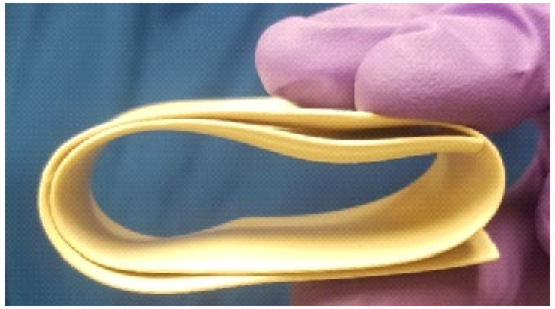


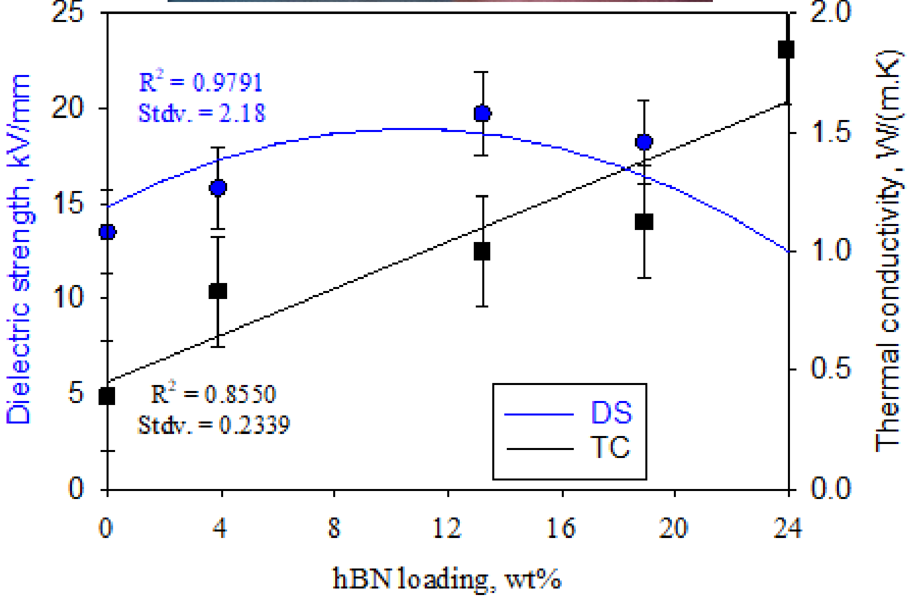
Altitude will impact partial discharge inception voltage (PDIV)

NASA internal work

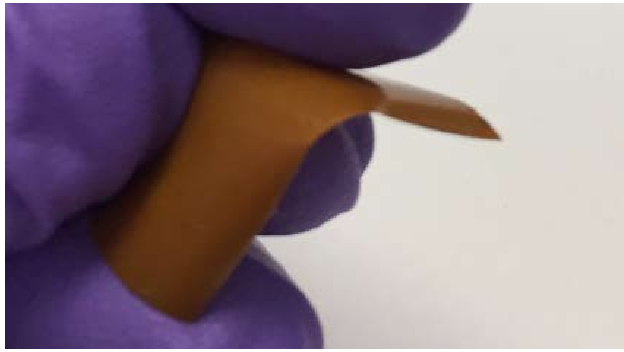
NASA investigating organic-inorganic composite materials

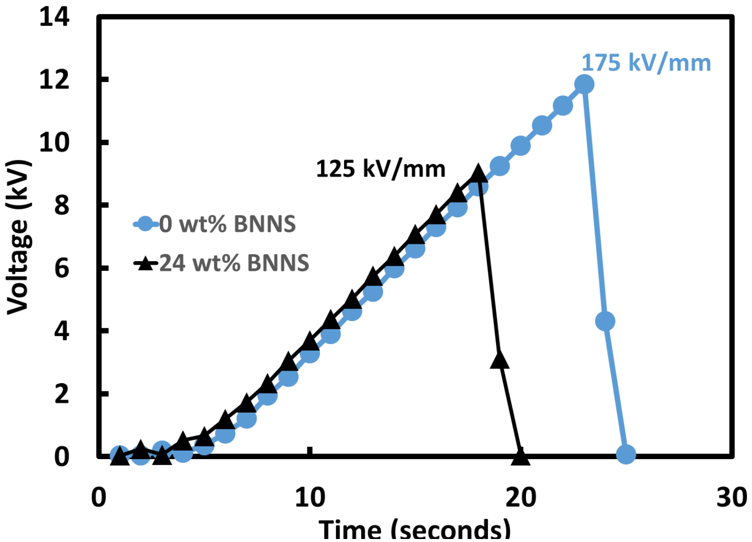
Extruded polyphenylsulfone hexagonal boron nitride composite

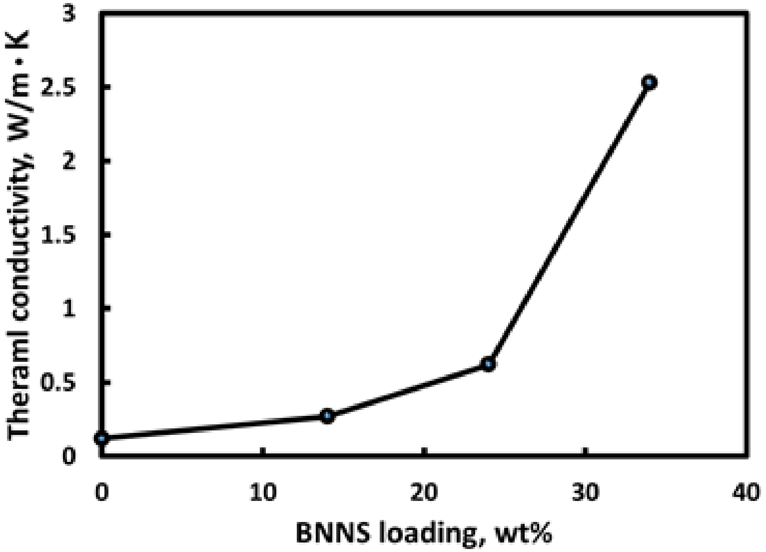




Polyimide-boron nitride nanosheet composite







Organic-inorganic composites show promise, but…

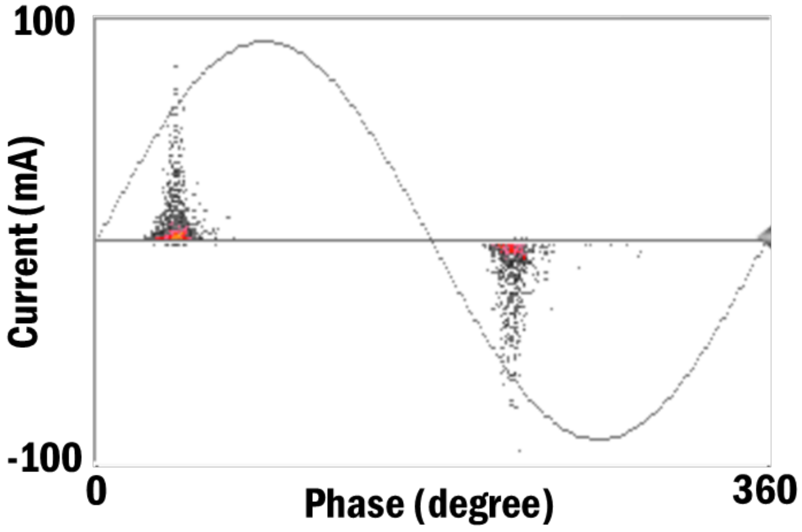
Preliminary Partial Discharge Data - NASA/OSU

60 Hz PDIV test results summary

Test sample #	A-1	A-3	A-4	B-1	B-2	B-3	B-4	B-5
Average PDIV (RMS)	595.0 V	438.0 V	357.3 V	369.3 V	349.7 V	363.7 V	473.3 V	389.3 V
Standard Deviation	7.76%	11.86%	3.37%	1.44%	2.04%	0.79%	2.38%	6.12%

Sample	BNNS loading (wt %)
A-1 to A-4	0 (neat polyimide)
B-1 to B-5	24 (in polyimide)

IEC(b) standard electrode system



Preliminary Partial Discharge Data - NASA/OSU

Test Conditions

- Applied excitation:
  - 1 kHz
  - Duty Cycle =0.5
  - rise time t_r=65 ns
  - unipolar repetitive pulses
- Environmental conditions:
  - 730 Torr, dry air

Note: Group A samples (0 wt%) showed early puncturing due to breakdown during this test and were deemed unsuitable.

Test sample #	B-1	B-2	B-3	B-4	B-5
Average PDIV [V]	1125.3	1229.0	1238.7	1336.3	1234.0
PDIV Standard Deviation	1.51%	10.98%	2.85%	7.73%	7.65%
Average Repetitive PDIV [V]	1125.3	1311.0	1238.7	1404.0	1246.0
Repetitive PDIV Standard Deviation	1.51%	1.46%	2.85%	2.82	6.32%

Inconsistencies in the results indicated further refining the virgin and composite film casting methodology

Takeaway points

- It all comes down to mass
- Insulation development is needed
- Organic-inorganic materials show promise, but PDIV impacts need to be better understood

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Thank you!

Panelist: Andrew Woodworth

email: andrew.a.woodworth@nasa.gov