Perspectives on Energy Harvesting for Aerospace Sensors

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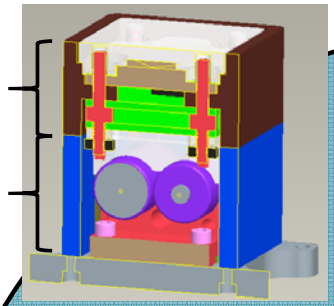
Why Energy Harvesting for Aerospace?

Wireless Sensor Module



Battery replacement every 227 operational hours!

Wiring Example: A380
- 530km of wire
- 40,000 connectors

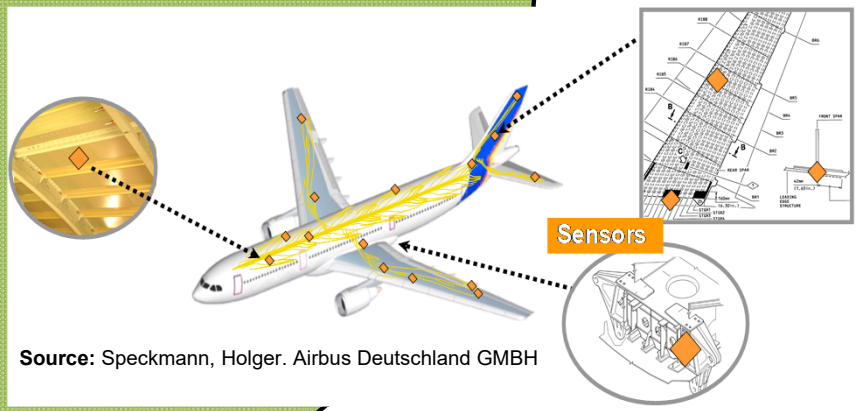
Batteries
- Initial and replacement battery cost $
- Battery change cost – A/C/D checks $$$$
- Battery volume

Wiring or Battery Replacements

Re-certifications

Sensors in Powerless Locations

PHM Example:
- Problem: failing ACM fan motors in flight
- Solution: simple real-time accelerometer spectrum analysis detects failure before catastrophic loss
- New problem: galvanic connection to sensor system requires re-cert
- New solution: wireless self-powered sensor



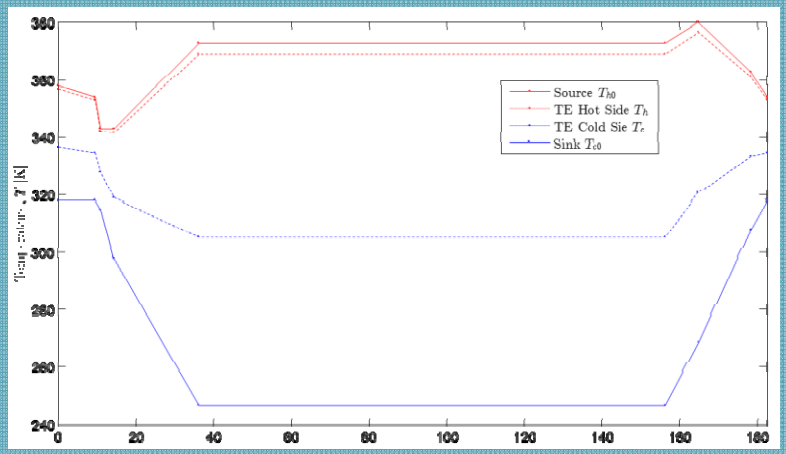
Source: Speckmann, Holger. Airbus Deutschland GMBH

Wings, fins, nacelles, and landing gear have need for sensors without extra wiring

Unique Aerospace Challenges for Energy Harvesting

Environmental

-55 to 85°C
10 to 100 kPa
4 LTO cycles/day



LTO Cycles Affect Components, Materials, and Energy Sources

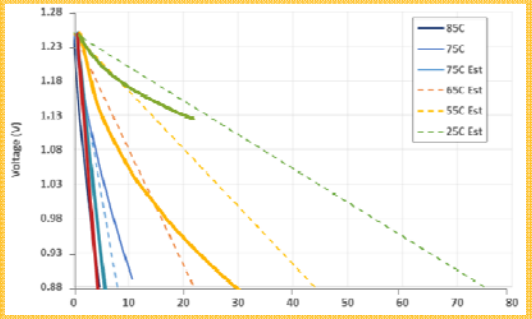
Component Leakage

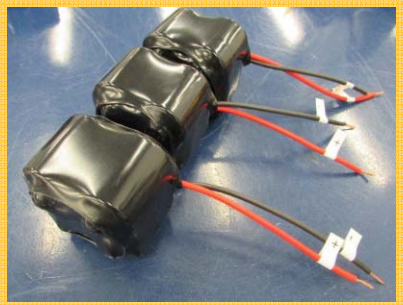
Parameter	0.01uF 16V	0.1uF 6.3V	1uF 6.3V	10uF 6.3V	2.5F 5V	500mA 20V	1A 40V
Component type	Capacitor	Capacitor	Capacitor	Capacitor	Super-Capacitor	Diode	BJT
Component size	0805	0201	0603	0402	"Can"	0603	SOT-563
Component material	Film	Ceramic X6S	Ceramic X7R	Ceramic X5R	Electrolyte	Si Schottky	Si PNP
Applied voltage	4.1V	4.1V	4.1V	4.1V	4.1V	4.1V	4.1V
Leakage current	0.08uA	0.14uA	0.13uA	0.12uA	15.6uA	12uA	55uA

Typical Sensor Component Leakage at 25°C

Problems at Temperature Extremes
- Rechargeable battery lifetime is poor at 85°C
- Super-capacitors stop operating below -40°C

Wide Temp Range Super-cap Development





Carbon Nanotube-based Structure
- Leakage current 10x lower than conventional
- Operates below -55°C, above 85°C

Unique Aerospace Challenges for Energy Harvesting

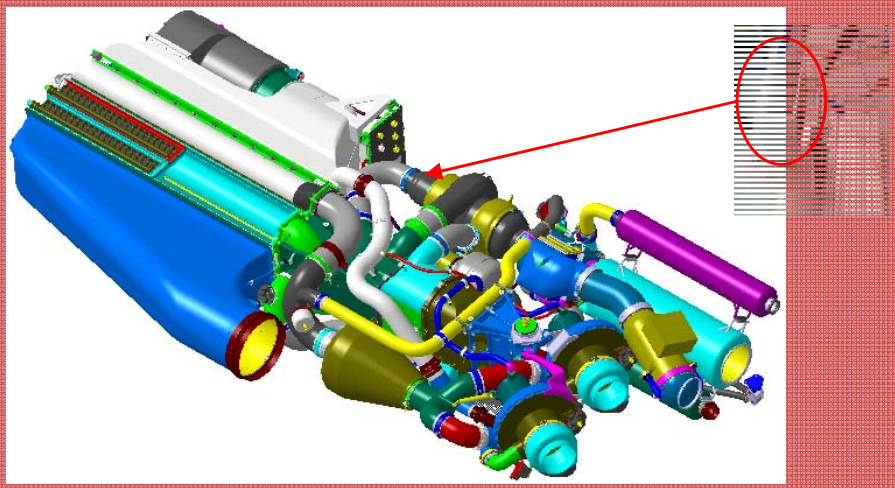
Energy Sources

Harvesting Estimates by Technology

Method	μW/cm³	
Solar (outside)	15,000	Has potential, esp. on wings
Air flow	380	Parasitic, little access
Human power	330	Not likely
Vibration	200	Fixed wing aircraft have little
Temperature	40	Numerous thermal systems
Pressure Var.	17	Numerous, difficult access
Solar (inside)	10	Very intermittent

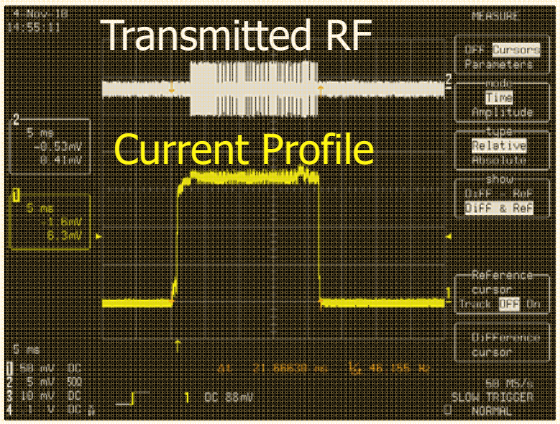
Thermal Harvester in Application

TEG ΔT	TEG Voltage	TEG Current	TEG Power	Matched Load	Peak Load Power	Average Load Power	Overall Efficiency
42°C	0.510V	41mA	21mW	37mW	52mW	6mW	29%
55°C	0.315V	76mA	24mW	60mW	52mW	8mW	33%



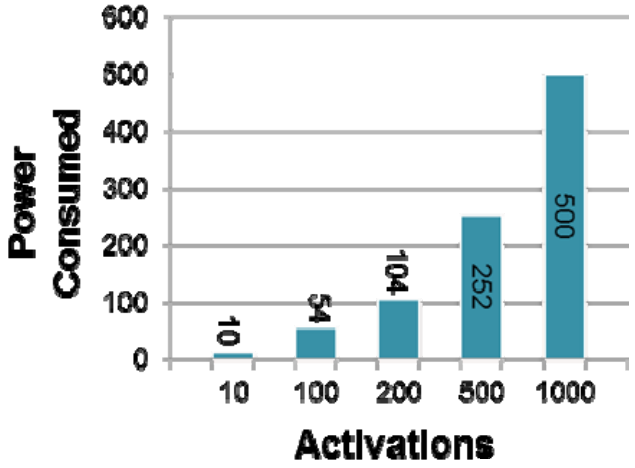
Need for Reduced Energy Consumption

In Practice, Sensors Consume More Energy Than Predictions

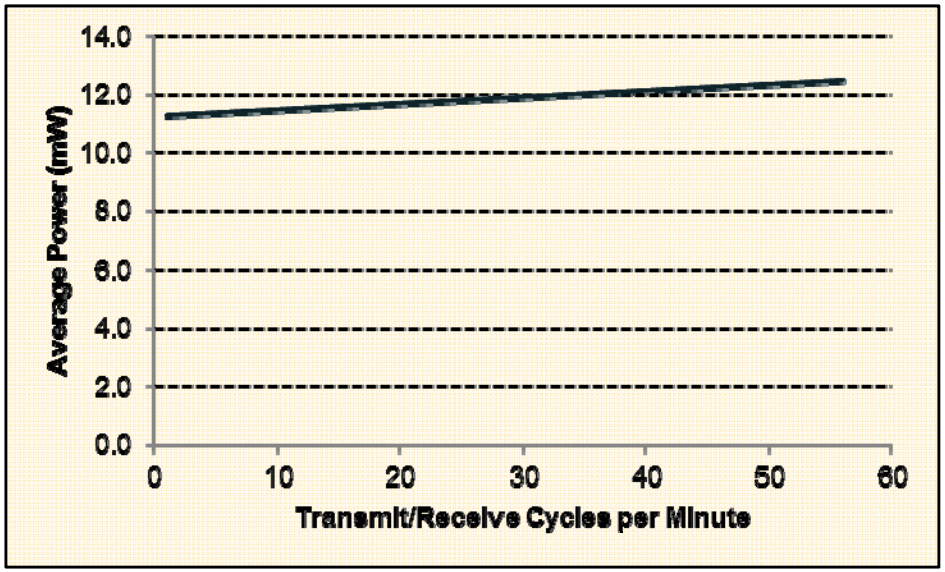


Sensor energy measurement

1µA Standby Current
22-27 ms packet duration
4ms startup
95% at 30 mA, 3.3V
J/packet=0.74 µJ
11.88 µJ/event
~10 nJ/bit (1 nJ/bit academic)



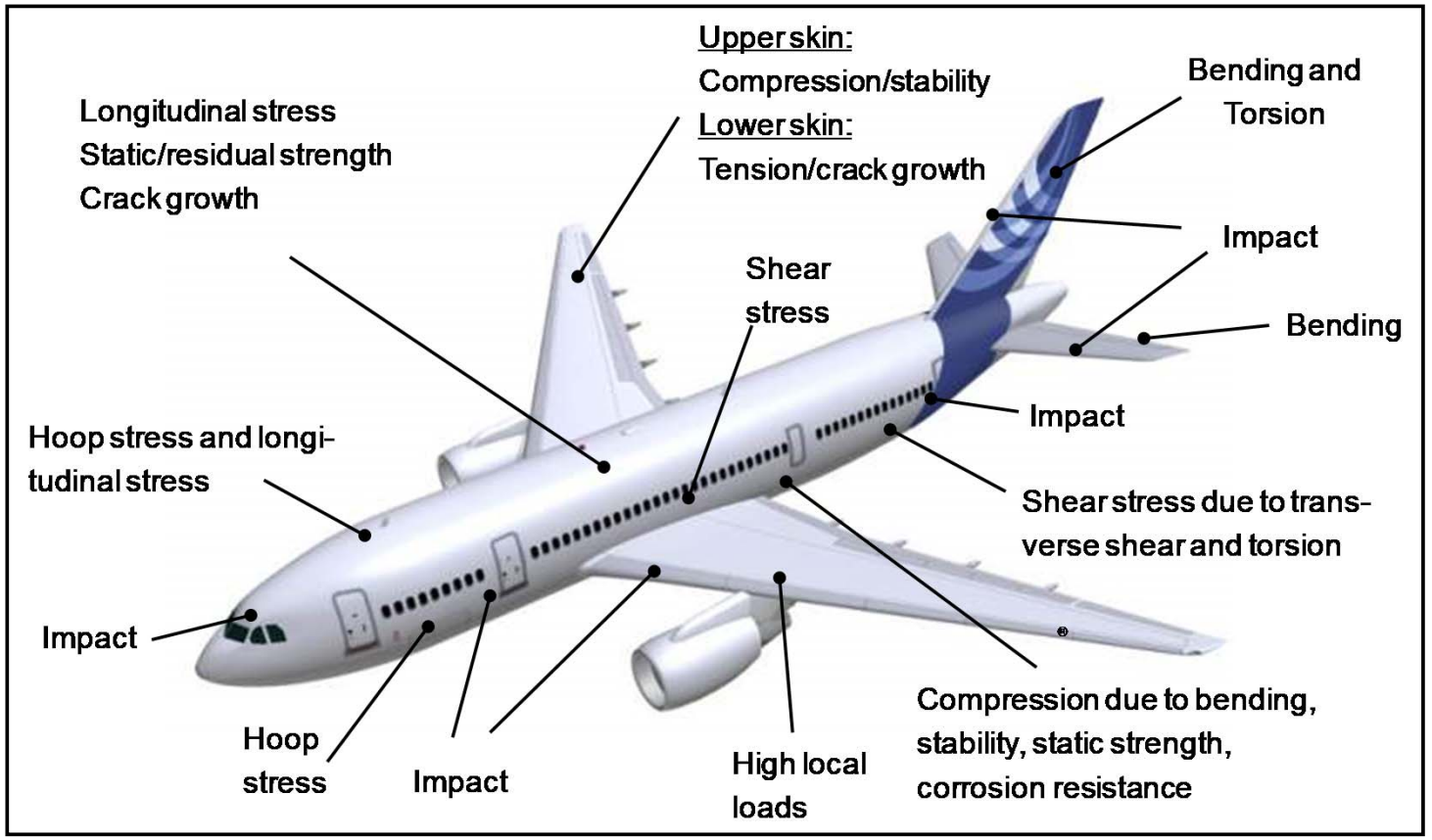
Wireless Sensor Activations Limited to Save Power



Example of Startup Energy Dominating – Not Designed for Energy Harvesting

Opportunities from Reduced Energy Consumption

Airframe Structural Health Monitoring (SHM) Sensors Enabled by EH



Existing Energy Sources and Storage Elements Won't Support SHM Networks Without Sensor Energy Consumption Reduction

Thank you!
Questions?

Backup

Outline

1. Why Energy Harvesting for aerospace?
2. Unique aerospace challenges for Energy Harvesting
3. Reduced energy consumption – needs and opportunities

Unique Aerospace Challenges for Energy Harvesting

Environmental

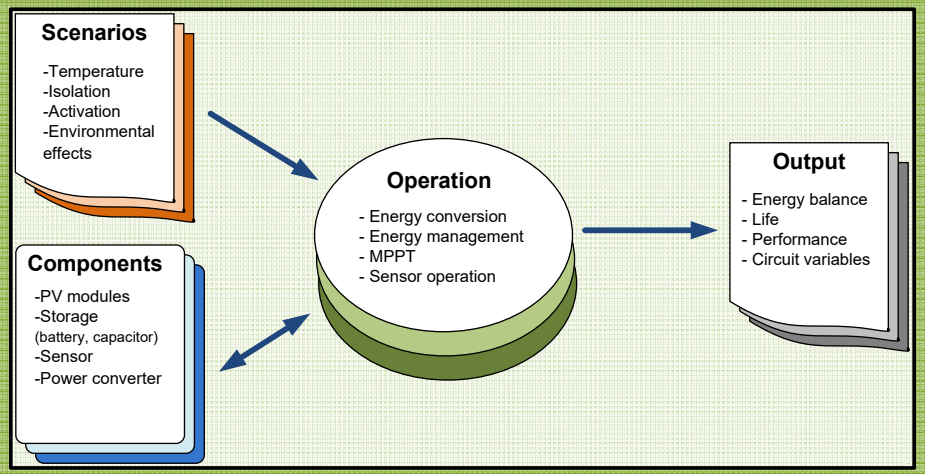
-55 to 85°C
10 to 100 kPa
4 LTO cycles/day

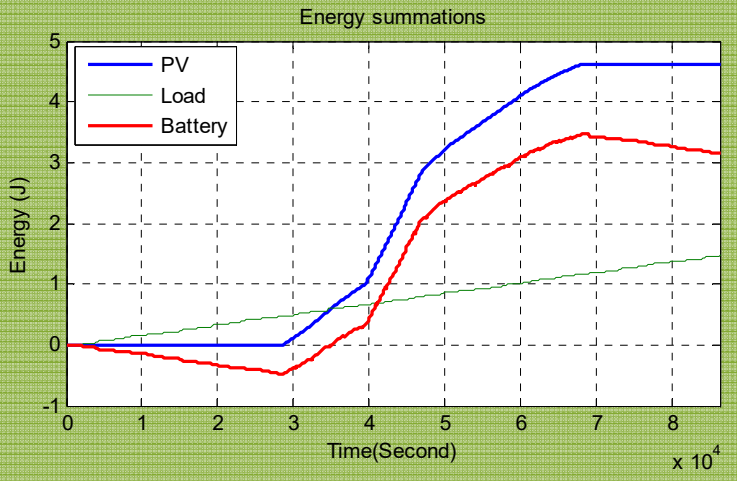
Component (unique instance or type)	Min. Operating (°C)	Max. Operating (°C)
SMT ceramic capacitors (0201 to 0805)	-55	+125/+150
Super-capacitor	-40	+85
SMT diodes (various)	-55	+150
SMT inductors (various)	-55	+125
SMT transistors (FET and NPN)	-55	+150
SMT resistors (0201 to 0805)	-55	+155
1.8V low current reference	-40	+85
Low current comparator	-40	+125
Power Manager IC	-40	+125
Transceiver + MCU IC	-40	+125
Single low current logic gates	-40	+125
Low current op-amp	-40	+125

Typical Sensor BOM Fails Full Temperature Range

Proving Sensor Availability

Extensive Component, Circuit, and Scenario Simulations





Some Scenarios Not Possible