National Aeronautics and Space Administration

Aeronautics Technologies

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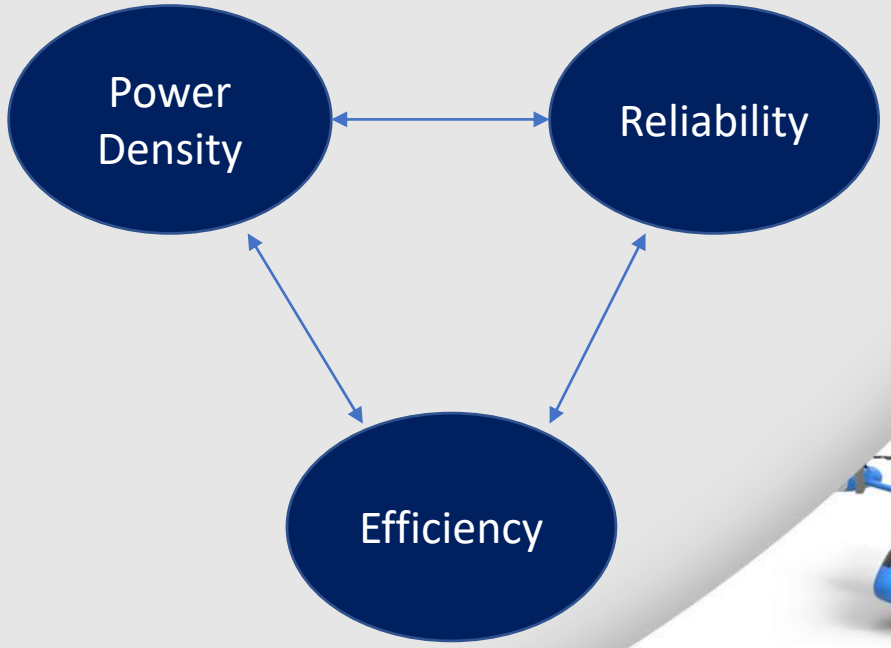
Aeronautics Technology Needs

- **Electrified Propulsion (both larger transport and RVLT-type vehicles(1-15 passengers)) need development in areas currently at TRL 2-3 due to high voltage/power (~1kV, 100's kW up to 2-3 MW):**
- Component Development
  - Batteries
  - Circuit protection
  - Converter topologies
  - Advanced cabling
  - Motors/inverters
- System Development
  - Fault protection
  - Architectures
  - Integrated Operation/Controls
- Test Capability Development
  - Test hardware
  - Techniques – enhanced real-time monitoring of dynamic electrical & physical parameter



Technology: Batteries

- **Lithium Ion technology currently at maximum energy density of approximately 250 Wh/kg per battery (not cell-level)**
- **Architecture studies only ‘close’ when use fictional 400 Wh/kg batteries**
- **Many entities are pursuing this field for breakthroughs**
  - Advance Li-Ion, Li-Air
  - Thermal batteries
  - Solid-State
- **RVLT not pursuing due to others working in this field; EAPT is funding some efforts**
- **In addition to the battery units, Battery Management Systems are needed**
  - LEM does have some experience here

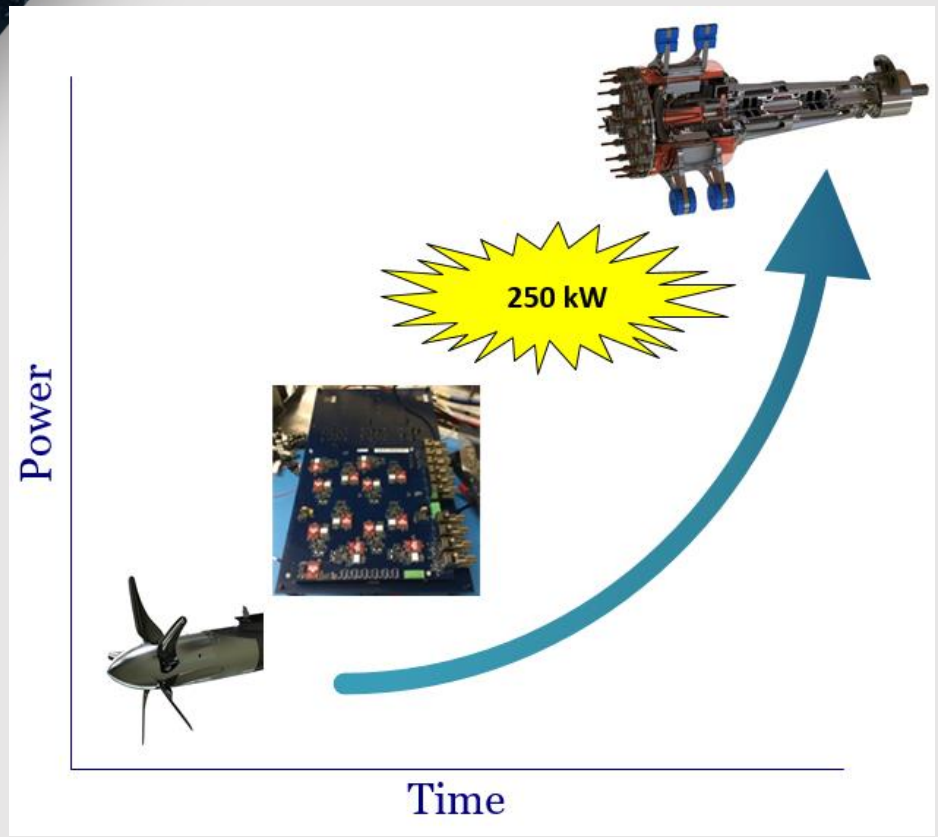
Technology: Converters

- Conversion needed from the source (battery, engine, etc.) to distribution, and distribution to loads
- Topologies needed for up to 1 MW
  - DC/AC Inverters
  - Active Rectifiers (AC/DC)
  - DC/DC Converters
    - Boost converters (batteries)
- Current SOA
  - Inverter/Rectifiers: 13-20kW/kg (without filtering)
  - DC/DC Converters: <5kW/kg

AATT 250kW Converter

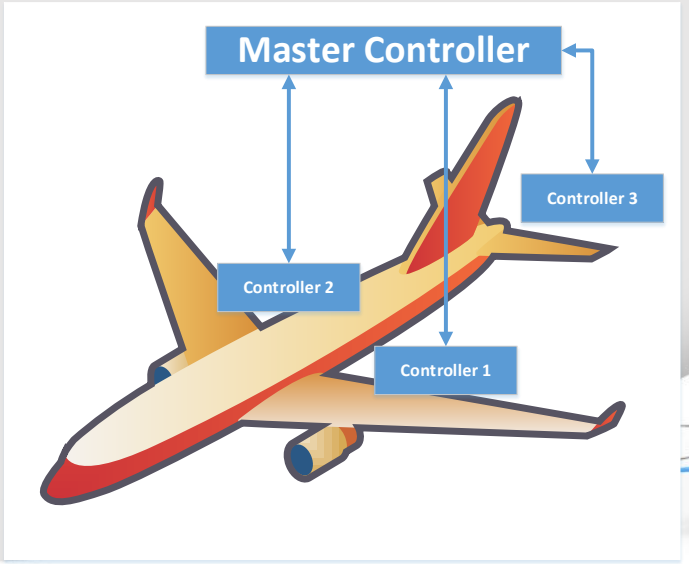
This project aims to make a 250 kW bidirectional power converter which accomplishes two complementary objectives:

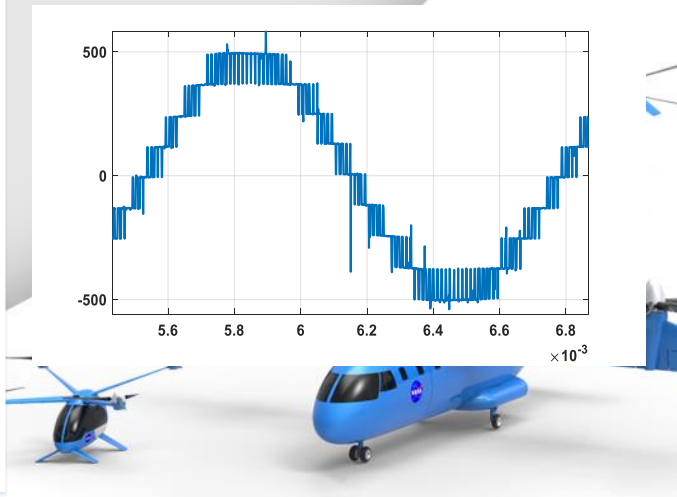
Advance converter technology for electrified aircraft



Develop technologies which enhance capabilities of NEAT

Higher Voltage Capability Lower THD Higher Efficiency Higher Power Density Streamlined Control Operation at Altitude



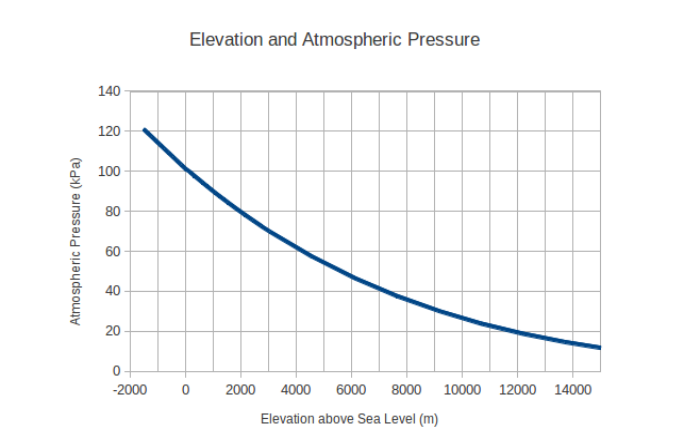


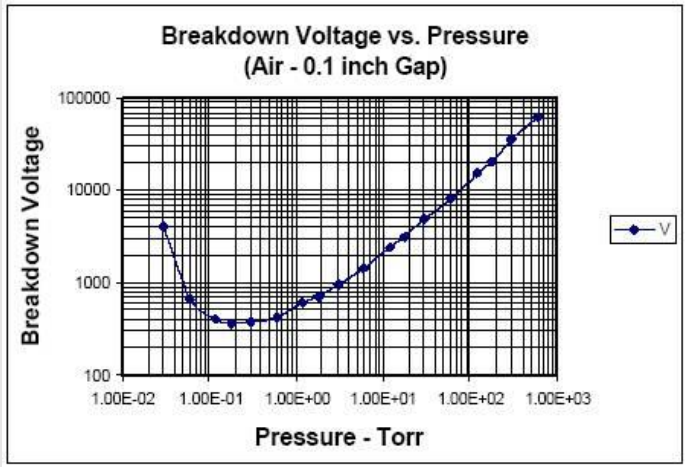
Technology: Motors/Inverters

- **High reliability motors and inverters are necessary for safe operation of flight**
  - Boeing FMECA listed these technologies as some of the most unreliable
  - Estimates of up to 10^{-9} failures required for certification (currently ~10^{-5})
- **RVLT, EAPT (HEATheR) working various motor topology designs**

Technology: Cabling

- **Due to high voltage/power ratings, new cabling technology required to ensure safe vehicle operation**
- **EAPT will fly at altitudes where Paschen's curve (partial breakdown) becomes an issue; RVLT may be near altitudes of concern**
  - Insulation breakdown causing soft faults in systems





Technology: Circuit Protection

- **High speed circuit protection does not exist for the voltage and power levels needed for flight (~ 1kV, up to 1 MW)**
- **For most electrified aircraft, protection will need to act quickly to ensure safe operations**
  - Working to determine where issues are – not well investigated
- **No Real SOA (only Solar applications)**
  - Eaton Breaktor closest near term development (mech)

Technology: System Protection

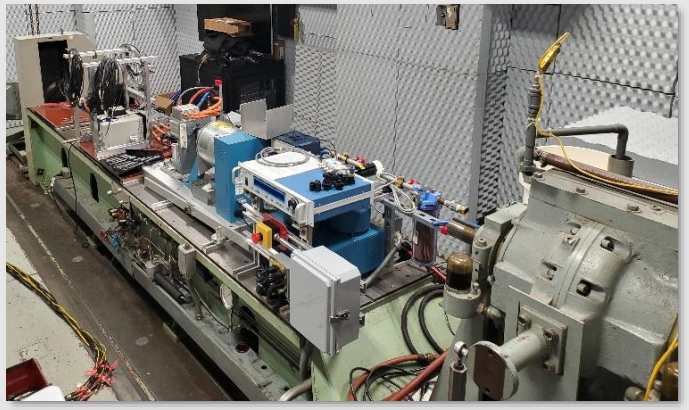
- **Power System is more like a utility**
  - Requires Utility type protection techniques
  - Just Overload/Overcurrent Protection is not acceptable
- **Fault Energy is incredible (High Power = High Voltage & Low Impedance)**
  - Electrical Arc Flash Demonstration – YouTube
  - DC Arc Flash events are much worse
  - Air Force has had several "lights out" events at 270Vdc
    - Explosions and Fires
    - Loss of Mission
- **High Impedance Faults are just as dangerous**
  - Hard to Detect
  - Definite need for AI/ Arc Signature Detection / Advanced Protection
- **Power System Manager**
  - Higher Level Autonomy Required
    - Pilot cannot react fast enough to reconfigure the system
    - Vehicles may not have pilots – need to fly safely in air space with other UAMs

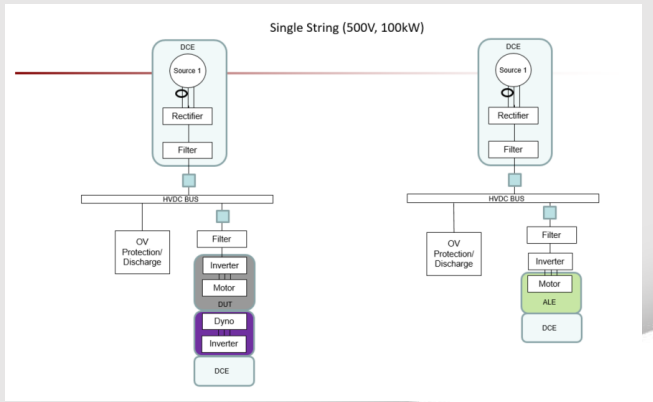
Technology: Modeling/Simulation

- **Modeling/Simulation is needed to provide basis for architecture examinations**
- **RVLT, EAPT, TTT all have efforts in this area**
- **RVLT In-house Developments are EPS-SAT and NPSS**
  - System and Component Sizing and Trades
  - Power System Architecture Studies
- **EPS-SAT**
  - Matlab Based (Easier to Learn)
  - Power System Focused
- **NPSS**
  - Multi-disciplinary (Power, Thermal, Mechanical, Propulsion)
  - C++ (hard to learn/balance interdisciplines)
  - GRC strong presence in International Power Model Development
- **Testbed data will be used to validate electrical models**
  - Models will be provided for industry use

Technology: Test Methods/Investments

- **RVLT working to provide best test practices to industry**
- **RVLT developing 2 labs**
  - Lower power testbed – up to 9 kW
  - Higher power testbed – up to 200 kW, emulators provide reconfigurability
  - Will be available to test various components (converters, motors, etc.)
- **EAPT developing NEAT – MW capability; HiPER**
  - Used to test MW generators and controls concepts
- **Data will be used to inform methods, Standards, certification**
- **None fully address all aspects of what is needed across all vehicles**





Example Higher Power Configuration Options

- **Use of Emulators Provides Flexibility to Investigate Various System Architectures Without Compromising Hardware**
- **Will Begin with Single String of 6 Passenger Quad Concept**
  - Single String = 1 source, inverter, motor, load
  - Allows for motor model validation
- **Plan to Further Tests Through Dual Channel Development**
  - Dual Channel = 2 sources, 2 inverters, 2 motors (or motor emulators), 2 loads – distributed propulsion concept
  - Allows for investigation of faults
  - Allows for more in-depth PQ analysis