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
  - Battery
  - Motor
  - Fan

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

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

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

Series/Parallel Partial Hybrid

Turbofan

Fan Fuel

Generator Battery

Electric Bus

Motor

Motor 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 Research & Technology, Boeing N+3 Subsonic Ultra Green Aircraft Research (SUGAR) Final Report
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)

<table>
<thead>
<tr>
<th>Feature</th>
<th>Specification</th>
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<tbody>
<tr>
<td>Passengers</td>
<td>150</td>
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<tr>
<td>Range</td>
<td>3500 nm</td>
</tr>
<tr>
<td>Cruise Speed</td>
<td>Mach 0.7</td>
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<tr>
<td>Tailcone Thruster Motor</td>
<td>2.6 MW (3500 hp)</td>
</tr>
<tr>
<td>Turbofan Generator</td>
<td>1.44 MW (1940 hp)</td>
</tr>
<tr>
<td>Turbofan Fan</td>
<td>1.95 MW (2615 hp)</td>
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<tr>
<td>Fuel Burn Reduction (vs same tech turbofan)</td>
<td>~10%</td>
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*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

#### B777-200LR

#### N3A/UHB

#### GE90-115B

#### N3-X

<table>
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<tr>
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<th>GE90-like</th>
<th>UHB</th>
<th>TeDP/Cryo</th>
<th>TeDP/LH2</th>
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<tbody>
<tr>
<td>Thrust – RTO</td>
<td>180,400</td>
<td>139,000</td>
<td>94,200</td>
<td>85,800</td>
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<tr>
<td>Non-electrical System - lbs</td>
<td>58,600</td>
<td>30,500</td>
<td>28,100</td>
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<tr>
<td>Electrical System/Gearbox - lbs</td>
<td>1800</td>
<td>21,300</td>
<td>16,300</td>
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<tr>
<td>Total Weight - lbs</td>
<td>47,300</td>
<td>60,400</td>
<td>51,800</td>
<td>44,400</td>
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</table>
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.