Electrified Aircraft Propulsion Flight Project
Motor & Inverter Industry Day

February 3rd, 2021

Virtual Meeting

Accelerate transition of 1MW class powertrain systems to US transport aircraft fleet

Authors:
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Ralph Jansen, NASA Glenn Research Center (GRC)
Amy Jankovsky, NASA GRC
Peter de Bock, Department of Energy
Danny Cunningham, Department of Energy

Agenda

NASA Aeronautics Electrified Powertrain Flight Demonstration (EPFD)
Motor & Inverter Industry Day
10:00am to 3:30 ET – February 3, 2021

Objectives: NASA Electrified Powertrain Flight Demonstration Project is partnering with industry to demonstrate electrified aircraft propulsion in flight in the 2023-2024 timeframe. Motors, inverters, and converters are an integral part of the overall power and propulsion system for the planned flight demonstrations. This gives a unique opportunity for demonstrating the performance of advanced motors and power electronics in flight. Collaboration between industry leaders in motors, power electronics and aircraft technology is necessary to meet this goal. The objective of this industry day is to connect aircraft airframe and propulsion companies that are developing the MW-class Electric Aircraft Propulsion (EAP) aircraft or systems with motor and power electronics companies that can provide powertrain components for those systems.

Final Agenda

Start Time EST	End Time	Topic	Session Speaker
10:00 AM	11:00 AM	NASA & ARPA-E	Introduction
11:00 AM	11:15 AM	Break	
11:15 AM	11:30 AM	Boeing	Kamiar Karimi
11:30 AM	11:45 AM	Wright Electric	Jeff Engler
11:45 AM	12:00 PM	Ampaire	Ed Lovelace
12:00 PM	12:30 PM	ESAero	Philip Osterkamp
12:30 PM	1:00 PM	Lunch	
1:00 PM	1:15 PM	General Atomics	Jake Calabretta
1:15 PM	1:30 PM	Cognicell	Kent Kristensen
1:30 PM	1:45 PM	Magnix	Roei Ganzarski
1:45 PM	2:00 PM	H3X	Max Liben
2:00 PM	2:15 PM	Hinetics	Dr. Kiruba Haran
2:15 PM	2:30 PM	Advanced Magnet Lab	Philippe Masson
2:30 PM	2:45 PM	Ohio State University	Codrin Cantemir (CG)
2:45 PM	3:00 PM	HyperTech	Mike Tomsic
3:00 PM	3:15 PM	Marquette University	Ayman EL-Refaie
3:15 PM	3:30 PM	Closing Remarks	

Outline of NASA & ARPA-E Introduction Presentation

Start	End	Session	Speaker
10:00 AM	10:05 AM	Welcome	Gaudy Bezos-O'Connor (PM
10:05 AM	10:15 AM	EPFD Project Overview	Gaudy Bezos-O'Connor (PM)
10:15 AM	11:25 AM	Power System needs for EPFD	Ralph Jansen
10:25 AM	10:35 AM	ARPA-E ASCEND	Peter De Bock (PM)
10:35 AM	10:45 AM	ARPA-E Efforts	Danny Cunningham – Technology to Market
10:45 AM	10:55PM	Overview of NASA AATT motor and inverter research	Amy Jankovsky (SPM)
10:55 AM	11:15 AM	Questions/Break	

NASA Electrified Powertrain Flight Demonstration (EPFD) Project

Gaudy Bezos-O'Connor

Project Manager

Why is Electrified Propulsion important?

- **EP enables favorable direct operating cost (DOC) trades**
  - Total Energy
  - Maintenance
- **EP creates a flexible design space opportunities**
  - Boundary layer ingestion
  - Distributed architectures
  - Reduced turbofan core sizes
- **EP coupled with advanced airframe architectures**
  - May enable functionally silent and ultra low emission flight
- **EP is synergistic with low emission airport infrastructure changes**

5-year EPFD Project start in FY21

Agency and ARMD Strategic Plan Flow Down to EPFD Project

Agency Goal

3.0 Address national challenges and catalyze economic growth
3.2: Transform Aviation Through Revolutionary Technology Research, **Development, and Transfer**

AERONAUTICS STRATEGIC THRUST

Thrust 3: Ultra Efficient Subsonic Transports
Realize revolutionary improvements in economics and environmental performance for subsonic transports with opportunities to transition to alternative propulsion and energy

AAVP and IASP CRITICAL COMMITMENT

Critical Commitment 3.1 - Demonstrate **practical vehicle-level integration of MW-class electrified aircraft propulsion** systems, leveraging advanced airframe systems to **reinvigorate the regional and emerging smaller aircraft markets and strengthen the single-aisle aircraft market**.

Technical Challenges

TC 5.2: Establish viable concept for 5-10 MW hybrid gas-electric propulsion system for a single-aisle class vehicle with reduced fuel burn, emissions and noise (TRL2) Finished in FY19
(AATT)

TC 10.1: Demonstrate representative hybrid electric powertrain having a total power of at least 3X the state-of-the-art that meets fault management, redundancy, and power quality requirements (TRL 4) and develop key components to TRL 6.
(AATT with EPFD Enhancements)

TC 14.1: Achieve 20% power extraction at altitude from a modern commercial turbofan engine with the thrust, efficiency, operability, and durability to enable the benefits of electrified aircraft propulsion at a vehicle level.
(AATT with EPFD Enhancements)

EPFD Approach

- **Accelerate US industry technology readiness of integrated MW-class electrified powertrain systems**
  - Facilitate jump to new aviation industry S – curve by focusing on integrated MW-class powertrain system technology
  - Focus on next generation single aisle (150 – 200 passenger seat class) commercial transport aircraft
  - Ensure an appropriate mix of potentially disruptive concepts and commercial transport products
    - Commercial thin haul transport transport aircraft can potentially disrupt hub and spoke system
  - Directly engage propulsion companies to facilitate timely integrated MW-class powertrain system development and transition

- **Plan and Conduct at least two integrated MW-class powertrain system flight demonstration**
  - Identify and address regulation and standards gaps
  - Identify and retire barrier technical and integration risks

- **Employ right-sized project management and procurement rigor for efficient execution and timely funding expenditures:** highly leveraging industry processes and practices with significant NASA insight to make informed decisions at periodic reviews

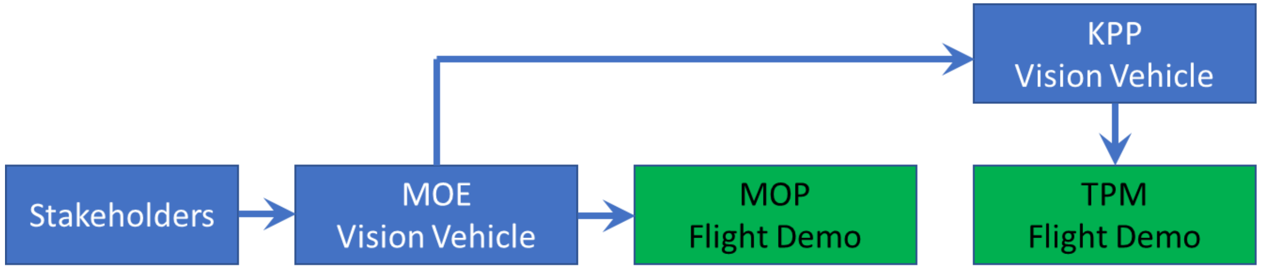
- **Coordinate closely with ARMD programs to fully leverage prior and ongoing ARMD electrified powertrain system investments**

Objectives of Motor & Inverter Industry Day

- Connect U.S. aircraft and propulsion companies with U.S. motor and inverter companies with interest in MW class Electrified Aircraft Propulsion
- Provide awareness of posted draft Electrified Aircraft Propulsion Project Request for Proposals and related project performance objectives
- Provide awareness of power system challenges for MW class Electrified Aircraft Propulsion
- Provide awareness of ARPA-E

Formulation Studies

- **Study contracts have been completed with six companies to define:**
  - The largest market opportunities for MW-Class EAP
  - A Vision Vehicle (potential product) for that market
  - Barrier Technical Risks that need to be overcome for the Vision Vehicle
  - Technology maturation needed for Vision Vehicle
  - A proposed flight demonstration to reduce the Barrier Technical Risks and increase the Technology Readiness levels for Integrated MW-class powertrain systems
  - Probabilistic assessments of cost and schedule for the proposed flight demonstration



Formulation studies informed the objectives and performance goals of the Electrified Powertrain Flight Demonstration project

Technical Measures of Effectiveness

- **The EPFD project has established a draft set of Technical Measures of Effectiveness**

MOE #	Measure of Effectiveness (MOE)
MOE-1	Establish at least two Vision Vehicles that address the single-aisle, regional, or thin haul markets.
MOE-2	Define a viable path that accelerates U.S. Industry product introduction of the Vision Vehicle and execute the part of the path that requires government participation.
MOE-3	Identify and reduce Barrier Technical Risks to the introduction of the Vision Vehicle through ground and flight tests.
MOE-4	Reduce regulations and standards barriers to the introduction of Vision Vehicles with Integrated MW-Class Powertrain Systems into the air fleet.
MOE-5	Collect the data defined in the Data and Intellectual Property Management (DIPM) plan to verify Key Performance Parameters and support regulations and standards work.

KPPs and TPMs

- **Draft Key Performance Parameters for the Vision Vehicle and draft Technical Performance Parameters for the flight demonstration have been established.**

Key Performance Parameter (KPP)#	Key Performance Parameter (KPP)	Full Success Single Aisle Part 25	Minimum Success 19 PAX Thin Haul Part 23
KPP-1	Total Power level of the Integrated MW-Class Powertrain System	2MW	500kW
KPP-2	Power Level of individual electrical components	1MW	250kW
KPP-3	Operating Voltage of the Integrated MW-Class Powertrain System	1000V	500V
KPP-4	Altitude Capability of the Integrated MW-Class Powertrain System	40,000 ft.	20,000 ft.
KPP-5	Specific Power of the Integrated MW-Class Powertrain System	1.25 kW/kg	0.5 kW/kg
KPP-6	End to End loss of the Integrated MW-Class Powertrain System	20%	
KPP-7	Mission Fuel Burn/Energy Reduction	4% for Part 25 Transport Aircraft	10% for Part 23 Transport Aircraft

Technical Performance Parameter (TPM)#	Technical Performance Parameter (TPM)	Full Success	Minimum Success
TPM-1	Total Power level of the Integrated MW-Class Powertrain System	1.5MW	500kW
TPM-2	Power level of individual electrical components	1MW	250kW
TPM-3	Operating Voltage of the Integrated MW-Class Powertrain System	1000V	500V
TPM-4	Altitude Capability of the Integrated MW-Class Powertrain System	30,000 ft.	15,000 ft.
TPM-5	Specific Power of the Integrated MW-Class Powertrain System	1.25 kW/kg	0.5 kW/kg
TPM-6	End to End loss of the Integrated MW-Class Powertrain System	20%	25%

Barrier Technical Risks

- **Barrier Risks**
  - Overarching risks applicable to future commercial transport applications by US Industry that the project will reduce over the life of the project
- **Six Barrier Technical Risks have been identified.**
- **The EPFD project intends to reduce these barrier technical risks to EAP Vision Vehicles through the execution of two or more U.S. Industry flight demonstration of integrated MW-class powertrains.**
- **Powertrain system integration is one of the six barrier risks. The industry day is being held to foster connections between motor and inverter companies and aircraft and propulsion companies.**

Risk Title	Statement
Powertrain System Integration	Given that this powertrain system is novel, there is a possibility that there it will not meet stability, EMI compatibility, or performance requirements which will require a redesign, resulting in an increase in cost and delay in schedule for Vision Vehicle development.

EPFD Draft Request for Proposals has been posted

- **Draft Request for Proposal has been posted.**
  - Link: https://beta.sam.gov/opp/09c460e4b5b14e22b43c4b60ae4010dc/view?keywords=80afrc21r0009&sort=-relevance&index=&is_active=true&page=1
- **Description**
  - Attached is the DRAFT Request for Proposal (DRFP) for the Electrified Powertrain Flight Demonstration. The objective of this requirement is to plan, manage, and conduct appropriate ground tests and flight tests of an integrated MW-class Powertrain System that enables the offeror's vision system, that meets the described needs, goals and objectives identified in the attached Statement of Objectives, and that are in alignment with system and data requirements defined in the System Requirements Document (SRD) and Data Requirements Document (DRD). See the attached Statement of Objectives for additional information. The DRDs and SRD will be provided via an amendment to this DRFP. Potential Offerors shall monitor bata.SAM.gov for amendments to this DRFP.
  - Potential Offerors are encouraged to review all aspects of the DRFP, including the requirements, schedules, proposal instructions, and evaluation approaches. Potential Offerors should provide questions and/or comments and identify any unnecessary or inefficient requirements relating to the DRFP no later than 2:00 pm Pacific, Dec 16, 2020.
  - An Industry Day will be held Dec 10, 2020. A registration link for the Industry Day will be provided.

ARPA-E ASCEND

Dr. Peter de Bock
Program Director

Advanced Research Projects Agency – Energy

ARPA-E: Enabling Transformative Energy Technologies through Power Electronics

Electrified Powertrain Flight Demonstration (EPFD) Motor and Inverter Industry Day

Dr. Daniel W. Cunningham. T2M Advisor, ARPA-E

Feb 3rd, 2021

NASA's Component Technology Development for Electrification of Transport-Class Aircraft

Amy Jankovsky, Power & Propulsion Subproject Manager
Advanced Air Transport Technologies Project
NASA Glenn Research Center

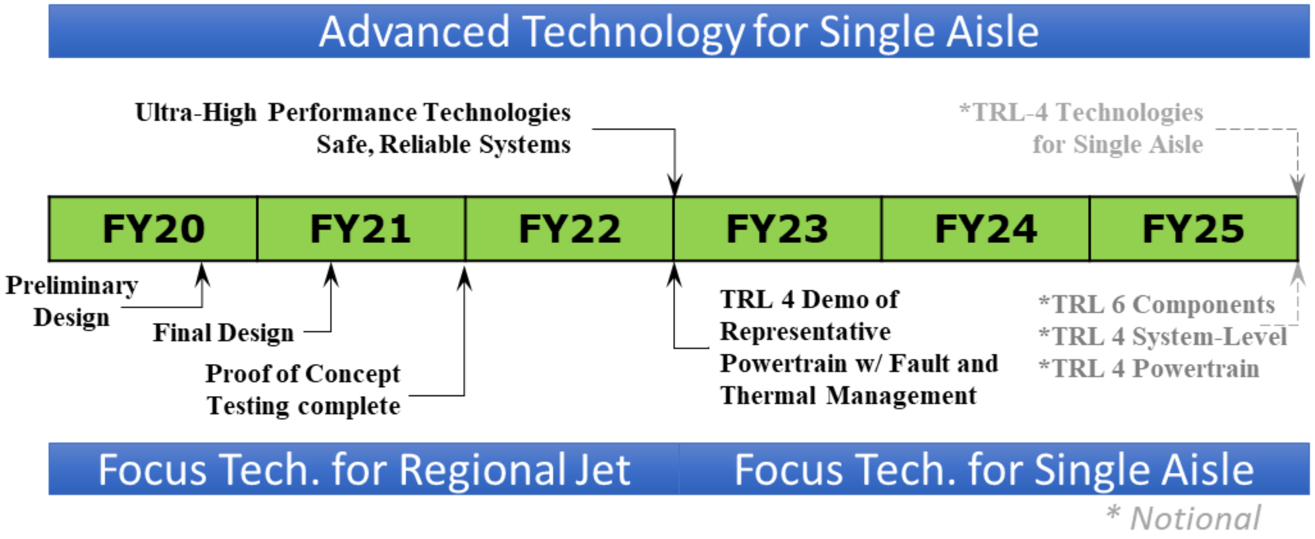
Current Technology Development Portfolio

- **Objectives Summary** Demonstrate representative hybrid electric powertrain having a total power of at least 3X the state-of-the-art (260 kW) that meets fault management, redundancy, and power quality requirements. (TRL 4), and develop key components to TRL 6.

- **Technical Approach**
  - In 2014-2019 we addressed the question, “Is there something here?”
  - In 2020-2024, we attempt to answer the question, “Can it fly?”
    - Focus on the key challenges (flight-weight, flight-like)

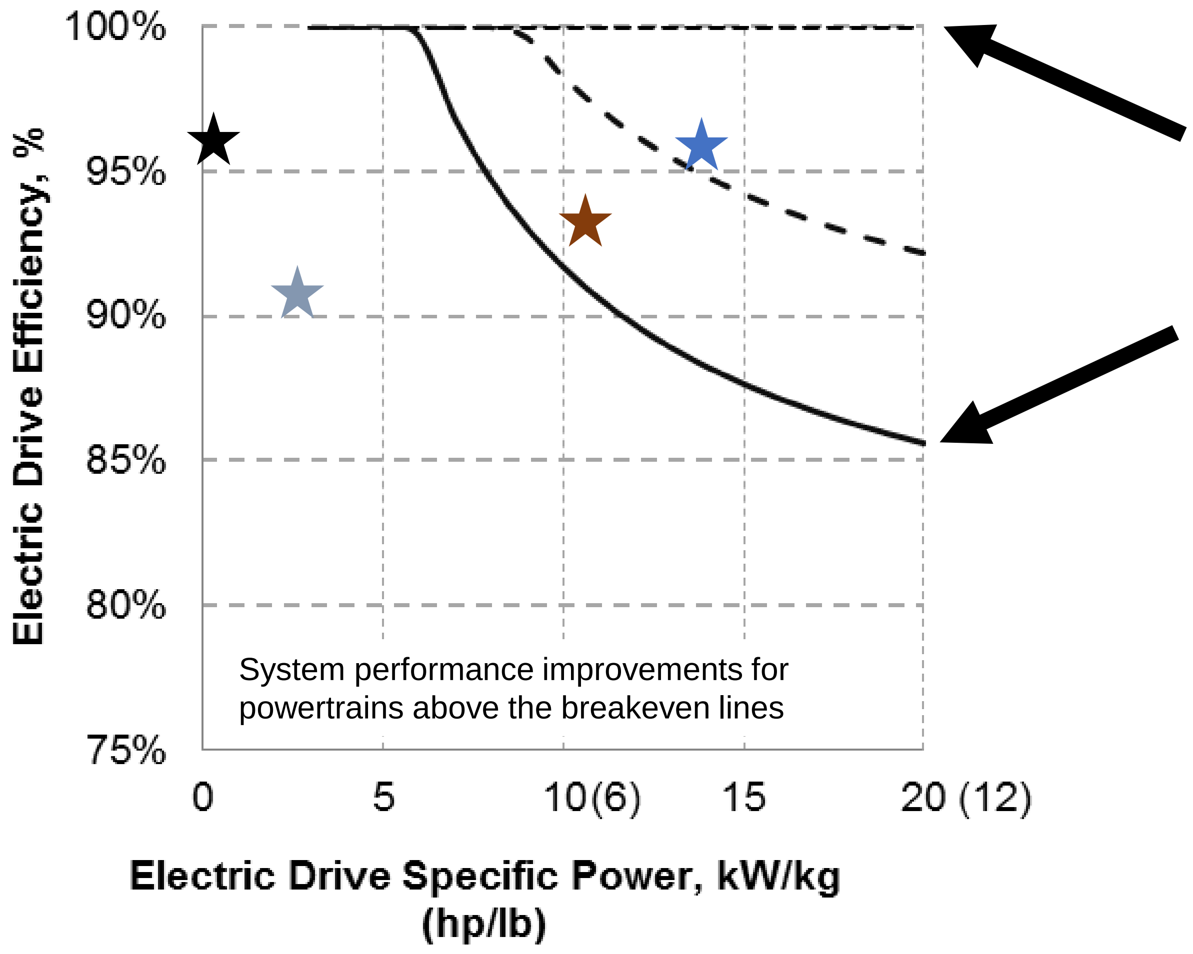
      1. Developing high power density, high efficiency components
      2. Overcoming >270 VDC safety barrier
      3. Packaging systems for flight readiness

  - eTC 10.1 “And what are the enduring challenges?”



Breakeven Analysis Guiding Component Dev't Goals

Analysis for 3 levels of aircraft performance



Powertrains need both specific power and efficiency

Aircraft with minimal PAI system benefit require perfectly efficient components

Aircraft with large PAI system benefits require less aggressive component performance

Example Motor performance:

- Typical 1 MW Industrial
- 2008 Lexus Hybrid Automotive
- 2012 Launchpoint UAV
- 2014 NASA NRA target performance

Focus Areas

- MW+ Electric Machines
  - OSU rim-driven induction machine
  - U of Illinois high frequency, outer rotor permanent magnet
  - Hinetics altitude capable permanent magnet
  - In-house 1.4MW wound field synchronous motor (HEMM)
  - Ultra-high efficiency (superconducting)
- MW Power Converters
  - Boeing SiC-based Cryogenic Inverter
  - U of I, Berkley GaN
  - GE SLIM Si/SiC

Ambient Machine Key Performance Parameters

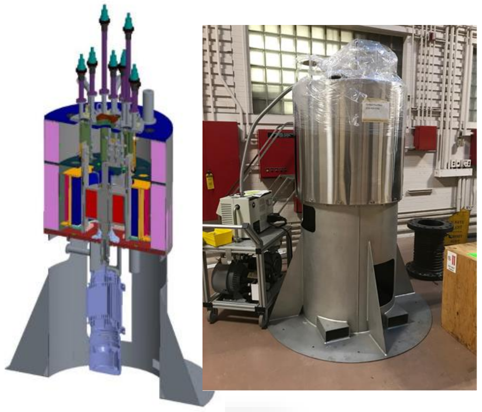
Key Performance Metrics	Specific Power (kW/kg)	Specific Power (HP/lb)	Efficiency (%)
Goal	13.2	8.0	96

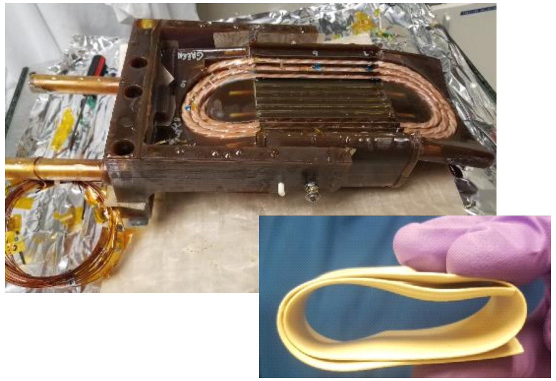
Ambient Converter Key Performance Parameters

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

Focus Areas

- System-Level Designs and Demo’s
  - Thermal Management for EAP
  - Fault Management
    - Circuit Interrupters
  - Turbine/Generator Controls
- Enduring Technologies
  - Advanced magnetic materials
  - Machine insulation solutions
  - Advanced Conductors



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Thank You!
Questions?