NASA Electric Propulsion System Studies

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Outline

• Why Electric Propulsion
• Overview of Electric Propulsion architectures.
• Example Implementations.
  – Boeing SUGAR Volt
  – ECO-150
  – STARC-ABL
  – N3-X
Why Electric Propulsion

• Allows the use of non-CO2 emitting terrestrial power sources in aviation

• High flexibility in moving power around the vehicle is a key enabler for several different ways to integrate propulsion into the aircraft in ways to further reduce the energy intensity of the vehicle
  – Boundary Layer Ingestion
  – Wingtip Propulsors
  – Highly distributed embedded propulsor arrays
Four Cardinal Electric Propulsion Architectures

- **Parallel Hybrid**
  - Electric Bus
  - Turbofan
  - Motor
  - Battery
  - Fan

- **Turboelectric**
  - Turboshift
  - Electric Bus
  - Generator
  - Motor
  - Distributed Fans
  - Fuel

- **Series Hybrid**
  - Turboshift
  - Generator
  - Electric Bus
  - Motor
  - Battery
  - Distributed Fans

- **All Electric**
  - Battery
  - Electric Bus
  - Motor(s)
  - 1 to Many Fans
But Wait, There's More!

Series/Parallel Partial Hybrid

Turbofan

Fan

Fuel

Generator

Electric Bus

Motor

Battery

1 to Many Fans
Boeing SUGAR Volt (Parallel Hybrid)

- 150 passenger
- 3500 nm range
- 750 Wh/kg battery energy density
- 1.3 MW motor meets NASA N+3 fuel reduction goal at the same energy consumption as SUGAR High
- 5.3 MW motor reduces fuel consumption further at the price of increased energy consumption compared to SUGAR High
Boeing SUGAR Volt CO2 Reduction Dependent on Terrestrial Charging Grid

Non-contract analysis from SAE 2013-01-2277

SUGAR Volt Hybrid Electric technologies provide additional benefits only if a renewable energy source is used to charge aircraft batteries.
Flow around an aircraft tailcone

- Diffusion into the base region of the aircraft means the velocity profiles represent more than just the viscous boundary layer of the fuselage
- Velocity profile nearly uniform circumferentially, so distortion is nearly all radial
STARC-ABL*  
(Partial Turboelectric/Fuselage BLI Fan)

- **Passengers**: 150
- **Range**: 3500 nm
- **Cruise Speed**: Mach 0.7
- **Tailcone Thruster Motor**: 2.6 MW (3500 hp)
- **Turbofan Generator**: 1.44 MW (1940 hp)
- **Turbofan Fan**: 1.95 MW (2615 hp)
- **Fuel Burn Reduction (vs same tech turbofan)**: ~10%

*STARC-ABL: Single-aisle Turboelectric AirCRaft – Aft Boundary Layer*
ESAero ECO-150
(Fully Turboelectric/Distributed)

- 150 Passenger/35k lbs Payload
- 3500 nm range
- Mach 0.8 Cruise
- 2 8-MW turbine driven generators
- 16 1-MW motor driven fans
- Fuel reduction from 737-700
  - 44% Non-cryo
  - 59% Cryo (with LH2 cooling)

Empirical Systems Aerospace: SBIR NNX13CC24P
Phase I 2013 / NNA10DA88Z Task 6 2012 / SBIR
NNX10CC81P Phase I 2009 / SBIR NNX09CC86P
Phase I 2008
NASA N3-X
(Fully Turboelectric/Distributed/BLI)

Baseline: B777-200LR/GE90-115B
Passengers: 300
Range: 7500 nm
Payload: 118,000 lbs
Cruise Speed: Mach 0.84
Fuel: 279,800 lbs

N3-X Superconducting
Passengers: 300
Range: 7500 nm
Payload: 118,000 lbs
Cruise Speed: Mach 0.84
Fuel: 76,000 lbs
(-72%)
Generators: 30 MW
Motors: 4.3 MW

### NASA N3-X Propulsion System Weight

#### GE90-115B

- **Thrust – RTO**: 180,400 lbs
- **Non-electrical System - lbs**: 58,600 lbs
- **Electrical System/Gearbox - lbs**: 1800 lbs
- **Total Weight - lbs**: 47,300 lbs

#### N3A/UHB

- **GE90-like**: 139,000 lbs
- **UHB**: 58,600 lbs
- **TeDP/Cryo**: 21,300 lbs
- **TeDP/LH2**: 16,300 lbs

#### N3-X

- **GE90-like**: 94,200 lbs
- **UHB**: 30,500 lbs
- **TeDP/Cryo**: 51,800 lbs
- **TeDP/LH2**: 44,400 lbs
For the power range bar for each aircraft class

- The left side is the smallest electrical machine in a partially electrified system
- The right side is the size of the generator in a twin engine fully electrified system

**Non-Cryo**

- 100 kW
- 1 MW
- 3 MW
- 10 MW
- 30 MW

**9 Seat/0.5 MW Total**

- 50 kW – 250 kW

**19 Seat/2 MW Total**

- 100 kW – 1 MW

**50 Seat/3 MW (prop)/12 MW (jet) Total**

- 300 kW – 6 MW

**150 Seat/22 MW Total**

- 1 MW – 11 MW

**300 Seat/60 MW Total**

- 3 MW – 30 MW