Aerospace and Aircraft Thermoelectric Applications

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Agenda

- What is “Aerospace”?
- How can thermoelectric contribute?
- Limitations & Suggested Improvement
- Aircraft Application
- Comparison of aircraft power generation means
- Potential benefit assessment
What is “Aerospace”?

- Anything that flies
  - Boeing 787
  - Delta-IV
  - Space Shuttle
  - Space Station
  - 702 Satellite
  - Lunar Lander
  - F-18A Hornet
  - V-22 Osprey
  - C-17 Globemaster
  - B-1B Lancer
  - FCS Vehicle
  - Radar Station
  - Air Traffic Management
  - Communication Center
  - Flight Training
  - Logistics
  - Maintenance

- Defense

- Associated infrastructures

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Characterizing Aerospace Applications

- Application Environment – **Severe**, e.g., vibration and thermal swing
- Life Cycle – **Long**, e.g., 30 years for airplane
- Complexity – **High**, e.g., chip-board-box-subsystem-system integrated systems
- Volumetric – **Limited**, e.g., cockpit & launch vehicle payload profile
- Cost – **High**, e.g., FAA certified
- Safety – High to **extremely high**, e.g., human life
How can Thermoelectric Contribute?

- Reduce Weight, e.g., high-efficiency cooling eliminating liquid cooling and associated thermal management weight
- Improve Performance, e.g., communication RF front end cooling reduces noise
- Improve System Efficiency, e.g., paired with solar cell to produce more power
- Reduce Cost, e.g., reduce fuel consumption through aircraft engine waste heat harvesting
- New Capabilities
Limitations & Suggested Improvement

**Thermoelectric Device**

- Efficiency Limitation: Available thermoelectric devices on the market have relatively low efficiencies and generally can’t compete with alternative approaches.
- Costs Limitation: For large scale and broad applications, the cost must be reduced.
- Suggested improvement: Develop high-efficiency devices that can be manufactured in volume with cost-effective techniques.

**Aerospace Platform**

- Space and Weight Limitations: Highly weight sensitive with limited space.
- $\Delta T$ Environment Limitation: Sustainable operating environment must be provided to match candidate device performance profile, e.g., operating temperature range vs. achievable energy conversion efficiency.
- Suggested improvements: Choose high payoff applications capable of circumventing above limitations to a maximum degree.
Aircraft Engine Waste Heat Harvesting has Large Potential Payoffs
Solution is Desirable to be a Totally Passive Design With no Moving Parts

Desirable Cold Sinks:
(1) Ambient Air
(2) Cool Fan Stream Flow

Desirable Heat Sources:
(1) Hot Air Flow
(2) Hot Surfaces
Knowledge in Engine Profile is Essential

Representative High By-Pass Engine Temperature Profile

Surface Temperature Ranges (°F)

- 100 – 200
- 200 – 325
- 325 – 375
- 350 – 500
- 450 – 800
- 550 – 1,100
- 600 – 1,200
# Comparison of Aircraft Power Generation

<table>
<thead>
<tr>
<th>Engine Generator (IDG)</th>
<th>Advantages</th>
<th>Disadvantages</th>
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</table>
|                        | • Proven technology  
                          • Operates over the entire aircraft flight envelope | • Power output may be limited by flight conditions |

<table>
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<tr>
<th>Auxiliary Power Unit (APU) Generator</th>
<th>Advantages</th>
<th>Disadvantages</th>
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</table>
|                                      | • Proven technology  
                          • Provides aircraft power on the ground when engines are not operating  
                          • Provides power to start main engine  
                          • Operates independent of engines and does not affect engine operations | • Some installation may not allow in-flight operation; non-operating APU is deadweight  
                          • Ownership costs are higher than those for aircraft engines |

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<tr>
<th>Fuel Cell APU/Generator</th>
<th>Advantages</th>
<th>Disadvantages</th>
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|                         | • Very efficient and no moving parts  
                          • Replaces both APU and IDG with a single system  
                          • Operates independent of engines and does not affect engine operations  
                          • Operates over the entire flight envelope | • New technology; currently heavy and reliability is uncertain  
                          • Requires a second fuel source, either a hydrogen fuel system or a jet fuel to hydrogen reformer system |

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<tr>
<th>Thermoelectric</th>
<th>Advantages</th>
<th>Disadvantages</th>
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|                | • Provides electrical power from waste heat – no fuel burn and no moving parts  
                          • Operates over the entire aircraft flight envelope  
                          • Operates independent of engines and does not affect engine operations | • New technology and unproven  
                          • Cost & efficiency; further development is needed  
                          • Power output limited by available waste heat, space, device efficiency, and sustainable $\Delta T$ |
Integration and Application Challenges are Non-Trivial

- Thermal, e.g., temperature swing
- Vibration and shock
- Material compatibility, e.g., CTE mismatch creates thermal stress
- Noise
- Parasitic thermal paths
- $\Delta T$ maintenance, e.g., provide sustainable operating environment
- Maintenance and upgrade, e.g., incorporating the latest technology
- Reliability
Potential Benefit Assessment

Fuel Reduction

• Preliminary analysis showed that 0.5% or more fuel reduction is achievable

Operating Cost Reduction

• Average monthly fuel costs for U.S. commercial planes is $2.415B for the first 4 months of 2009 (Source: EIA)
• A 0.5% fuel reduction translates into $12.075M monthly operating cost reduction

Carbon Emission Reduction

• Aircraft contributes ~2% of global carbon emission (Source: EPA)
• Passenger airlines accounts for ~85% of fuel consumed by U.S. airlines, which account for an estimated 35% of global airline fuel consumption (Source: EIA)
• A 0.5% fuel reduction on U.S. passenger aircraft alone contributes to ~0.03 global carbon emission reduction