Gaudy Bezos-O'Connor, PM
Electrified Powertrain Flight Demonstration Project
NASA ARMD/Integrated Aviation Systems Program

NASA EPFD Project's Progress Towards Reducing Barrier EAP Technology and Integration Risks

8th UTIAS International Workshop on Aviation and Climate Change, June 2nd, 2023

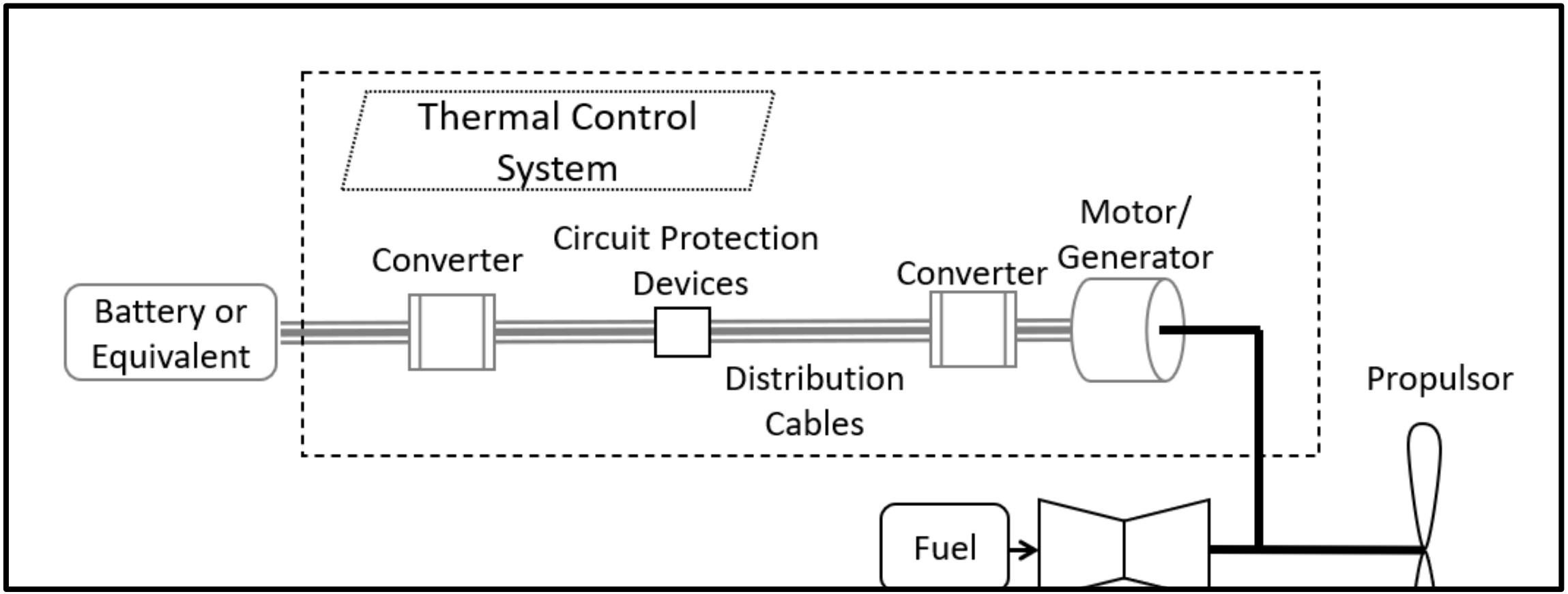
Potential Industry EAP Markets

- **EPFD Goals:**
  - Demonstrate integrated MW-Class electrified powertrains in flight using industry platforms
  - Facilitate **new aviation industry S – Curve: Propulsion Electrification**
  - 2030-2035 EIS: **Thin haul, regional and next generation SA markets**

EPFD Industry Partner Markets

Market	Regional Air Mobility	Regional Turboprops & Turbofans	Single Aisle
Passengers	1-19	20-150	150-more
Speed	≈150-250 mph	≈300-400 mph	≈500-700 mph
Range	≈100-500 miles	500-1500 miles	1500-3500 miles
Power	≈1MW	1 to 5 MW	3 to 30MW
Heat	**≈200 kW heat**	**200kw to 1MW heat**	**600kW to 6MW heat**

Integrated MW-Class Powertrain Boundary



Consist of all the electrical parts of the aircraft used for propulsive purposes along with the portion of the thermal management system which services those electrical parts.

- Typical components included are electric machines, inverters, converters, circuit protection devices, switches, cables, and connectors.
- If an electrical energy storage system like a battery is used, it is not included in the boundary for defining performance of the powertrain system.

MW-Class Powertrain Barrier Technical and Integration Risks

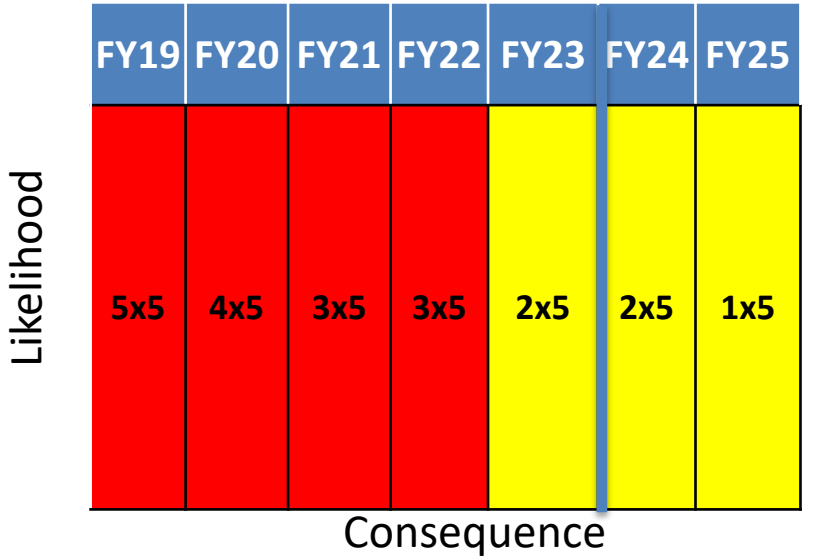
Barrier Risk	Risk Statement
High Voltage Operation at Altitude EPFD-026	Given that arcing, partial discharge and corona of high power/voltage transmission cables can occur at cruise altitudes or due to life effects, there is the possibility that the demonstrator could have power system failures, resulting in potential loss of aircraft.
Thermal Management EPFD-027	Given that the amount of electrical power required for the demonstration is unprecedented in flight and generates significant low quality/low grade heat, there is a possibility that there will be unforeseen challenges in designing a low parasitic power thermal management system.
Propulsion System Integration EPFD-024	Given that this electrified aircraft propulsion system is novel, there is a possibility that there are unforeseen conflicts in the turbomachinery integration with electric machines, resulting in, but not limited to, reduced operability and larger system weight that decreases overall Vision Vehicle performance.
Battery System Performance Shortfall EPFD-028	Given that the battery pack requirement exceeds current state of the art technology, there is a possibility that the battery system design does not meet performance requirements, resulting in a higher battery weight and decrease Vision Vehicle performance.
Powertrain System Integration EPFD-025	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.
Aircraft System Integration EPFD-023	Given that MW EAP has never been deployed on an aircraft before, there is a possibility that there are unforeseen conflicts integrating EAP system into the aircraft, resulting in an increase in cost and a delay in schedule and an inefficient aircraft.

Barrier Technical and Integration Risk: **High Voltage Operation at Altitude**

Risk Statement

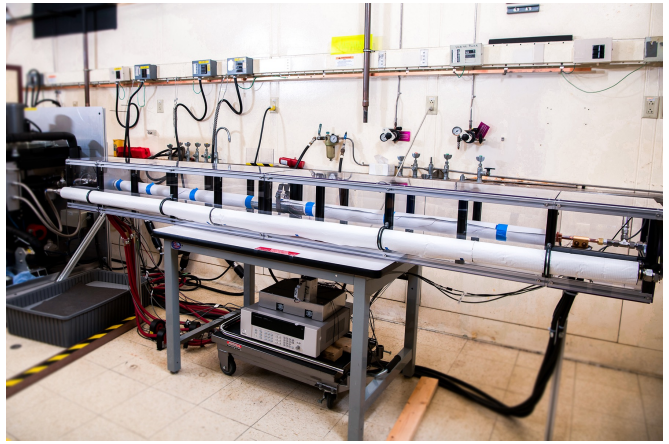
Given that arcing, partial discharge and corona of high power/voltage transmission cables can occur at cruise altitudes or due to life effects, there is the possibility that the demonstrator could have power system failures, resulting in potential loss of aircraft.

Barrier Risk Burndown



Accomplishments and Mitigations

- MW Ground Demonstration Risk Reduction
  - Electric machine design and development
  - Inverter/Converter design and development
- NASA Electric Aircraft Testbed (NEAT)
  - MW-class altitude capable test facility
  - Integrated Powertrain Testing at Altitude
- High voltage cable technology development



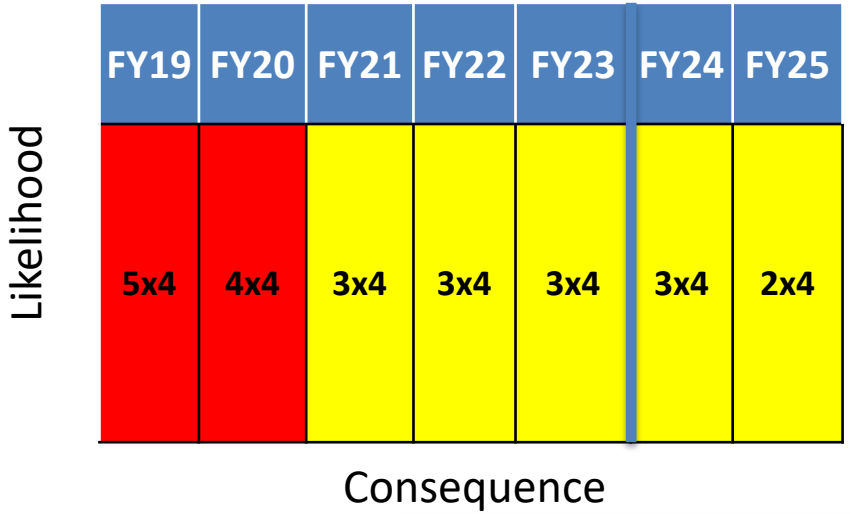
The High-Power Advanced Cable Technology rig facility for electrified aircraft research and development. Credits: NASA

Barrier Technical and Integration Risk: **Thermal Management**

Risk Statement

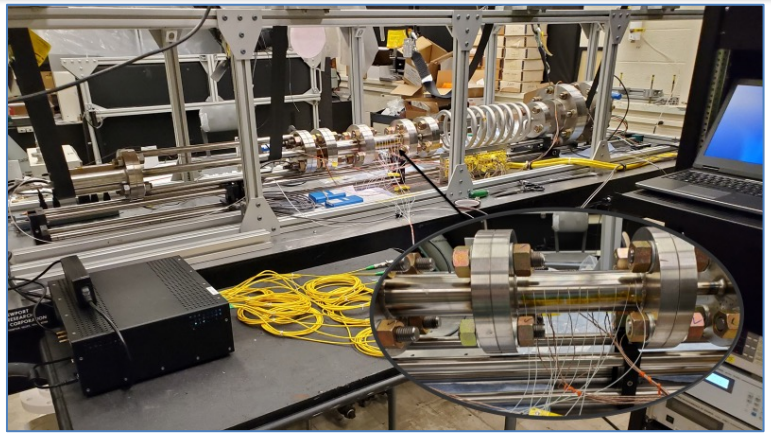
Given that the amount of electrical power required for the demonstration is unprecedented in flight and generates **significant low quality/low grade heat**, there is a possibility that there will be unforeseen challenges in designing a low parasitic power thermal management system.

Barrier Risk Burndown



Accomplishments and Mitigations

- MW Demonstration Risk Reduction
  - Industry partnership to address specific application needs
- NASA Ground Demonstration Thermal Management System
  - Thermal Recovery Energy Efficient System
  - Aircraft optimization with acoustic heat pumps



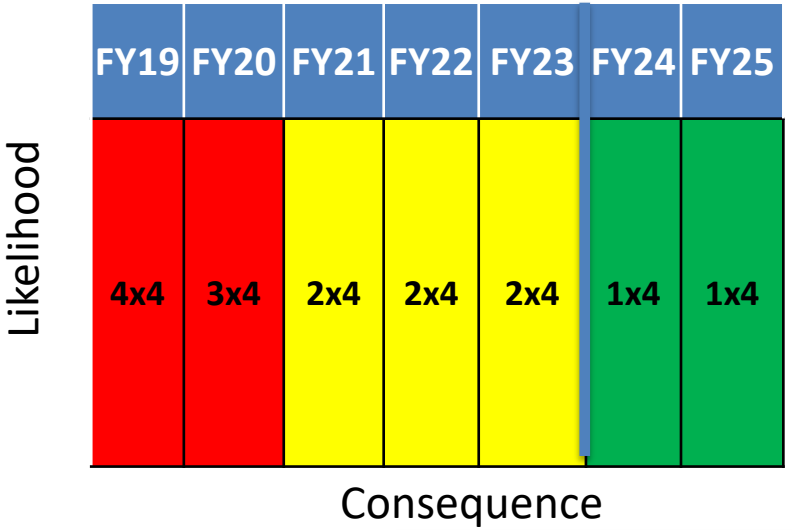
Industry partners developing thermal management technology for specific applications and NASA exploring new conceptual approaches. CREDIT NASA.

Barrier Technical and Integration Risk: **Propulsion System Integration**

Risk Statement

Given that this electrified aircraft propulsion system is novel, there is a possibility that there are unforeseen conflicts in the turbomachinery integration with electric machines, resulting in, but not limited to, **reduced operability and larger system weight** that decreases overall Vision Vehicle performance.

Barrier Risk Burndown



Accomplishments and Mitigations

- Industry Partners conducting ground and flight test to reduce risk for EPFD propulsion system integration
- NASA supporting project developing technology Hybrid Thermally Efficient Core – Power Extraction
- Trade studies with academic partners to determine sensitives during propulsion-powertrain key modes of operation

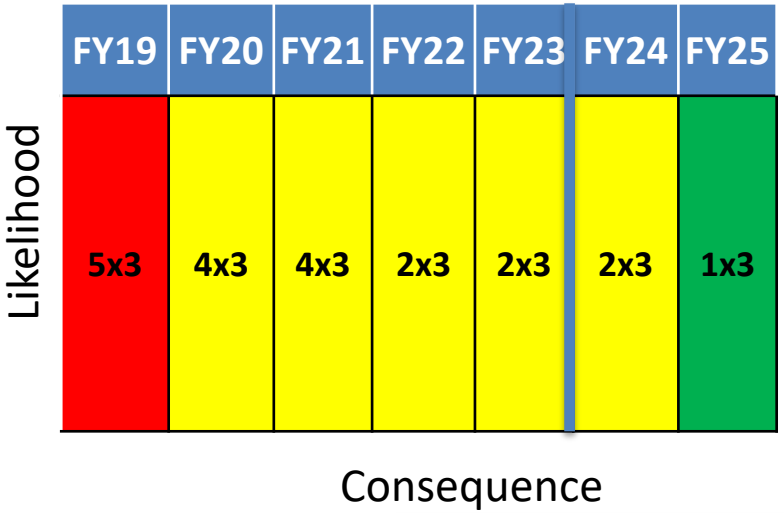
magniX supports Alice technical demonstrator aircraft, powered by two magni650 Electric Propulsion Units. CREDIT: PRNEWSWIRE and magniX

Barrier Technical and Integration Risk: **Battery System Performance Shortfall**

Risk Statement

Given that the **battery pack requirement exceeds current state of the art technology**, there is a possibility that the battery system design does not meet performance requirements, resulting in a higher battery weight and decrease Vision Vehicle performance.

Barrier Risk Burndown



Accomplishments and Mitigations

- Industry partners developing aerospace grade energy management solutions
  - Performance Analysis And Testing
- Risk reduction studies for alternative battery
- NASA technology development on advanced cells and modules

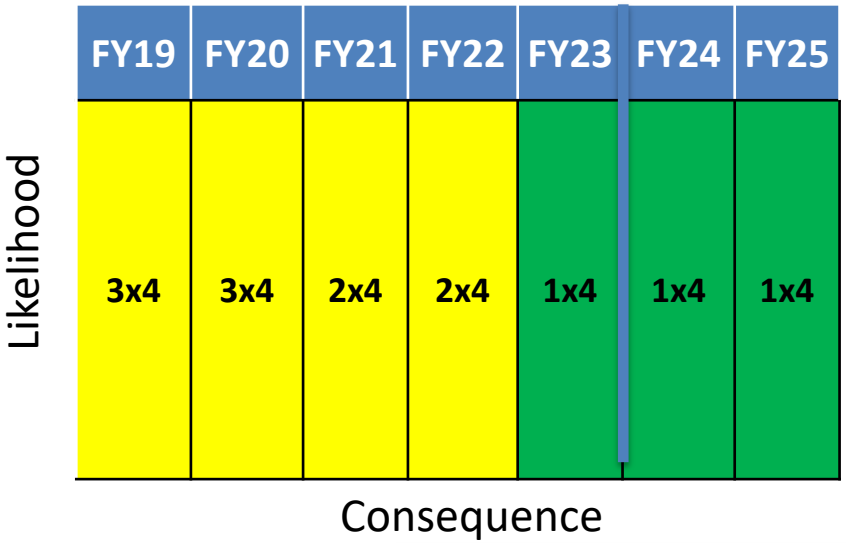
BAE Systems will design, test, and supply energy management components for electric aircraft in the megawatt power class. CREDIT: BAE

Barrier Technical and Integration Risk: **Powertrain System Integration**

Risk Statement

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.

Barrier Risk Burndown



Accomplishments and Mitigations

- Megawatt-class and multi-kilovolt hybrid-electric propulsion system tested in simulated altitude conditions at NASA NEAT facility
- Integrated MW-class powertrain fault management
- Performance sensitivity analysis to optimize and mature technology with academic partners

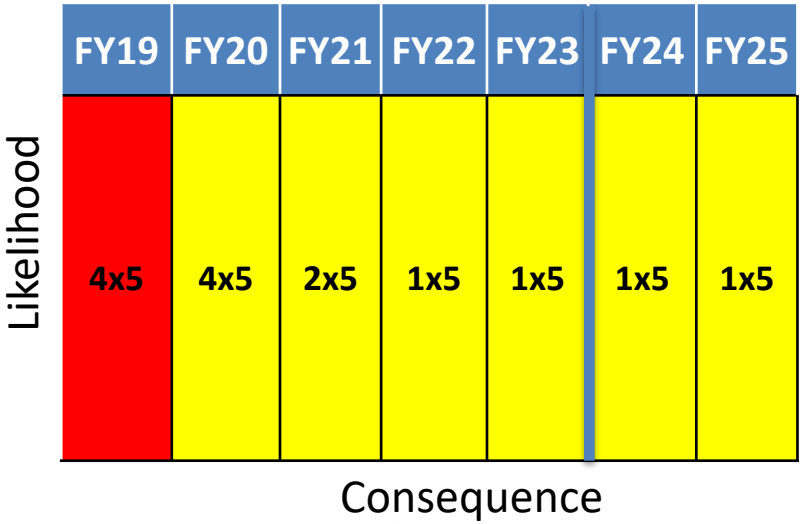
The GE Hybrid-Electric Motor and its related components were tested in NASA's Electric Test Bed (NEAT) in Sandusky, Ohio. Credits: GE Aerospace

Barrier Technical and Integration Risk: **Aircraft System Integration**

Risk Statement

Given that MW EAP has never been deployed on an aircraft before, there is a possibility that there are **unforeseen conflicts integrating EAP system into the aircraft**, resulting in an increase in cost and a delay in schedule and an inefficient aircraft.

Barrier Risk Burndown



Accomplishments and Mitigations

- GE partnered with Boeing to modify Saab 340B powered by GE CT7-9B turboprop engines
- magniX Partnered with Air Tindi and AeroTEC to demonstrate electric propulsion technology to power a hybrid De Havilland Canada Dash 7 aircraft
- Performance analysis to optimize key electric powertrain elements

Hybrid Electric Propulsion Development for Commercial Aviation

GE Aerospace Hybrid Electric Ground and Flight Test Program

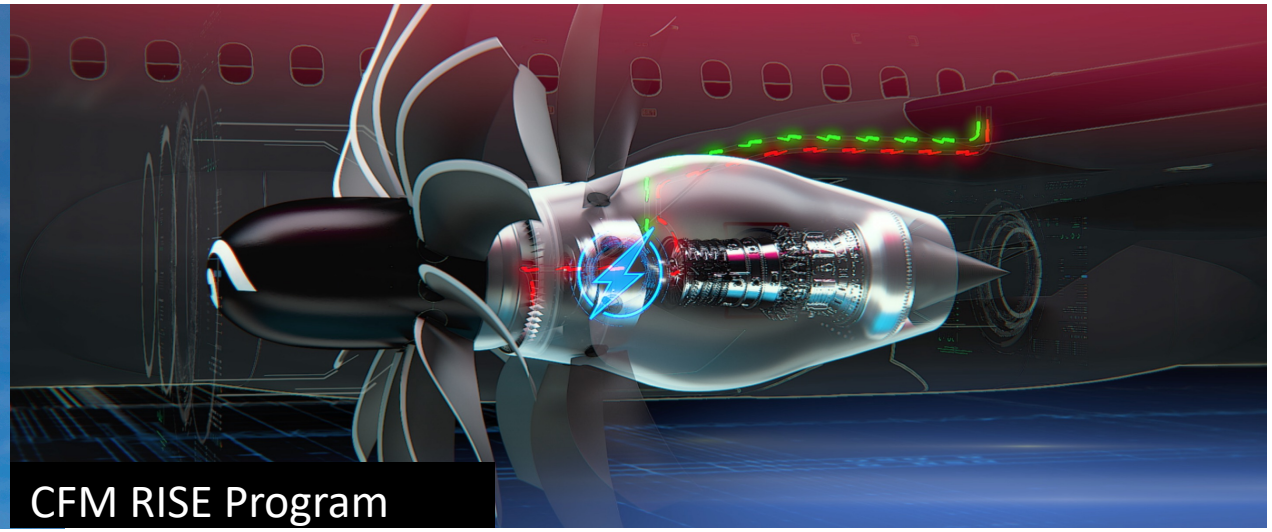
Flight Demonstration mid-2020s

- Modified Saab 340B testbed powered by GE CT7 engines
- GE-Boeing partnership to support flight tests
- Feasibility and reliability of hybrid electric propulsion system

Future Engine Designs

- Hybrid electric compatible with Sustainable Aviation Fuel and hydrogen
- Demonstrator informs future GE engine product designs with hybrid electric capability


EPFD


CFM RISE Program

More electric future of aviation propulsion

RISE is a trademark of CFM International, a 50-50 joint company between GE and Safran Aircraft Engines.

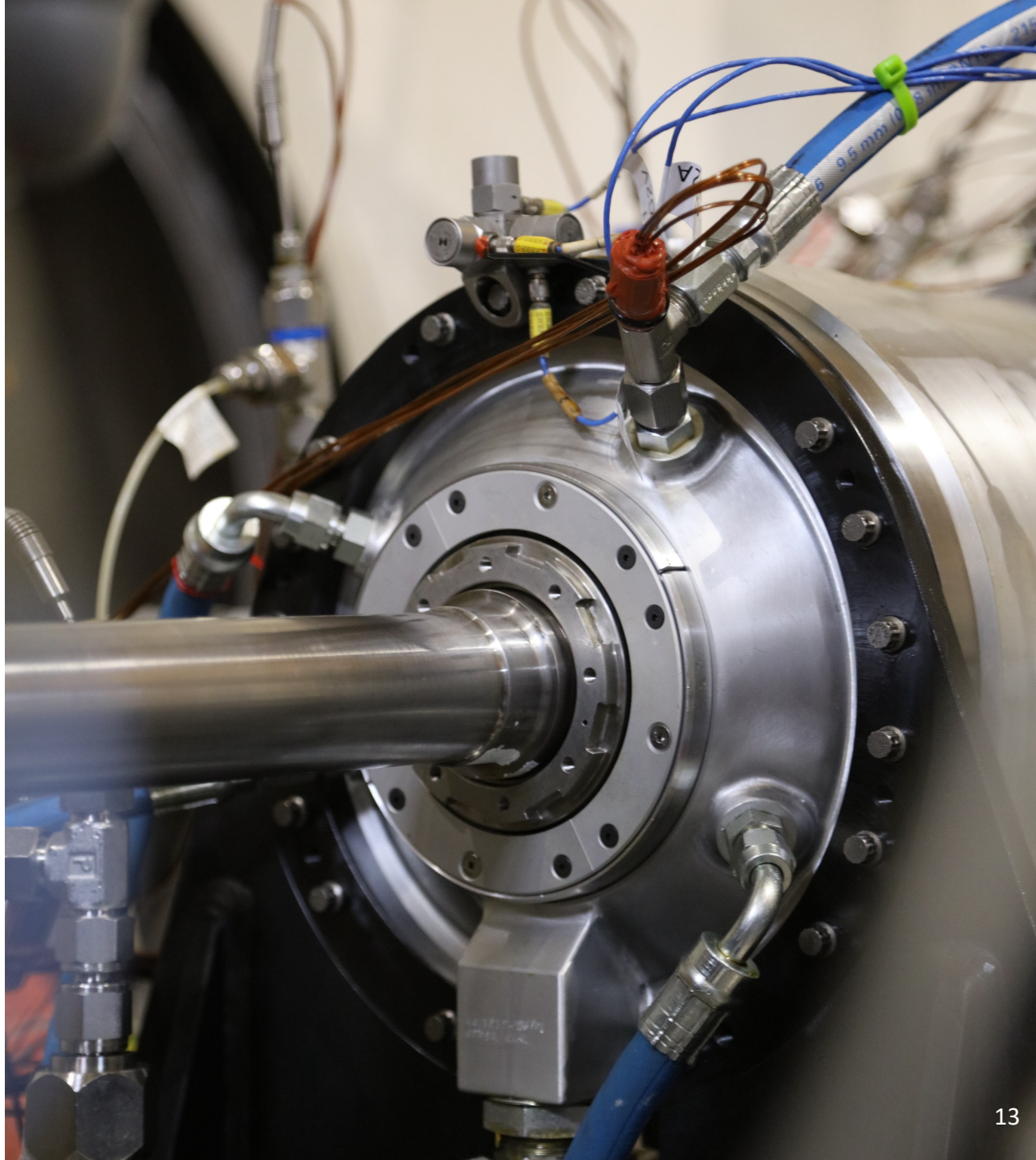
GE is world's first to test high power, high voltage hybrid electric components in simulated altitude

Demonstrated performance and component operation:

- Megawatt (MW) class, multi-kilovolt (kV) system
- Simulated altitude up to 45,000 feet
- Integrated system: Electric motor/generators, power converters, power transmission and power control systems

NASA collaboration:

- Altitude integration test completed at NASA's Electric Aircraft Testbed (NEAT) facility
- Tests continue under Electrified Powertrain Flight Demonstration (EPFD) project with NASA

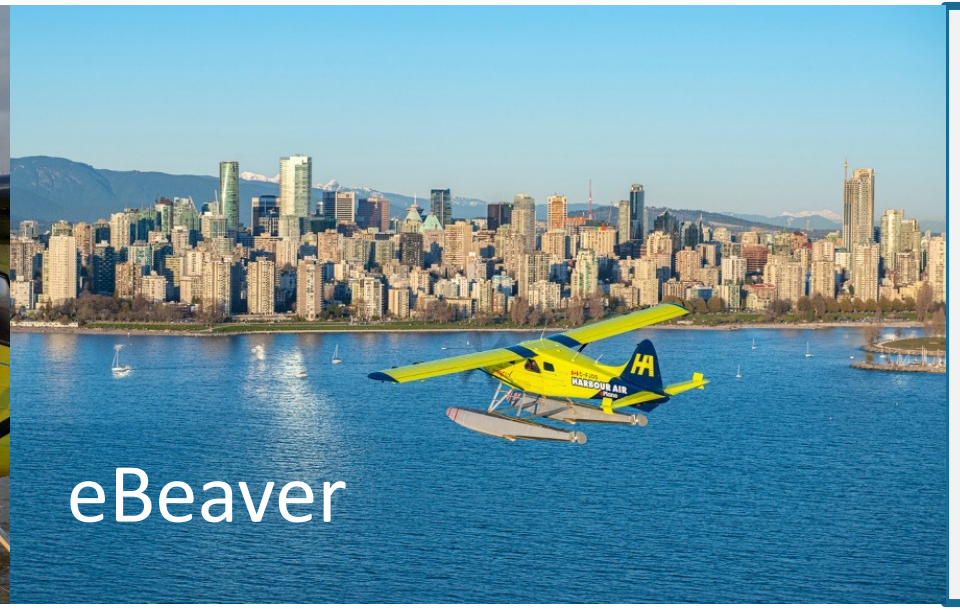


NASA Electrified Powertrain Flight Demonstration Program (EPFD)

Key deliverables:

- ✓ **$260M demonstrator**
- ✓ **Flying megawatt-class power grid**
- ✓ **Demonstrating 10X power-to-weight ratio**
- ✓ **Certifiable airworthy hardware**
- ✓ **Integrated electrical system**
- ✓ **Aligns with any energy source … SAF, H_2**


magniX



- First all-electric commercial airplane
- First flight Dec 10, 2019, continues to fly
- Follow-on program in work, STC expected 1Q-24

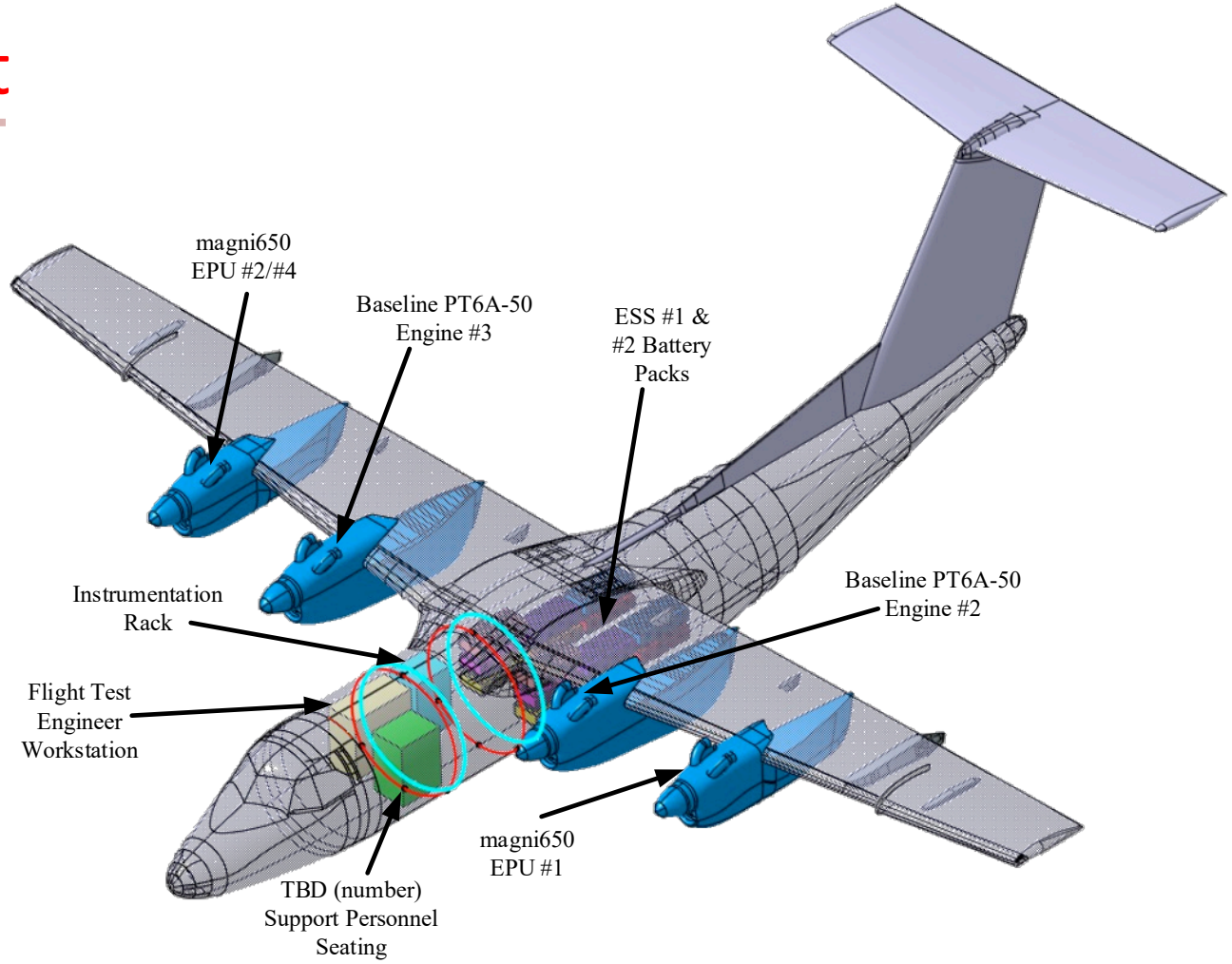
- Cessna 208B grad Caravan
- Magni500 motor
- 253kw battery
- World's largest electric airplane
- First flight June 4, 2020
- On-going program with Surf Air and AeroTEC

Eviation Alice

- Battery powered all electric airplane
- 2x magni650 EPU's

DHC-7 Parallel Hybrid Concept

- Replace the two outboard engines with magni650 based 700kW electric power train.
- Maintain the inboard engine gas turbine engines and potentially replace with larger ones to facilitate turbine only cruise
- A mixture of gas turbines and magni650's eliminates some common mode failures
  - The gas turbines and e-motors are not connected in any way; failures associated with one device will not affect the other
  - Utilizing the existing engines is both cost savings as well as a safety net which may appeal to regulatory agencies/customers while experience with electric powertrains is accrued
- Fuel savings ~45% over a 200nm mission



IMPACT of NASA's and Industry Partners' EPFD Investment

- Accelerate the introduction of MW class Electric Aircraft Propulsion (EAP) systems across a range of aircraft.

- Transforms the aviation fleet to enable sustainable aviation
  - EAP has the potential to reduce energy use, carbon and nitrogen oxide emissions
  - EAP systems enable favorable direct operating costs (total energy and maintenance) resulting in benefits for both the public and the airline operators and is synergistic with low emission airport infrastructure changes

- Move Up EAP to Transport Category Regulations and Standards Development