NASA Electrified Propulsion Research Summary

Barbara Esker, Deputy Director, Advanced Air Vehicles Program
Aeronautics Research Mission Directorate
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Potential Benefits of Electrified Aircraft Propulsion

Improvements to highly optimized aircraft like single-aisle transports

- Enables significant fuel burn reduction from alternative architectures and operational schemes in addition to other benefits from improved engine cores or airframe efficiencies

Help open Urban Air Mobility market

- Enable new VTOL configurations with the potential to transform transportation and services.

Revitalizing the economic case for small short-range aircraft services

- The combination of electrified propulsion aircraft with higher levels of autonomous operations could reduce the operating costs of small aircraft operating out of community airports resulting in economically viable regional connectivity.

Electrified Aircraft Propulsion – a 60,000 ft Perspective
(a range of vehicles and range of needs)

	UAS	UAM, Small A/C	RJ, Single Aisle	Twin Aisle
		 	 	
Implementation Status	All electric vehicles in operation	All electric or hybrid applications being developed	Potential for hybrid or turbo-electric within 10 years	Significant progress needed for practical implementation
NASA Role	NASA research not needed	NASA focus on informing standards, regulations & design tools	NASA focus on enabling technologies, demonstrating benefits, addressing safety needs	Still too long term – not yet a NASA focus

Small Vehicle EAP

Energy & cost efficient, short range aviation

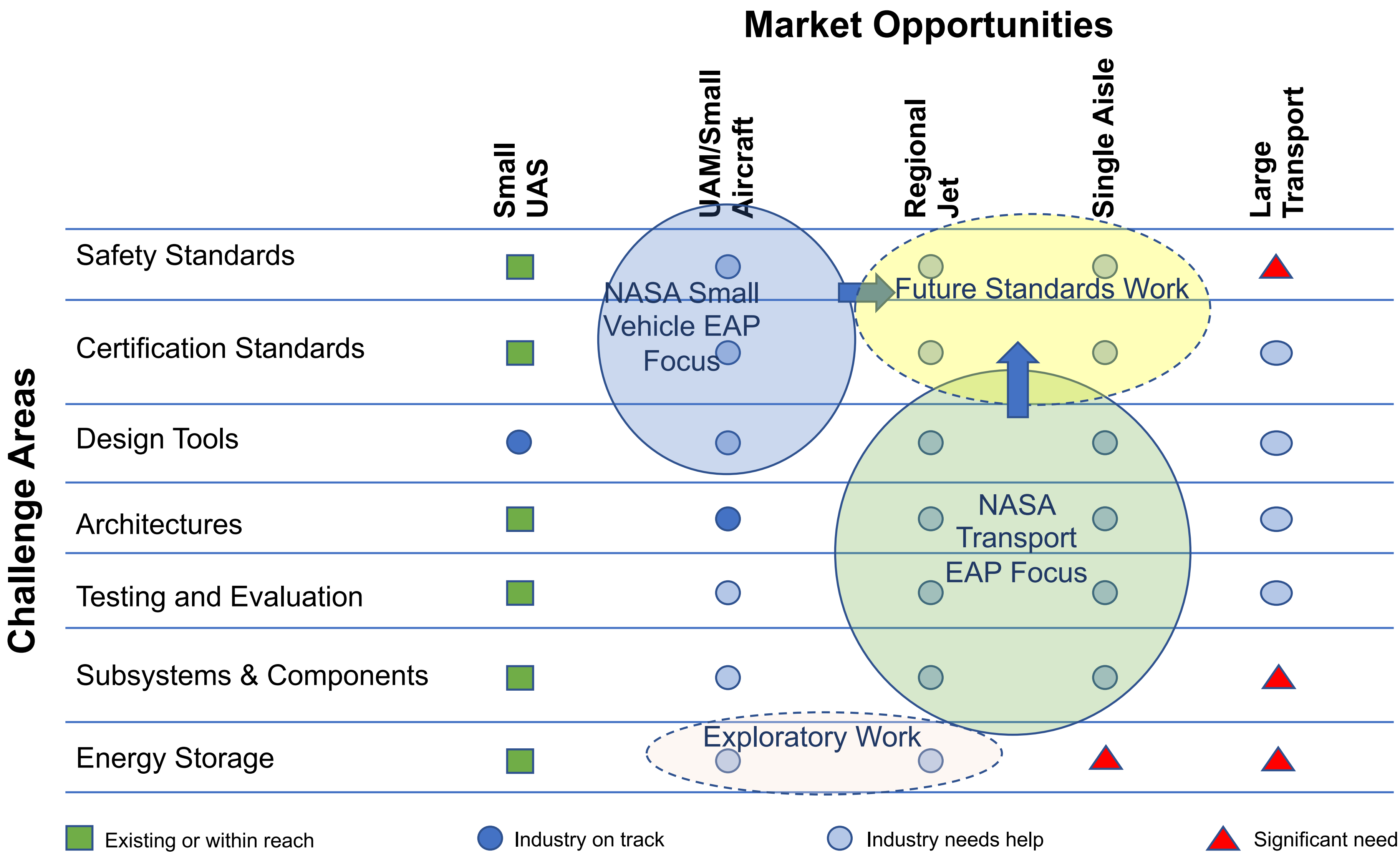
Transport Scale EAP

Energy & cost efficient, transport aviation

Leverage learning at smaller size to inform scale-up

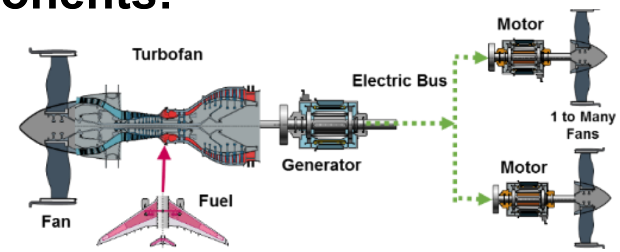
Fundamental challenges span range of sizes

EAP Challenges Across Multiple Vehicle Classes

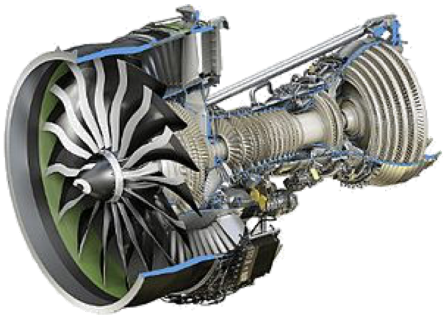


Multiple Aspects to Electrified Aviation Propulsion

EAP encompasses more than just electrical components:

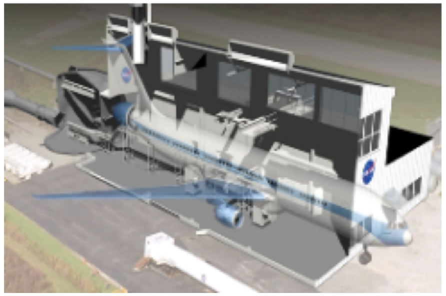


Electrical generation, storage and distribution
- Electrical power components (e.g. inverters, motors, generators & systems)
- Power storage
- Power extraction
- System architectures



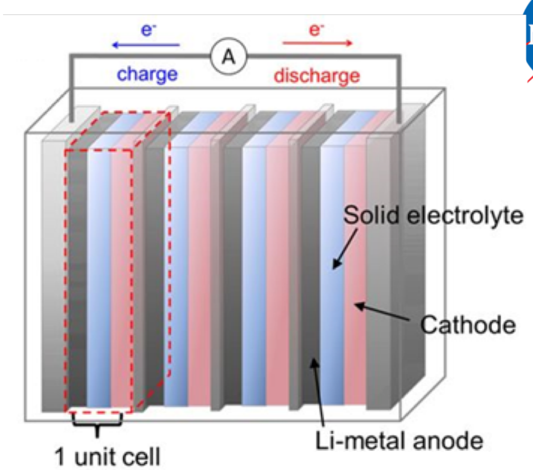
Coupled turbine systems
- Small core turbomachinery
- New material systems

System benefits
- Novel propulsion airframe integration
- Systems analysis tools
- Test capabilities



Electrified Aircraft Propulsion (EAP) – the suite of technologies and capabilities that will enable air vehicles to leverage benefits of electricity in their propulsion systems.

EAP Research Approach



Computational/Laboratory
- Develop tools for better design trades
- Investigate new materials (e.g. insulators)
- System studies
- Component development

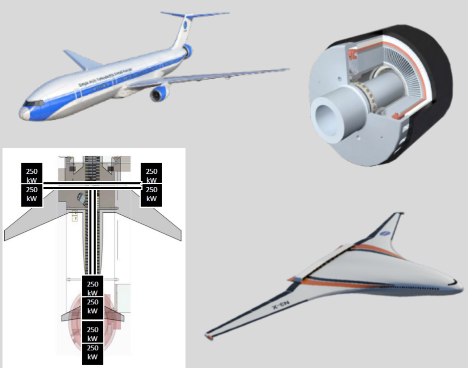
Ground Test
- Develop ground test capabilities (e.g. NEAT)
- Altitude simulation
- Component development & testing
- Reliability and thermal management

Flight Test
- Validation of system performance
- Better understand altitude & environmental effects

Utilize the approach that is best suited to achieve results

Transport-Class
Advancing Technical and Integration Readiness

0 **Early conceptualization & identification of KPP's/ technology gaps; component advancement; ground test capability gap assessment**

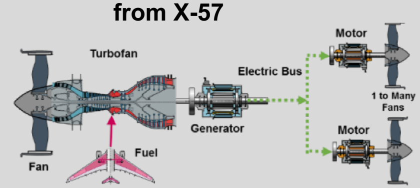


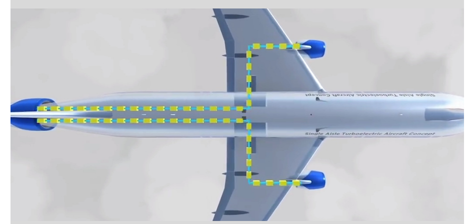
2009-2015
TRL 1-2
NASA in-house & NASA-sponsored university/industry efforts advancing MW motors & inverters for EAP

1 **Ground testing of Key electrical components (work is ongoing but must accelerate)**

2016-2018+
TRL ~3
NASA in-house & industry efforts raise the TRL level of motors and inverters

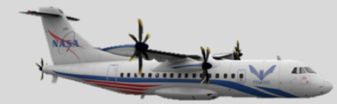
2 **Integrate in a flight system (likely existing airframe) – leveraging experience from X-57**





2018-2020
TRL ~4
NASA in-house & industry efforts leading to ground demo of TRL 4 level end-to-end power system

3 **Flight Experiments in relevant environment**



- **Key data informing product decisions**
- **Knowledge to support certification**
- **Learning to inform further fundamental research**

2021-2023
TRL 5-6
Flight demo of end-to-end MW EAP power system with application to transport aircraft.

Small Vehicle (Fixed Wing) EAP

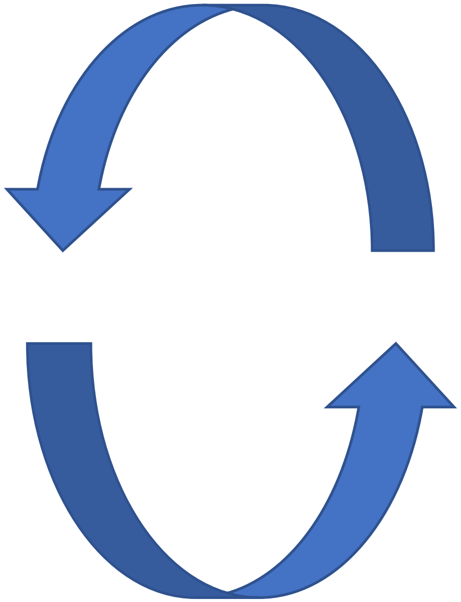
Build – Learn – Fly – Share

Why is flight important? What can't we learn on the ground?

Design
- Mission vs. vehicle sizing
- Hardware margins

Build & Integrate
- Fabrication and workmanship
- System Compatibility

Fly
- Model vs. Reality checks
- Operations and maintenance



Industry
- Contractors learn from us
- Standard developments

Government
- Standard developments
- Better Buyer
- NASA direct experience

Academia
- Standard developments
- Models and tools

X-57 will be successful if Nation’s ability to design, test, and certify electric aircraft has advanced – evidenced through successful knowledge transfer to industry, government, and academia; product commercialization; and TRL advancement

Small Vehicle (eVTOL) EAP

Target unique challenges of eVTOL propulsion systems:

- low power, high-density motors
- high duty cycle
- high C-rate (current draw) in high power conditions (hover)
- multi-rotor vehicle = multi-string propulsion systems; wide range of possible architectures
- small operating volume = thermal management issues

Use NASA eVTOL concept vehicles to focus work & conduct trade studies

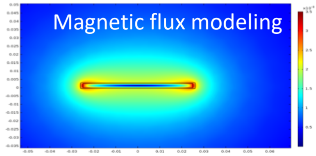
Lift + Cruise: Turboelectric

Tiltwing: Turboelectric

Side-by-side: Parallel Hybrid-Electric

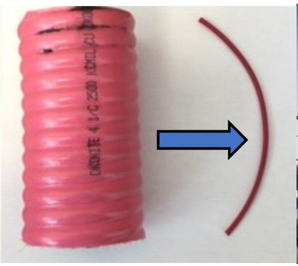
Quadrotor: Electric

Enabling Fundamental Technologies for EAP



High Voltage Power Cabling

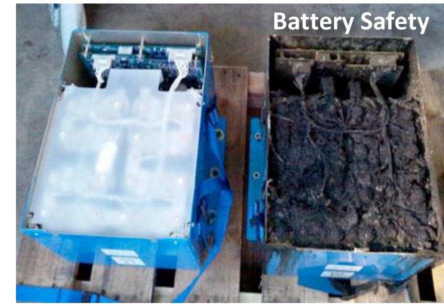
Goal - large reduction of weight & concurrent increase in power for high voltage power distribution.
Why do more?- SOA high voltage cabling is large & heavy. Planes are limited to 250V. Industry is actively pursuing 500 V operation. 1-2 MW needed for urban air mobility; 30 MW is required for regional jet service. Thermal management issues.

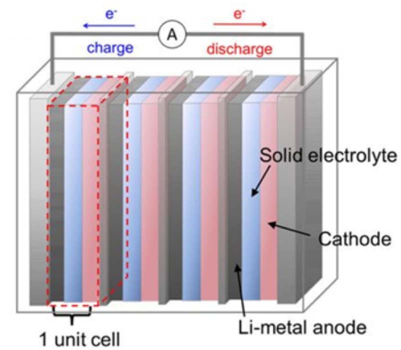


New Energy Storage

Goals
- Solid state architectures
- Safer
- New chemistries
- Higher energy densities
- Lighter weight

Why do more?- aero has unique requirements – higher cycle life, lighter weight, safety.





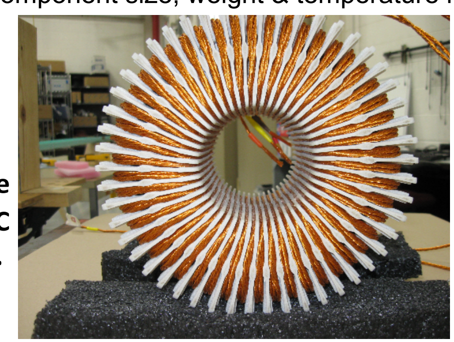
Advanced Multi-Functional Materials & Manufacturing

Goals - Light weight components & actuation
- Stream line processing & manufacturing
- Efficient interface design
- Near net shape actuator design by additive manufacturing

Why do more?- replace heavy components and hydraulics.

Soft Magnetic Materials

Goal - improved efficiency
Soft magnetics are in all electric motors, inductors & components, actuators, EMI shielding, electronics, sensors, etc. *Why do more?*- otherwise component size, weight & temperature increase with higher voltages.



Inductor made with NASA GRC Ribbon for Eaton.

Coil of Soft Magnetic Ribbon

Summary

- More electric systems will impact aviation ranging from small all-electric vehicles to larger aircraft with hybrid or turbo-electric propulsion.
- US industry collaboration interest is high and international competition fierce with increasing R&D budgets in pursuit of more electrified vehicles
- NASA has developed strategy that provides leadership and a vision for this more electric future and addresses key areas where industry needs assistance.

Thank you