# Aerospace and Aircraft Thermoelectric Applications

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# Agenda



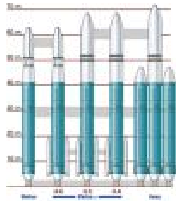
- What is “Aerospace”?
- How can thermoelectric contribute?
- Limitations & Suggested Improvement
- Aircraft Application
- Comparison of aircraft power generation means
- Potential benefit assessment

# What is "Aerospace" ?



- Anything that flies

**Boeing 787**



**Delta-IV**

**Space Shuttle**

**Space Station**

**702 Satellite**

**Lunar Lander**

- Defense

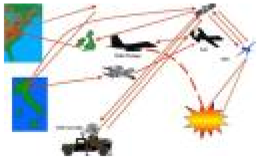
**F-18A Hornet**

**V-22 Osprey**

**C-17 Globemaster**

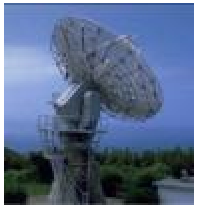
**B-1B Lancer**

**FCS Vehicle**

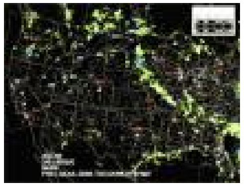


**Network Centric Operation**

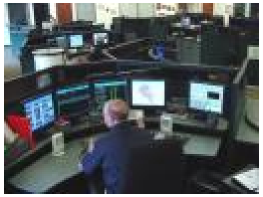
- Associated infrastructures



**Radar Station**



**Air Traffic Management**



**Communication Center**

**Flight Training**

**Logistics**

**Maintenance**

# 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

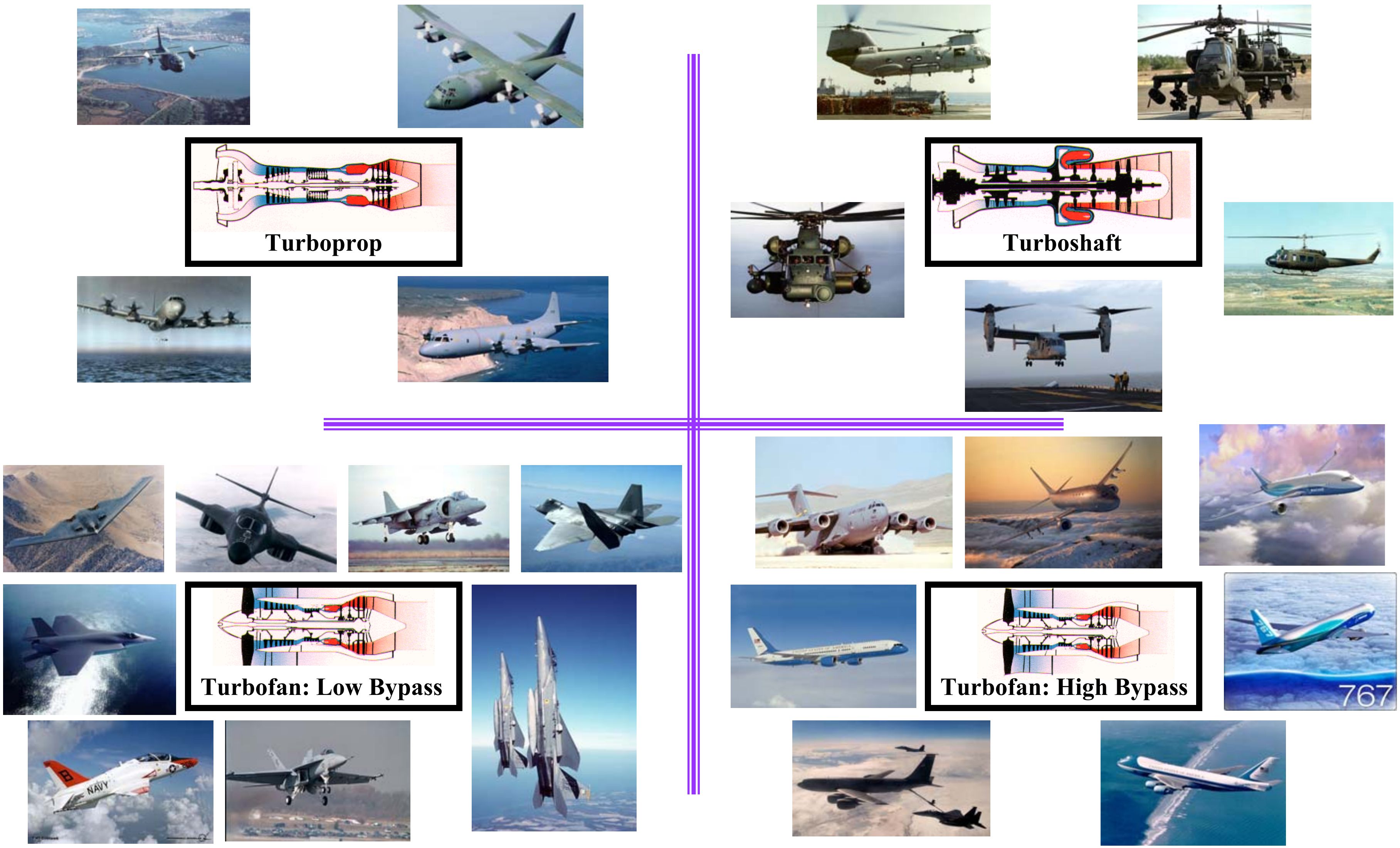
- Efficiency Limitation: Available thermoelectric devices on the market have relatively low efficiencies and generally can't compete with alternative approaches
- Costs Limitation: For large scale and broad applications, the cost must be reduced.
- Suggested improvement: Develop high-efficiency devices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

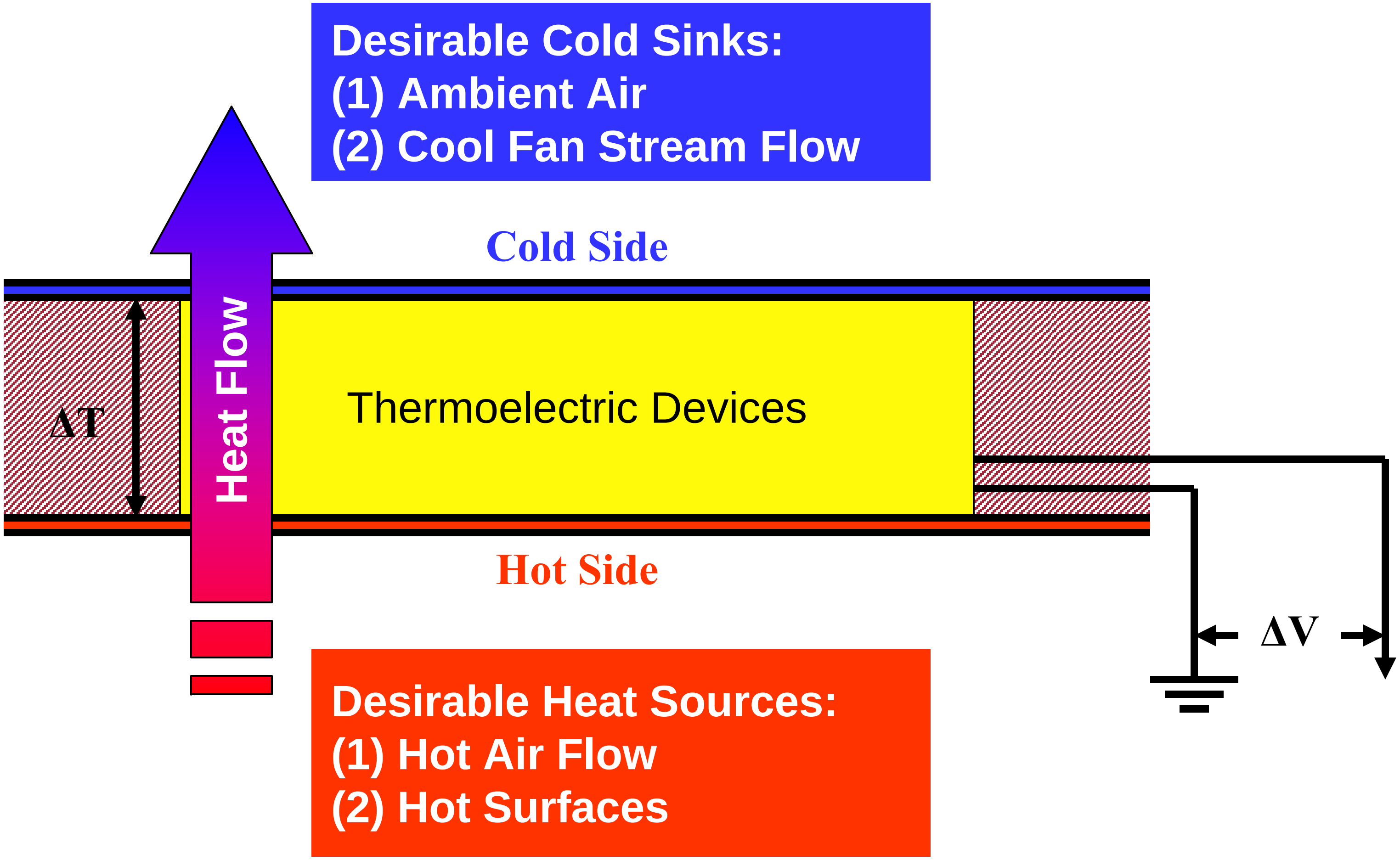
# Aircraft Engine Waste Heat Harvesting has Large Potential Payoffs





# Solution is Desirable to be a Totally Passive Design With no Moving Parts



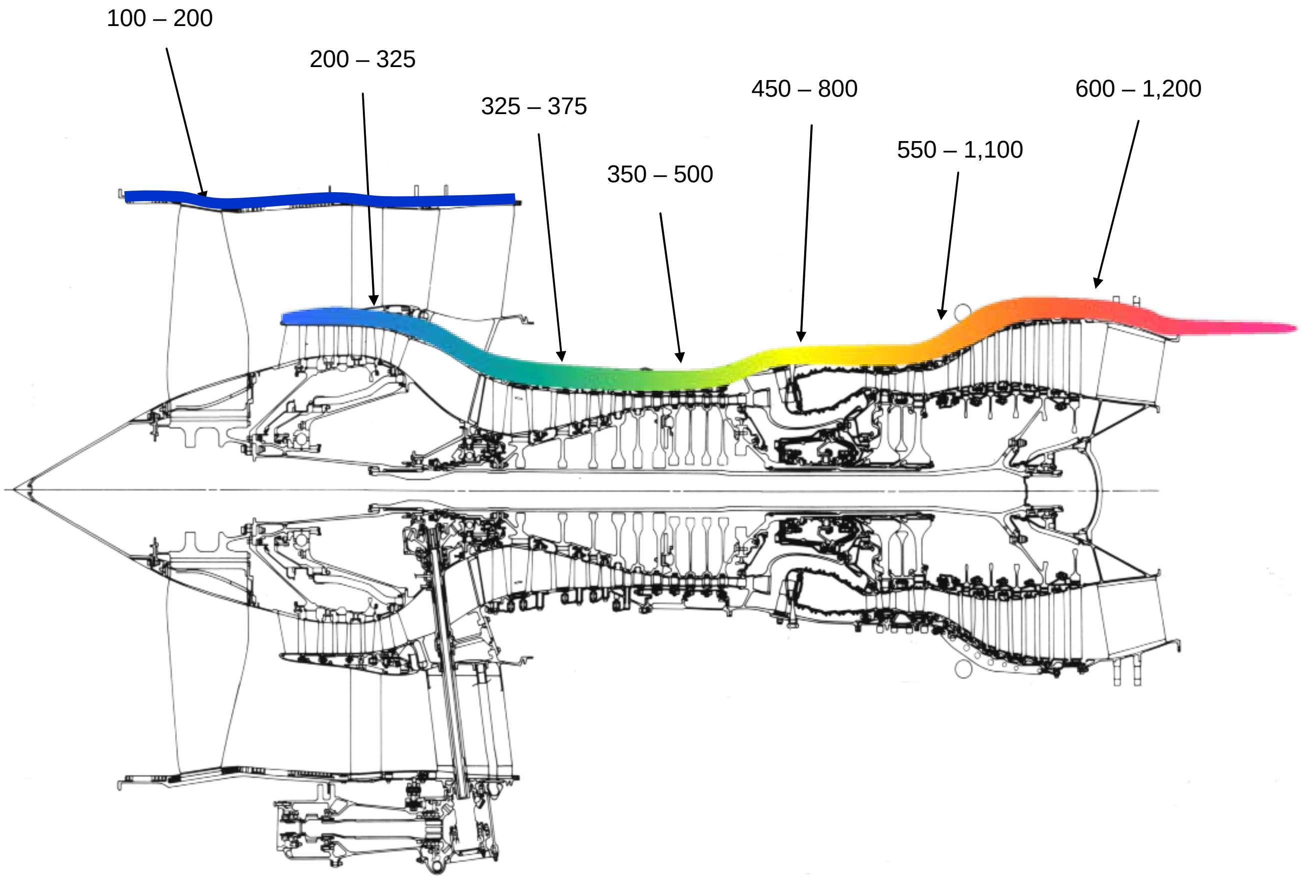


# Knowledge in Engine Profile is Essential

Engineering, Operations & Technology | **Boeing Research & Technology**

## Representative High By-Pass Engine Temperature Profile

***Surface Temperature Ranges (°F)***



# Comparison of Aircraft Power Generation



| | Advantages | Disadvantages |
|---|---|---|
| Engine Generator (IDG) | • Proven technology<br>• Operates over the entire aircraft flight envelope | • Power output may be limited by flight conditions |
| Auxiliary Power Unit (APU) Generator | • Proven technology<br>• Provides aircraft power on the ground when engines are not operating<br>• Provides power to start main engine<br>• Operates independent of engines and does not affect engine operations | • Some installation may not allow in-flight operation; non-operating APU is deadweight<br>• Ownership costs are higher than those for aircraft engines |
| Fuel Cell APU/Generator | • Very efficient and no moving parts<br>• Replaces both APU and IDG with a single system<br>• Operates independent of engines and does not affect engine operations<br>• Operates over the entire flight envelope | • New technology; currently heavy and reliability is uncertain<br>• Requires a second fuel source, either a hydrogen fuel system or a jet fuel to hydrogen reformer system |
| Thermoelectric | • Provides electrical power from waste heat – no fuel burn and no moving parts<br>• Operates over the entire aircraft flight envelope<br>• Operates independent of engines and does not affect engine operations | • New technology and unproven<br>• Cost & efficiency; further development is needed<br>• 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