A Review of Distributed Electric Propulsion Concepts for Air Vehicle Technology

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OUTLINE

1. Introduction to DEP concept
2. DEP aircraft (CTOL, STOL, & VTOL)
3. DEP/HE system research at NASA
4. Propulsion-Airframe-Integration (PAI) effects
   • Aero-propulsive coupling
   • Aircraft control
   • Noise reductions
5. R&D in electric components
6. Issues & Challenges
7. Conclusions

(DEP - Distributed Electric Propulsion, HE - Hybrid Electric)
What is Distributed Propulsion? – No formal definition but,
- Jet flap or distributed jet from one or more engines
- Multiple small independently powered propulsors
- *Distributed propulsors driven by one or more power sources through various power transmission methods*

Computational Fluid Dynamics (CFD) simulation

Hunting H.126 (https://en.wikipedia.org)

F117 (http://www.af.mil)

Cruise Efficient Short Take-off and Landing (CESTOL) aircraft - NASA

YB-49 (http://www.nationalmuseum.af.mil)
DP - Distributed propulsors driven by one or more power sources through various power transmission methods

- Fluidically driven propulsor concepts
- Mechanically driven propulsor concepts
- Electrically driven propulsor concepts (DEP)


NASA dual-fan concept

http://silentaircraft.org/sax40

Wright Flyer (http://www.nationalmuseum.af.mil)
What is Distributed Electric Propulsion (DEP)?

- A propulsion system where electrical energy sources are connected, via transmission lines, to multiple electric motor-driven propulsors

Key Features

- Power sources can be any combination of electrical power-producing devices (i.e., electric generator, fuel cell, etc.) and/or energy storage devices (i.e., battery, capacitor, etc.)
- Propulsors can be any combination of thrust producing devices such as electrically-driven propellers or fans
- Decoupled feature between the power sources and propulsive devices enables flexibility in aircraft design and efficient operation if efficient & compact electric machines and transmission system are employed
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DEP Aircraft

VTOL Configurations
- Aurora eVTOL
- Joby S2
- Airbus Vahana
- Lilium
- NASA X-57
- ESAERO ECO-150
- NASA STARC-ABL

CTOL Configurations
- Aurora XV-24
- Zunum Regional Aircraft
- NASA N3-X

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DEP/HE system research at NASA

Propulsion Electric Grid Simulator (PEGS) subscale electric power system for TeDP at NASA Glenn Research Center

Hybrid-Electric Integrated Systems Testbed (HEIST) at NASA Armstrong Flight Research Center
DEP/HE system research at NASA

NASA Electric Aircraft Testbed (NEAT) platform for full-scale turboelectric powertrain testing at NASA Glenn Research Center
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Propulsion-Airframe-Integration (PAI) effects

- Aero-propulsive coupling
- Aircraft control
- Noise reduction
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Aero-propulsive coupling

- Boundary layer ingestion (BLI) benefit – increased propulsive efficiency
- Wing-tip vortex suppression and wake-filling – reduced (induced) drag
- Enhanced lift or control authority
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Aero-propulsive coupling

- Wing-tip vortex suppression – reduced (induced) drag

Figure 1. Vorticity Model of Wing-Propeller Combination
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- Aero-propulsive coupling
  - Enhanced lift or control authority

Joby S2
Airbus Vahana
NASA X-57
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- Aero-propulsive coupling
  - Enhanced lift or control authority

Aurora XV-24
Lilium

ESAERO ECO-150
Hunting H.126
NASA N3-X

https://en.wikipedia.org
Aircraft Control

- Propulsion controlled aircraft origins (PCA)
  - 1989 DC-10 United Airlines Flight 232 accident in Sioux City, Iowa
  - Fault tolerant control (FTC)

- Initial concept challenges
  - Development of MD-11 testbed
  - Slow gas turbine response time

- The bright future
  - DEP enabled control
  - Fast electric motor response time
    - Variable pitch blades, variable area nozzles

https://en.wikipedia.org/
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- **DEP-based Aircraft Control**
  - Propulsion units as thrust-line control actuators
    - Thrust vectoring (Lilium)
  - Enhanced control authority from blown surfaces
  - Improved control redundancy/robustness to vehicle damage
  - Reduction/elimination of traditional stabilizer/control surfaces
  - Propulsion induced aeroelastic responses

Aurora XV-24
DEP-based Aircraft Control

- Several concepts exhibit DEP control
  - Thorough system identification tests for controller development (GL-10)
- Ongoing research at UIUC
  - Scaled Cirrus SR22 DEP variant
  - Flight tests – influence of propulsors on dynamics
    - Compare to baseline
Noise Reductions

- NASA Chapter 4 far term noise goal: cumulative margin 52EPNdB
- High effective bypass ratio for low FPR (N3-X margin of 32EPNdB)
- Shielding propulsion units from ground (N3-X margin of 64EPNdB)
- Electric machine noise
- X-57 Acoustic studies
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R&D in electric components

- Current capabilities
  - Applicable to general aviation aircraft and UAVs

- Areas of research
  - Megawatt scale electrical machines (UIUC)
  - Hybrid electric systems
  - Power transmission architectures for DEP
  - Inverters, converters, power transmission

Table 1 Current electrical component capabilities for aircraft applications.

<table>
<thead>
<tr>
<th>Motor Power Capability (MW)</th>
<th>Motor Specific Power (kW/kg)</th>
<th>Electronics Power Capability (MW)</th>
<th>Electronics Specific Power (kW/kg)</th>
<th>Battery Specific Energy (Wh/kg)</th>
</tr>
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<td>2.2</td>
<td>0.25</td>
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<td>200-250</td>
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Issues & Challenges

➢ Inlet distortion from BLI (NASA GRC tests)

➢ Electrical component technology readiness
  • Weight, power ratings, certification, energy density

➢ Noise generation for eVTOL in urban environment

➢ Loss of propulsion units used for control/lift augmentation
  • Must be able to take off and land
  • Must be able to control vehicle
Conclusions

- **Distributed Electric Propulsion**
  - Electrical energy sources are connected to multiple electric motor-driven propulsors
  - Mechanical decoupling of power production and propulsive power expenditure
  - Use across CTOL, STOL, VTOL

- **Advantages**
  - Improved efficiency and performance
  - DEP-enabled vehicle control
  - Reduced operational noise

- **Electrical Systems Research Thrusts**
  - Components: motors, drives, electronics, energy storage
  - Power distribution architectures
  - System performance and control

- **Challenges for Future Study**
  - Inlet distortion
  - Redundancy and fault tolerance
  - Impact of VTOL and increased vehicle traffic on community noise
  - Battery systems and electrical components