Electric Motors for Hybrid/Electric Aviation – Technology Developments & Challenges
Introduction

John Yagielski
Senior Principal Engineer
GE Research

BSEE Clarkson University (‘90)
MSEPE Rensselaer (‘93)

GE Power 1990 – 2018
- Large turbo-generator design (40-1500MW)
- Stator Manufacturing Quality
- High speed, PM motors for O&G (5-15MW)
- New product development & systems integration

GE GRC 2018 - now
- Supporting GE Aviation Hybrid Electric Team
- Armature development & Prototypes
- IEEE Senior member
- Vice-Chair of the Power & Energy Society Electric Machine Committee

- Part of GE team that spans technology development through maturation and productization
- Exciting opportunity to help transform an industry
Hybrid Electrification of Narrow-Body Aircraft
Key in decarbonization of transportation sector

- As power sector switches to low emission technology, - Transportation sector taking lead in US CO₂ emissions\(^1\)

- Within Transportation, Aviation has highest emissions per passenger/mile and is fastest growing segment\(^2\)

- Narrow body segment (Regional + Single Aisle) consumes 60%+ of commercial aviation fuel\(^3\)

- Hybrid architecture w/embedded generators & tail-cone propulsor can deliver significant fuel burn reduction\(^3\)

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(2) https://www.eea.europa.eu/publications/progress-of-eu-transport-sector-1, Fig. 1; EEA report: Focusing on environmental pressures from long distance transport, doi: 10.2800/857401, Fig. 5.3

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Focus technology, component & system development on narrowbody architectures
Elements of Tail-cone Propulsion Hybrid System

MW level, high voltage distributed power providing new propulsion lever

1. **Engine and generator**
   - Compact, integrated and reliable

2. **Power management and transmission**
   - High voltage, compact, lightweight, power electronics and potentially battery system

3. **Motor-driven fan**
   - Compact, light, integrated with fuselage

4. **Thermal Mgmt. Syst.**
   - Integrated with overall system

**System Characteristics**
- System-level optimization
- Highly integrated, altitude-capable components
- High-voltage bus(es)
- Direct/Embedded-cooling
- Prime reliability
2016/2017: Demonstrators

**F110-GE-129 dual-spool engine**

MW-level POWER EXTRACTION at 51,000 ft

NASA Glenn PSL

**Electric motor/generator**

Dayton EPIScenter and Engine Test Facility Peebles, OH

1 MW MOTOR / GENERATOR

HIGH DENSITY & EFFICIENCY
2018: Component characterization and system testing
Ground level tests at GE’s EPIScenCer in Dayton, Ohio
2018: Inverter technology
Component/System test at GE Research and the GE EPIScenter
Preparing the technology building blocks

**Challenges**

- Higher voltage systems at altitude
- Performance and HALT testing at altitude
- Prime Reliable subsystems
- System-Level power densities

**Enabling technologies**

- Integration concepts and technologies
- Altitude-ready HV machines and inverters
- Advanced cooling & thermal systems
- New materials and additive manufacturing
- Compact energy storage technology
Enabling technologies for motor / generator - Physics

Energy Conversion Principles

- Electrical Network
  - Voltage, Current

- Electrical Machine
  - Speed, Torque

- Mechanical Network

Power

Energy Conversion Principles

\[ P \propto n L D^2 \sigma \beta \]

Utilization Factors

- **Magnetic**: Flux density
  - Magnetic Materials

- **Thermal**: Heating from current
  - Insulation Materials
  - Cooling systems

- **Kinetic**: Material Strength
  - Machine architecture
  - Magnetic / Structural Materials

Thermal & Weight Budgets

- Electric machine max temperature often limited by insulation & magnetic material capabilities
- Higher operating temperatures reduce:
  - Weight through higher power density
  - Thermal management system (TMS) weight & drag

Technology Levers for Power Density

- Machine Architecture & Subsystem integration
- Embedded cooling & thermal systems
- High temperature Electrical Insulation
- Magnetic Materials

System level integration & interdisciplinary design required

Electric Motors for Electric Aviation Workshop
August 2019
Opportunities for Technology Development

Materials
- Alternatives to mica-based insulation
- Alternatives to soft magnetic alloys

Motor Architecture & Thermal Management
- System & machine configurations
- Alternate cooling fluids & components

Subsystem & System Demonstrators
- Machines at scale (power, voltage)
- Performance & HALT testing at altitude
A mature, viable HEP system requires technology breakthroughs on all fronts.

With support, the industry can transform commercial aviation in a carbon-constrained world.