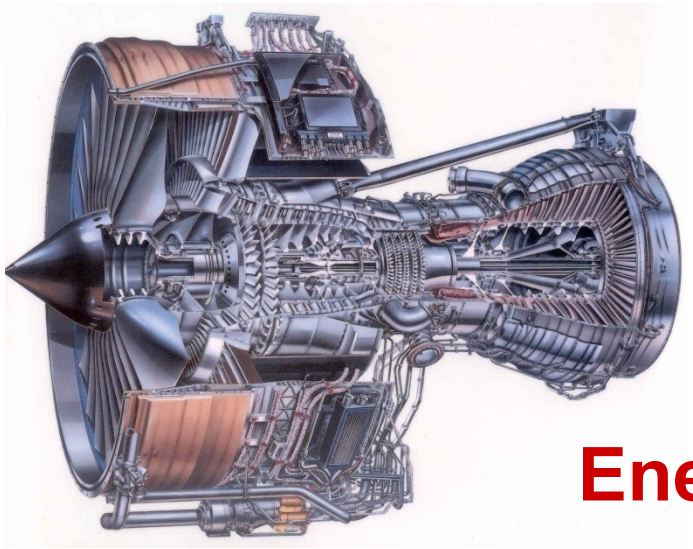
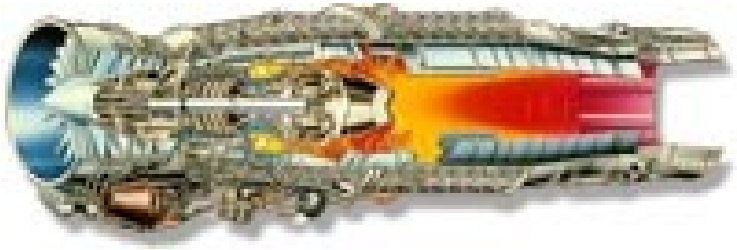
The University Of Sheffield.



Energy Harvesting

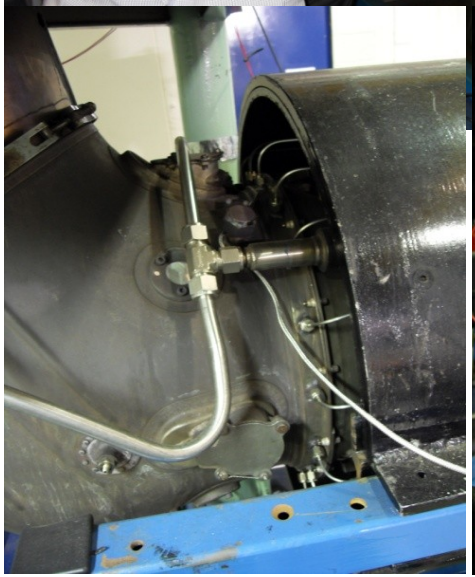
Haydn Thompson

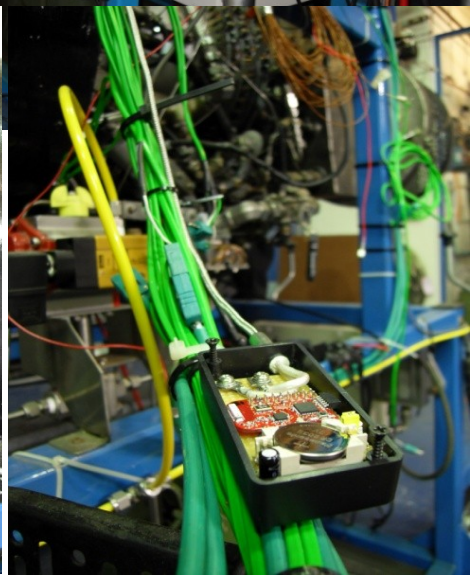


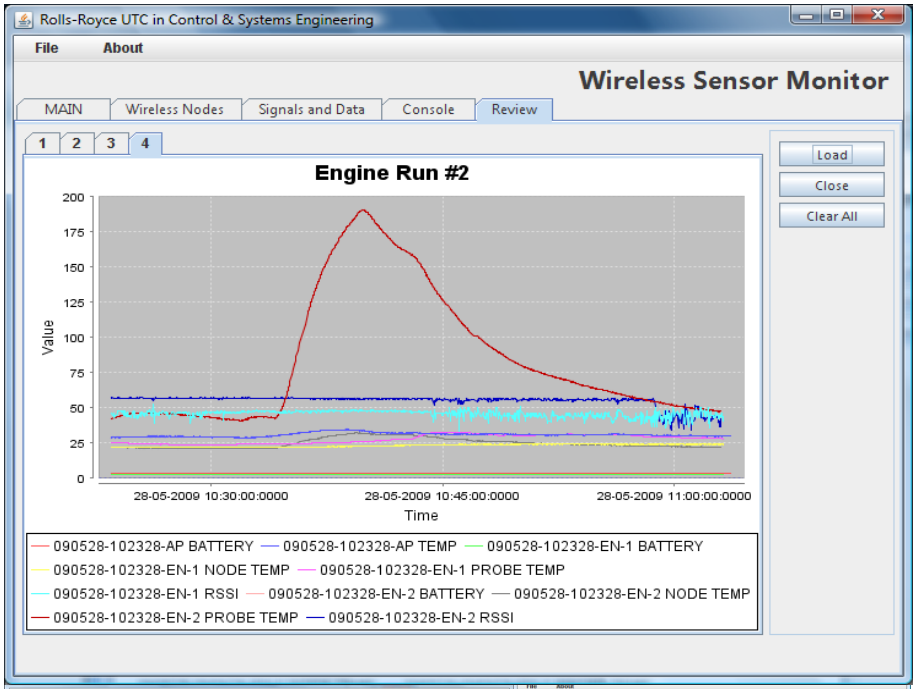
University Technology Centre
supported by Rolls-Royce

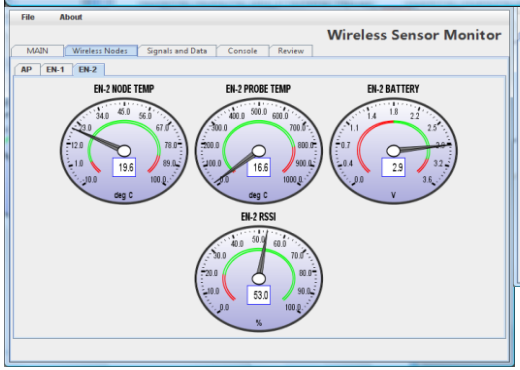
Rolls-Royce Control and Systems UTC

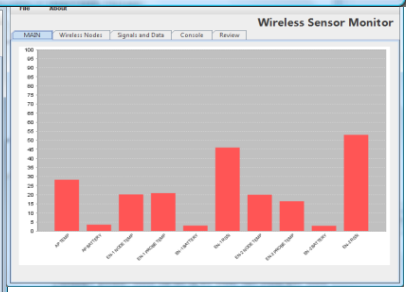
Thermocouple Test on Jet Engine





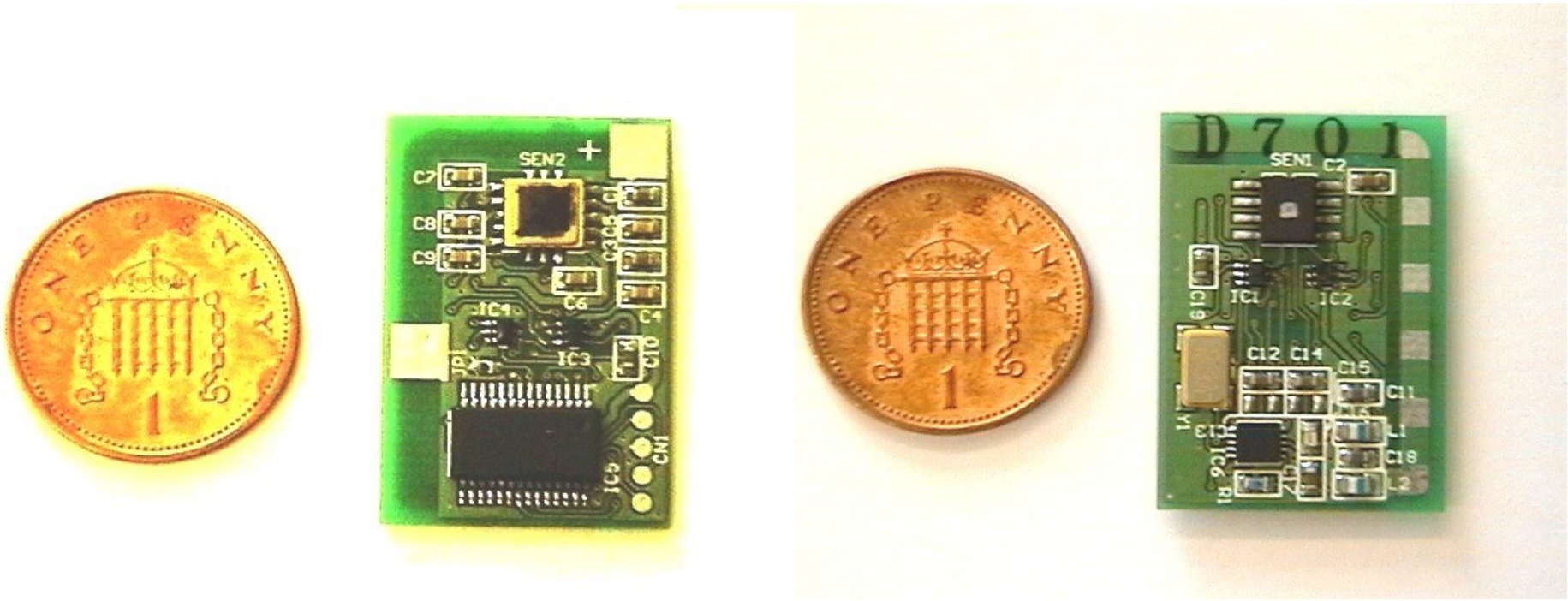




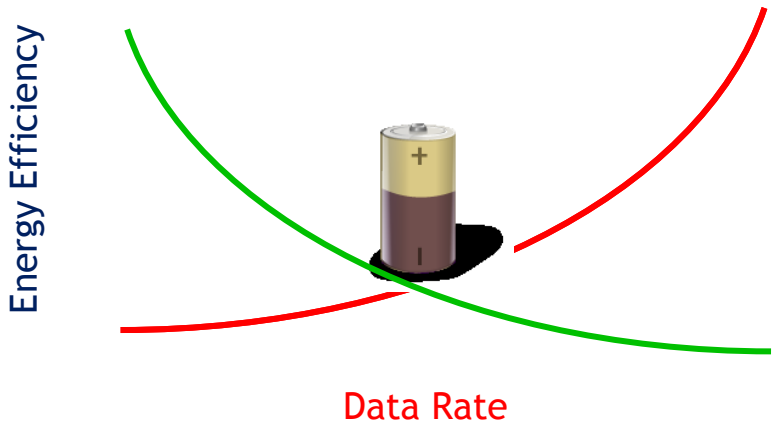


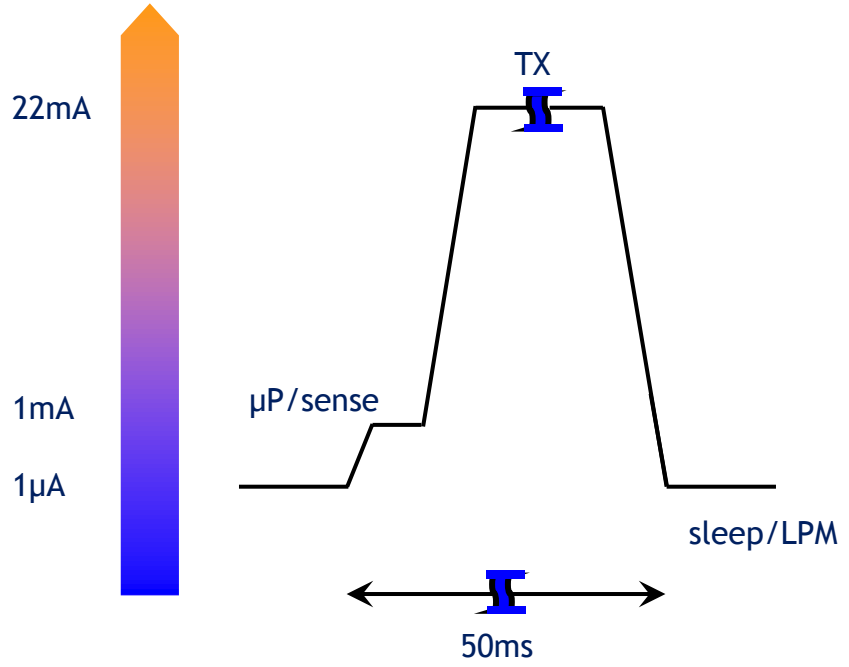
University Technology Centre
supported by Rolls-Royce

Wireless 3-axis G, Temperature and Pressure Sensor



Wireless Node Energy Usage



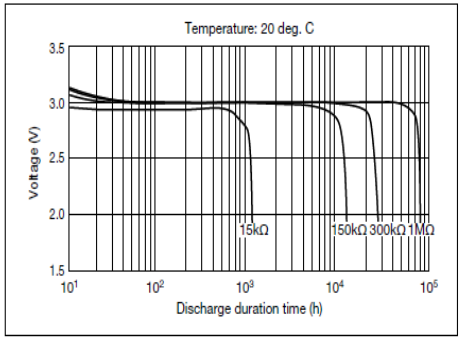


Button Cell Batteries

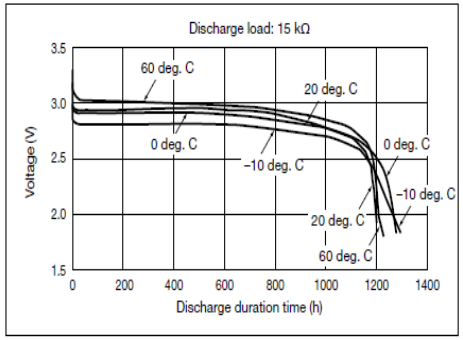
CR2032 (3v 220mAh lithium) vs ML2032 (3v 65mAh Rechargeable)

CR2032

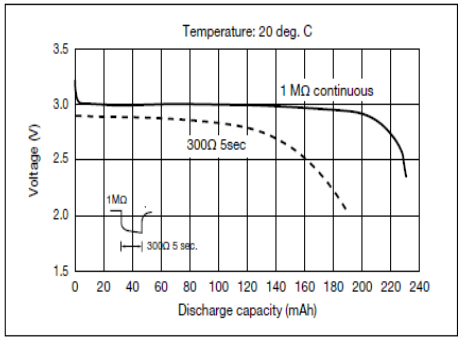
● Discharge Characteristics



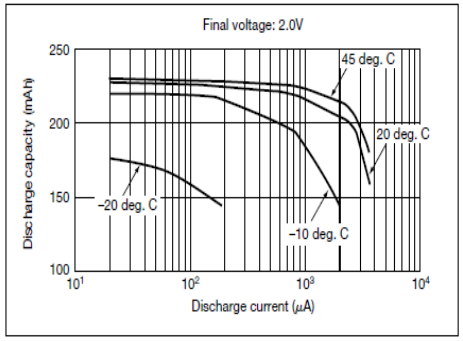
● Temperature Characteristics



● Pulse Discharge Characteristics

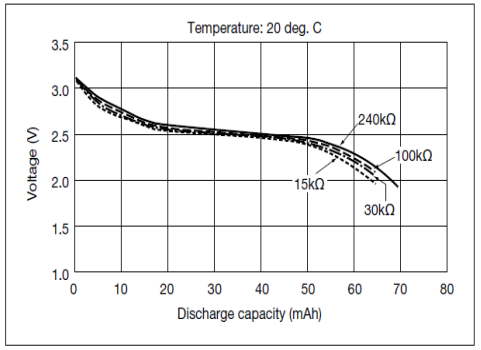


● Relationship between Discharge Current and Discharge Capacity

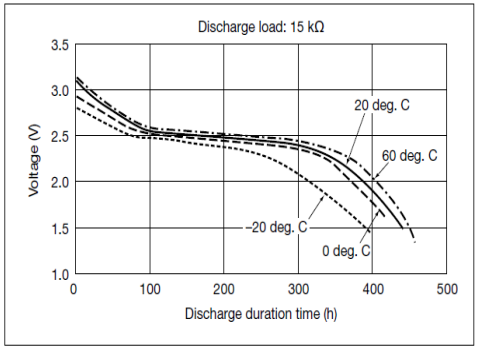


ML2032

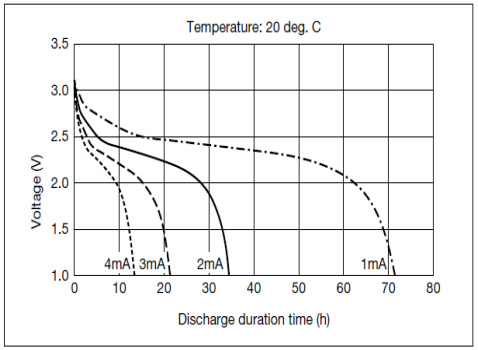
● Discharge Characteristics



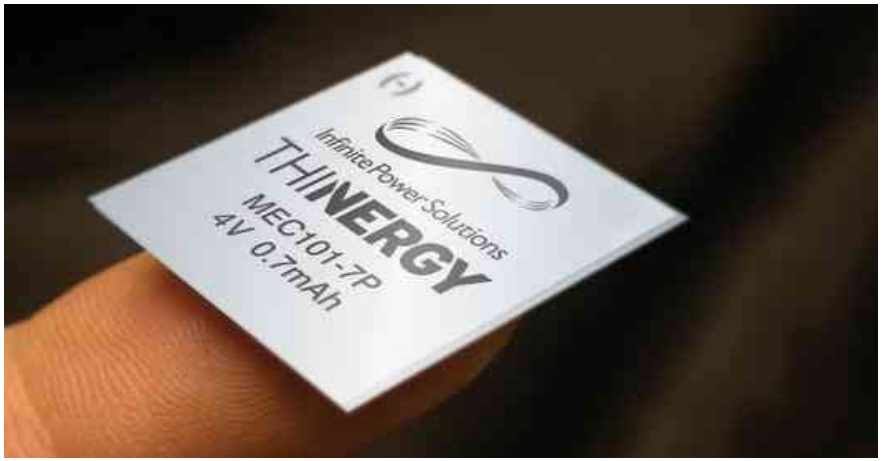
● Temperature Characteristics



● High Rate Discharge Characteristics



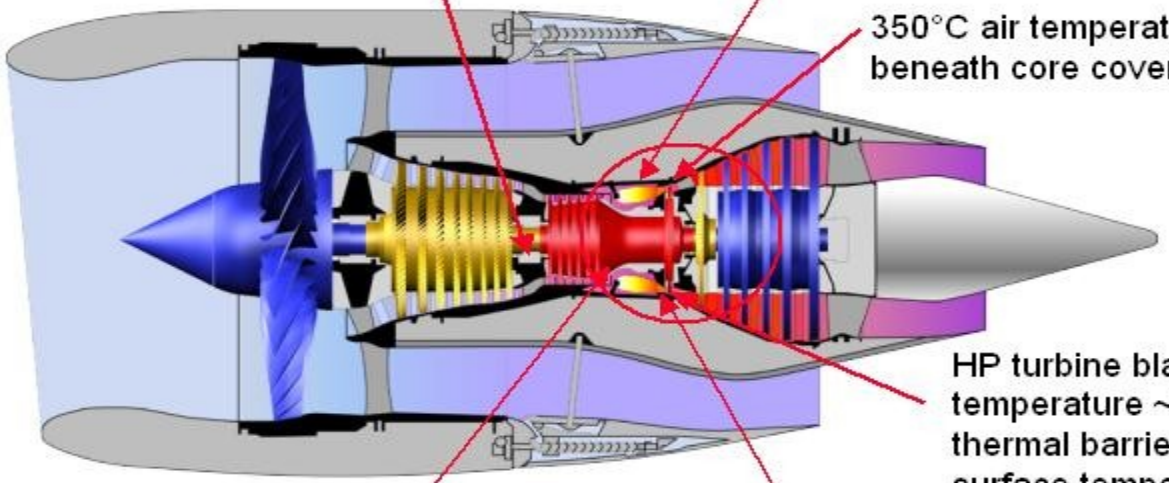
New Batteries - Thin Film, Long Life Batteries



University Technology Centre
supported by Rolls-Royce

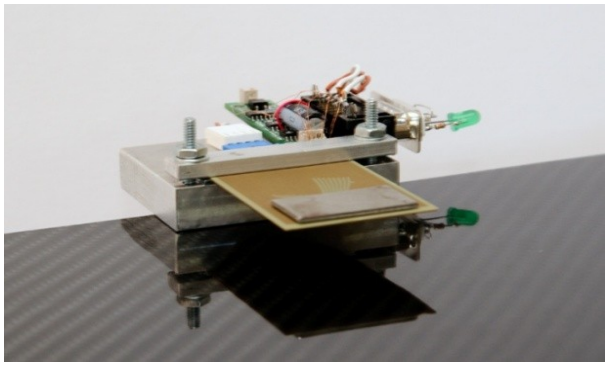
Engine Environment

-55^{0}C!!

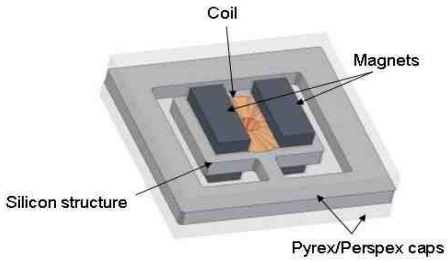


Energy Harvesting Approaches

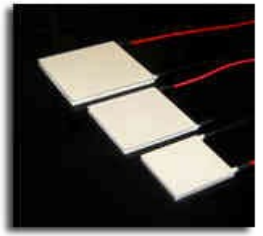
- Piezoelectric generators utilise a cantilever/mass structure



- Electromagnetic generator - Motion of a moving coil through a static magnetic field induces a voltage across the coil

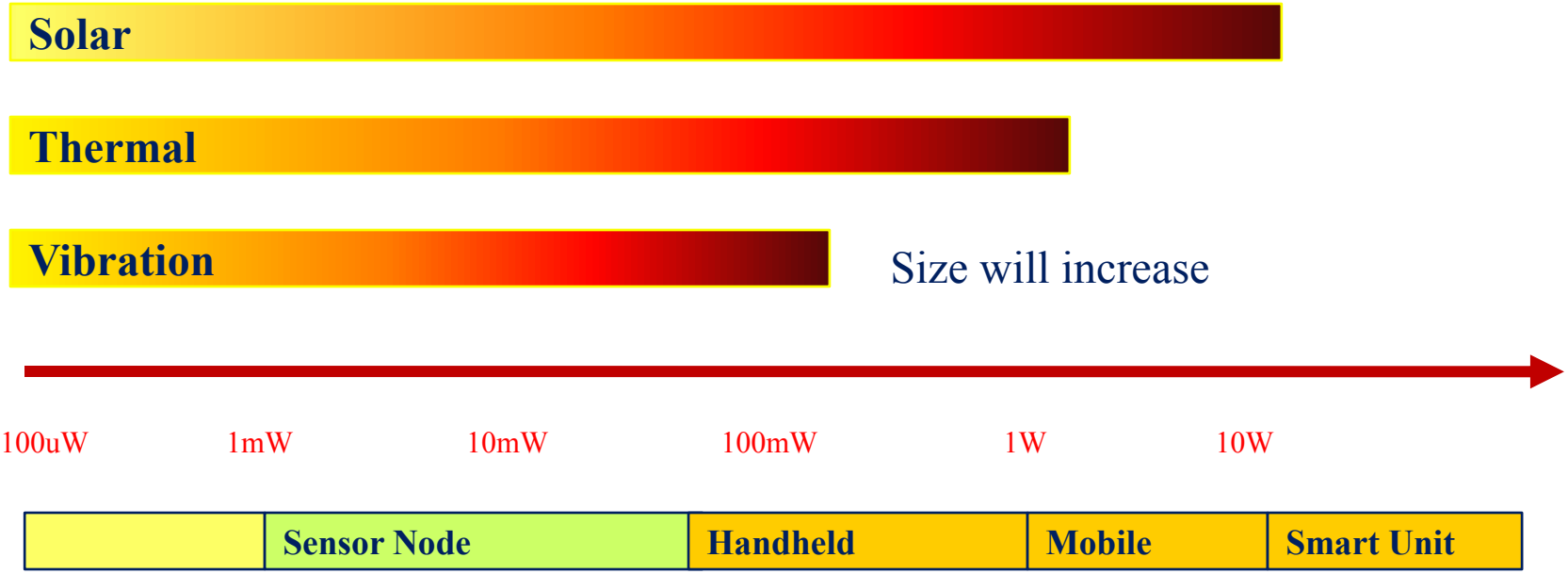


- Thermoelectric generator - Seebeck effect

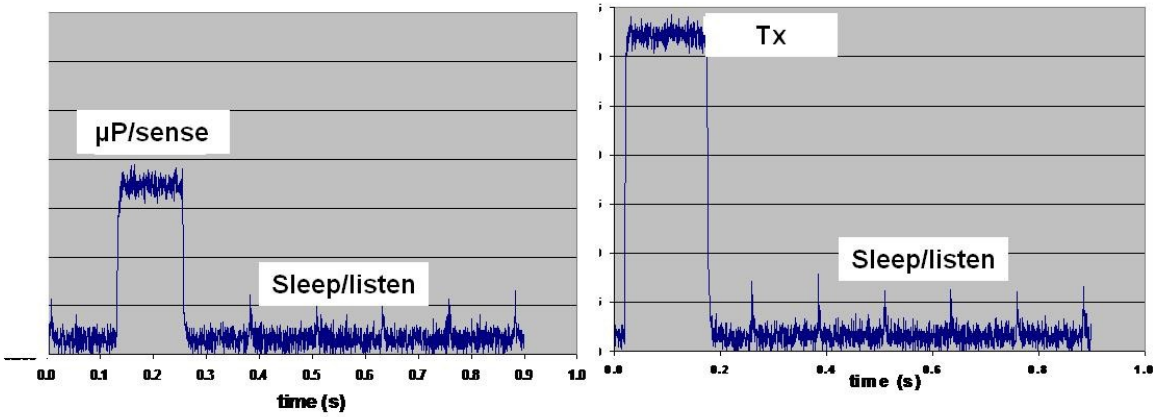


- Solar Power

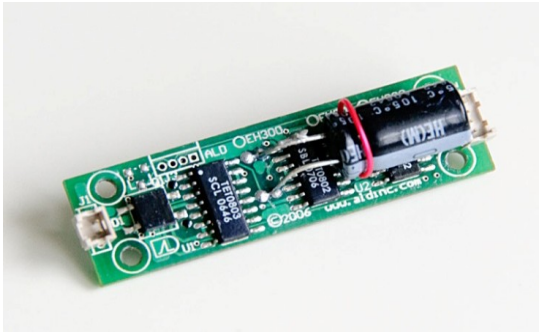
Power Requirements

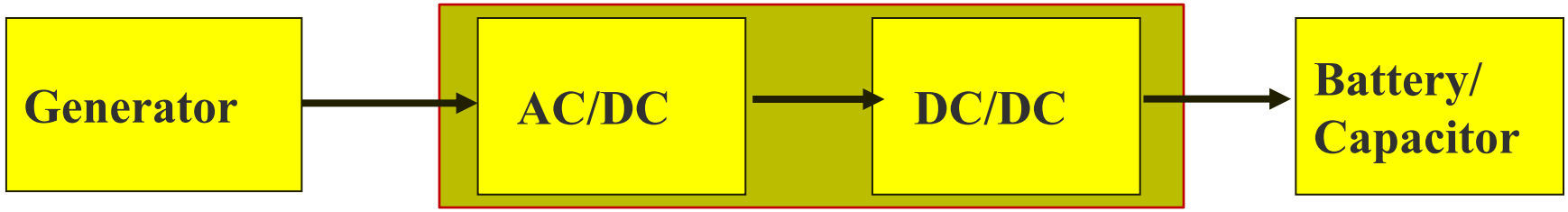


- Sample Rate?
- Sensor head?
- Power requirement dictates cost and weight



Power Conversion

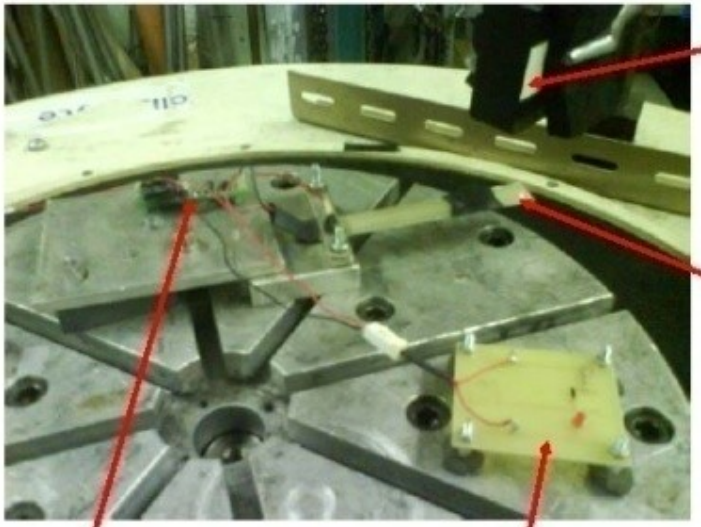


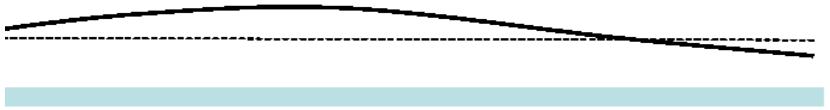


- Signal from vibration generator is AC and needs to be rectified and then converted via a DC/DC circuit to charge the battery (or capacitor) – lose a lot of energy here!!!
- Solar or Seebeck – need to impedance match and perhaps DC/DC circuit – lose a lot of energy here!!!

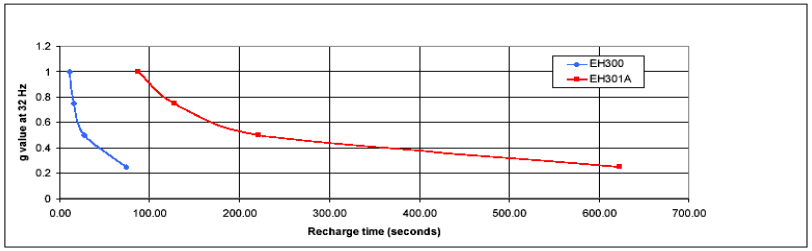
Piezo-Biomorph Beam on Table

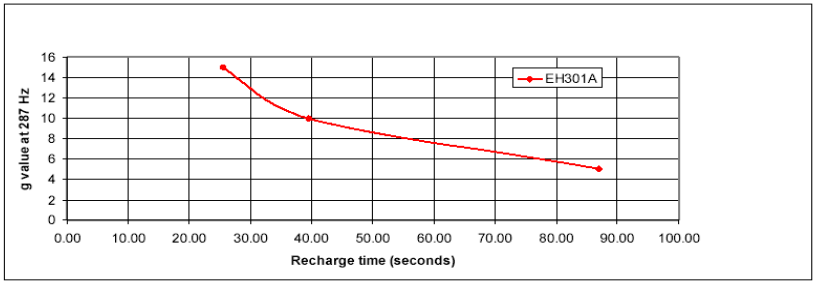
First mode Cantilever vibration





Second mode Cantilever vibration

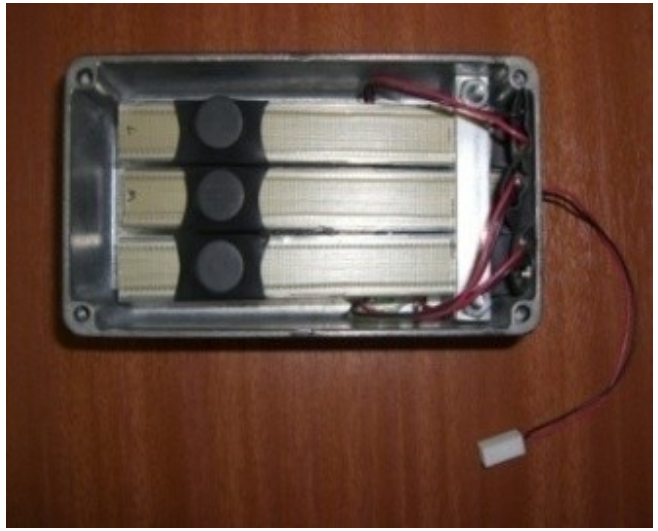


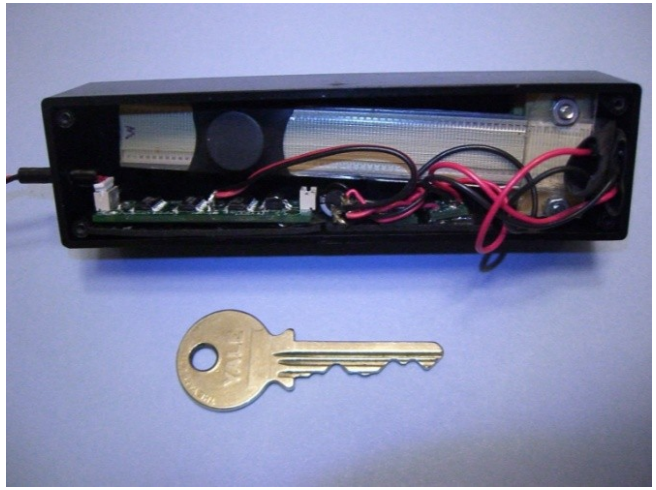


University Technology Centre
supported by Rolls-Royce

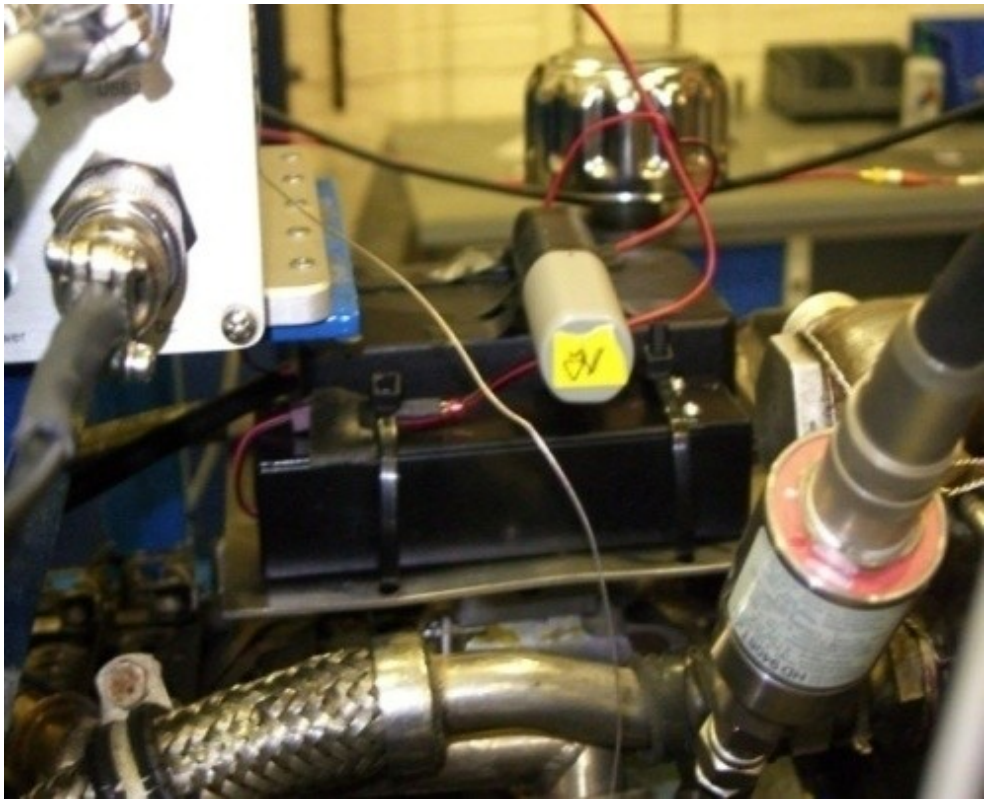
Piezo Bimorph Testing

Challenge – Small space envelope and lightweight





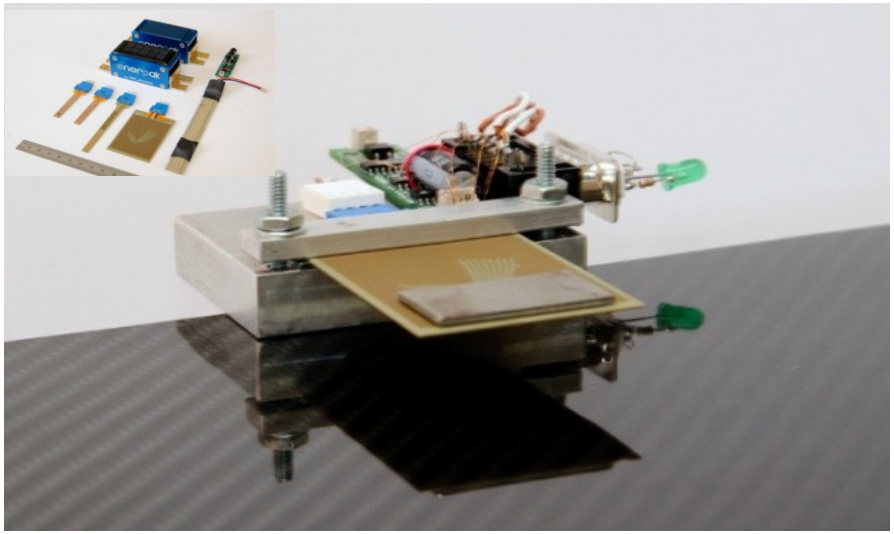
Dual Beam Compact Unit



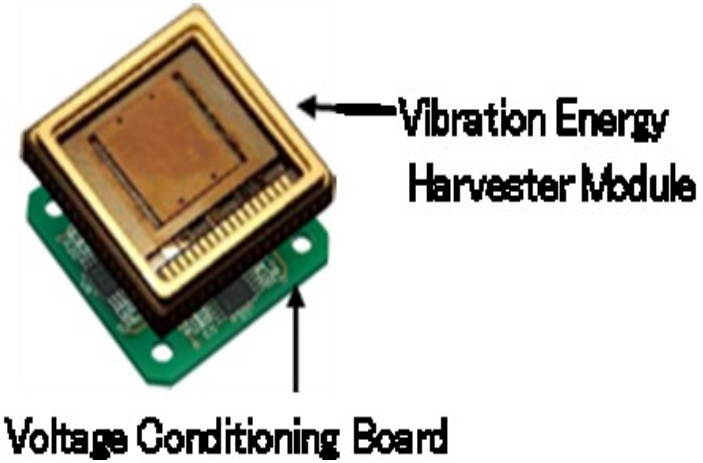
Harvester Unit on Helicopter Engine

University Technology Centre supported by Rolls-Royce

Vibration Energy Harvesting

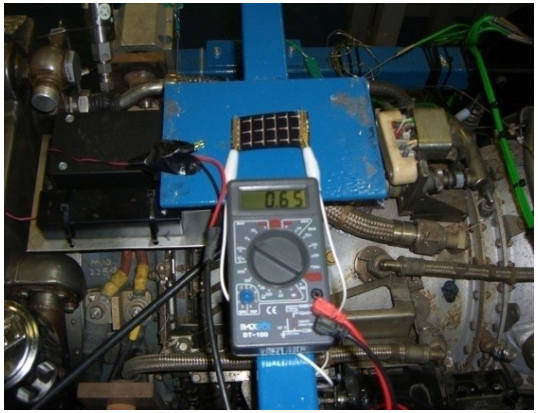


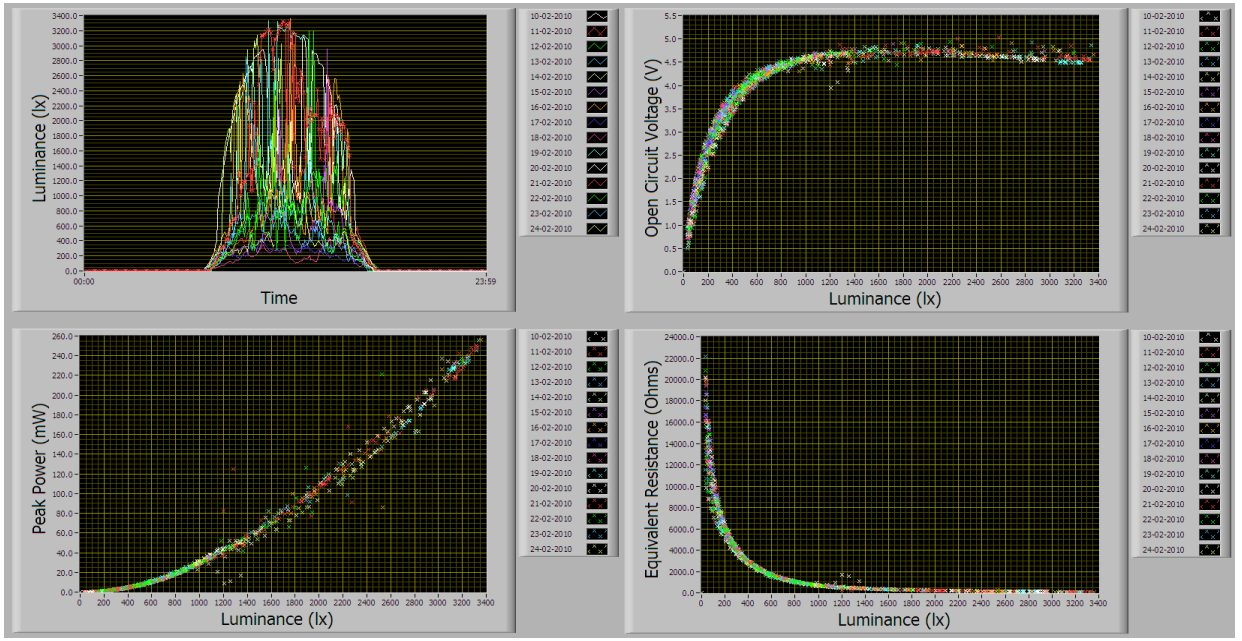
Piezoelectric Harvester (100mW)



Electrostatic Harvester (0.7mW)

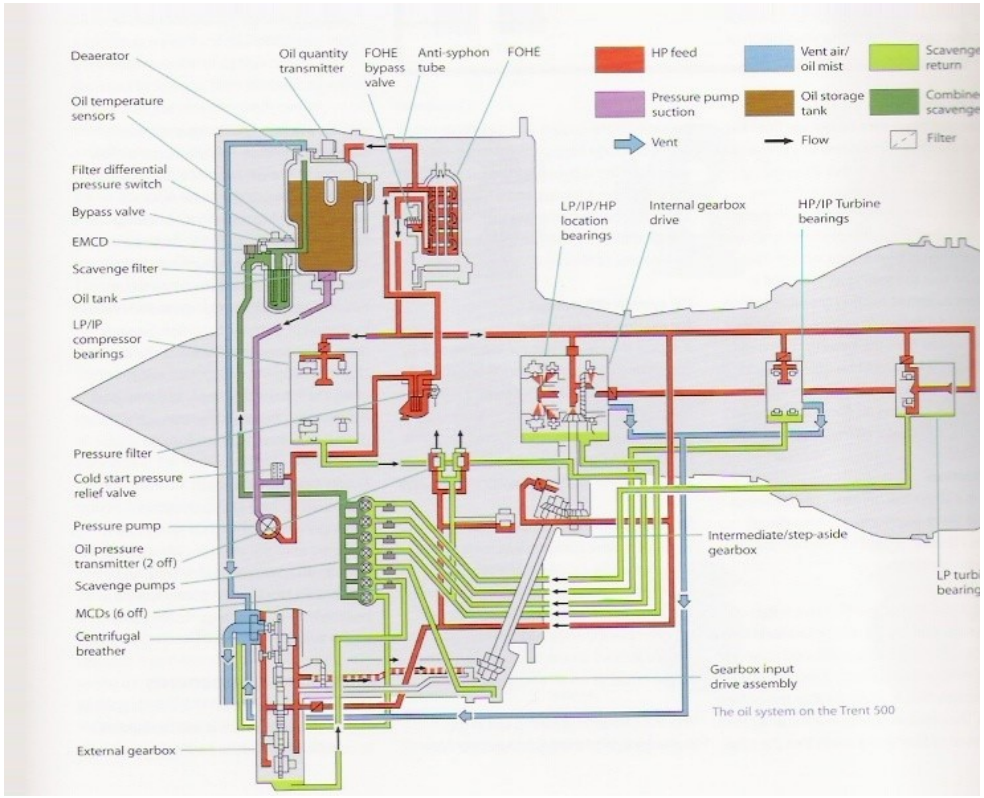
Solar Energy Harvesting

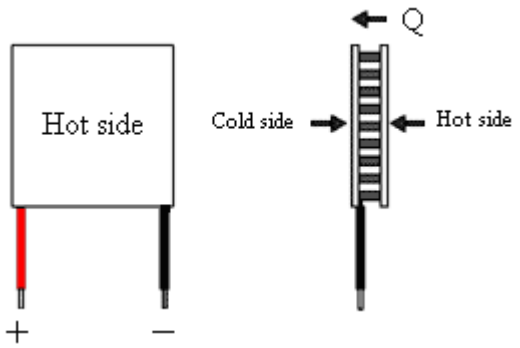


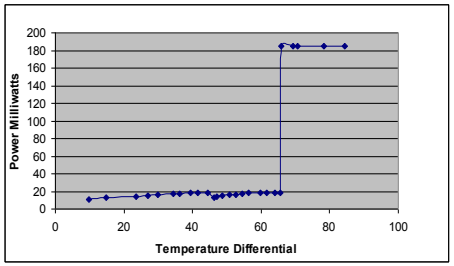


Dependencies – light level, load, temperature, angle

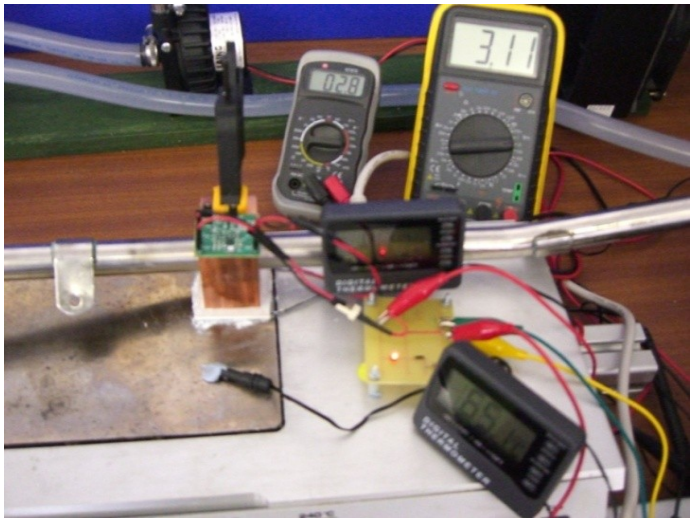
Thermal Harvesting - Engine Fluid System Harvesting





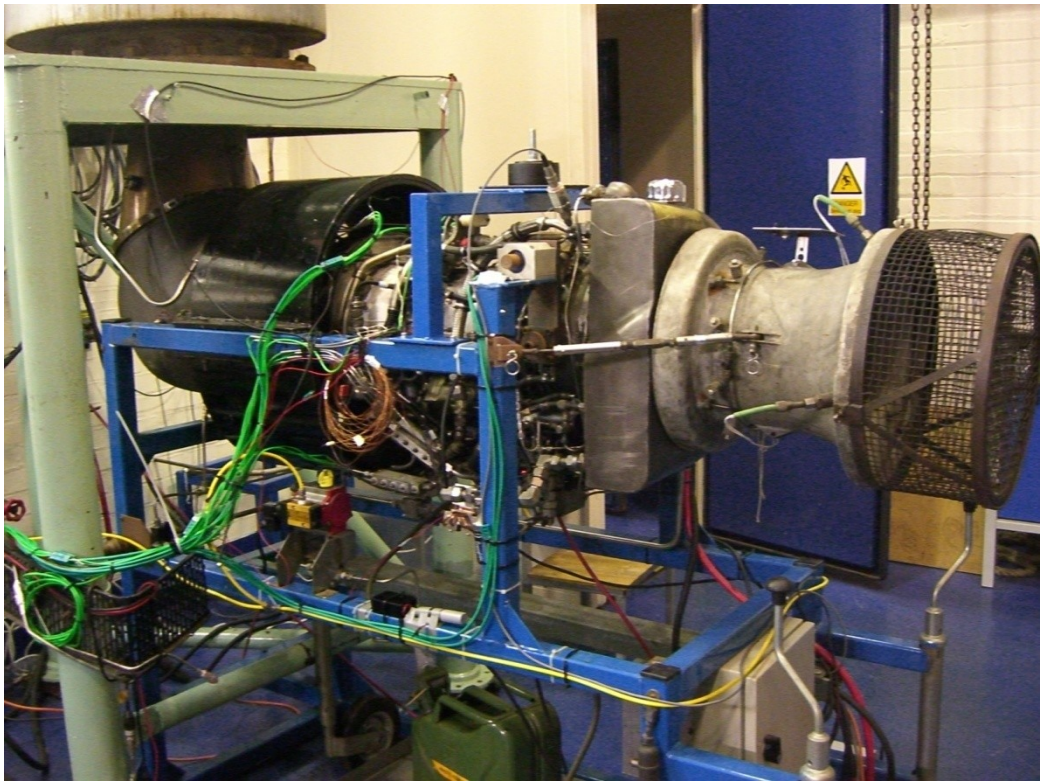


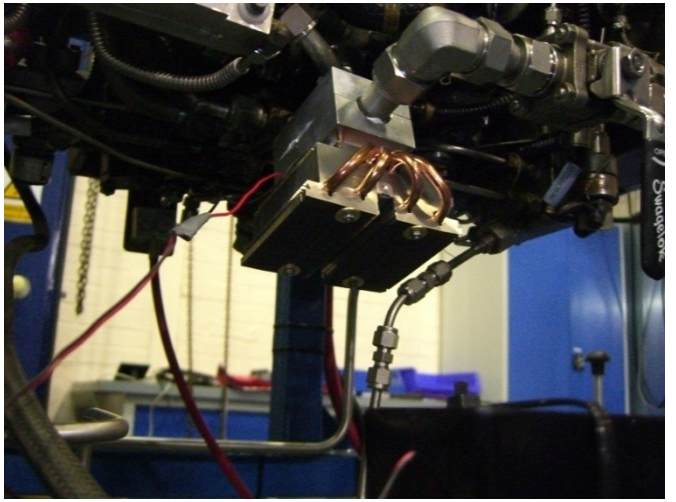
Pipe



University Technology Centre supported by Rolls-Royce

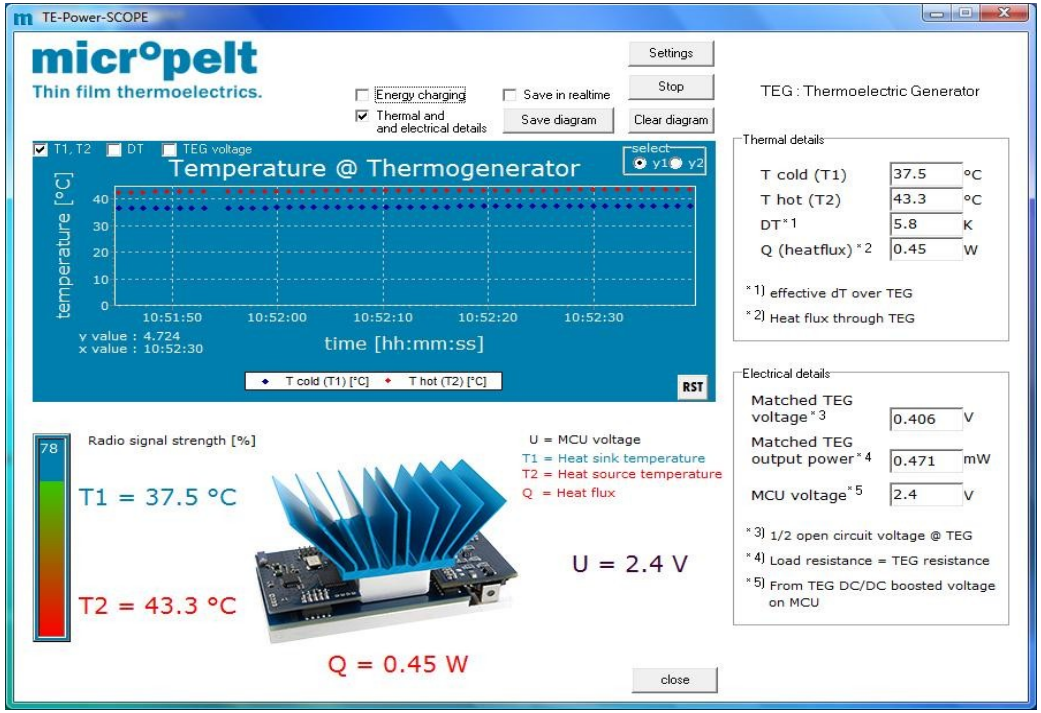
Energy Harvesting Helicopter Engine Testing

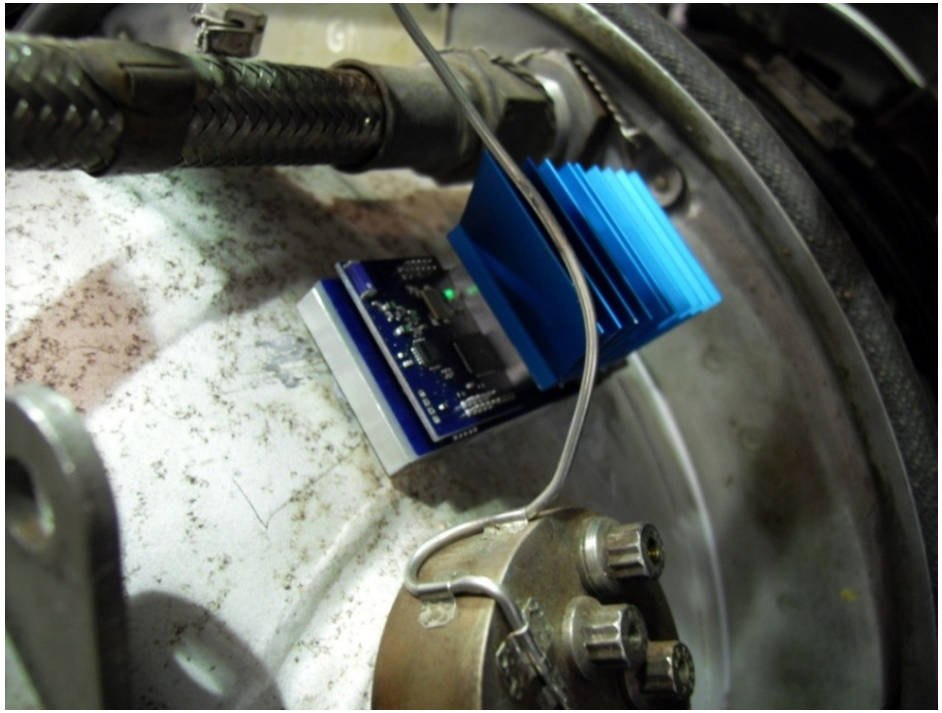




University Technology Centre
supported by Rolls-Royce

Thermally Powered Wireless Sensor

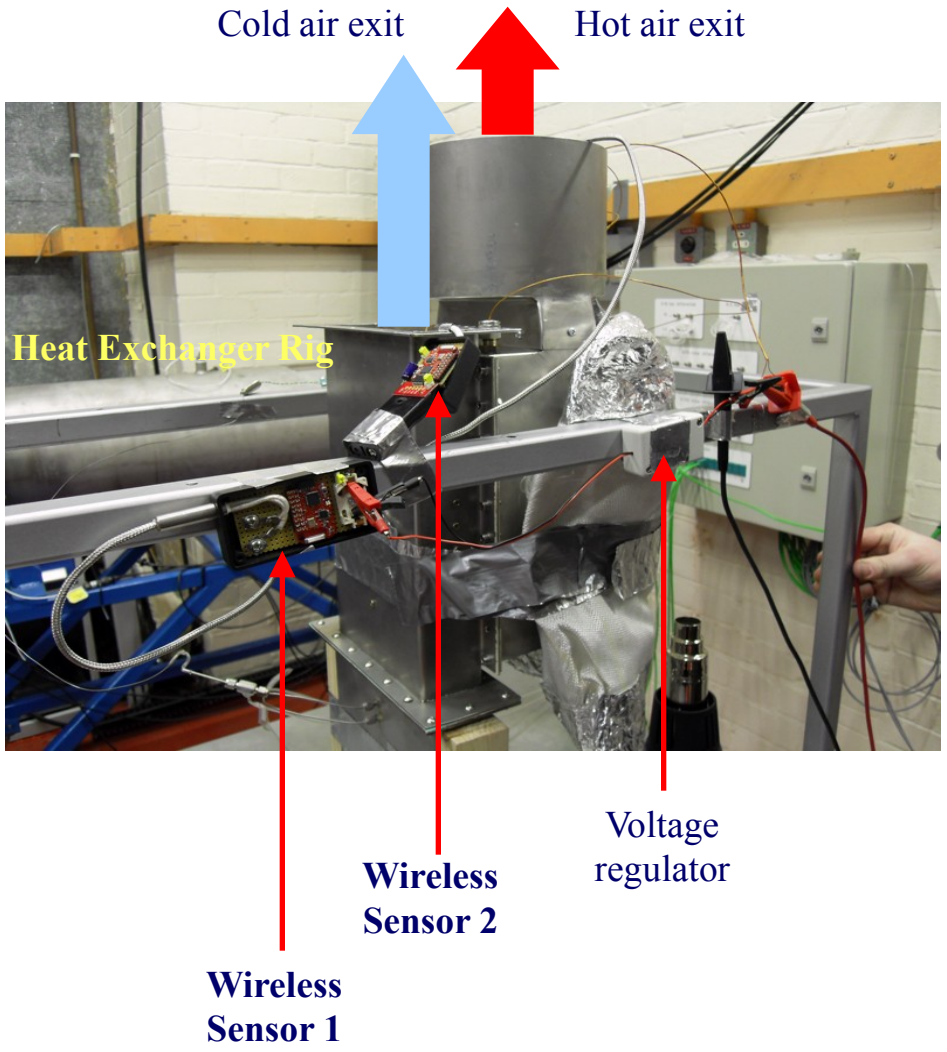




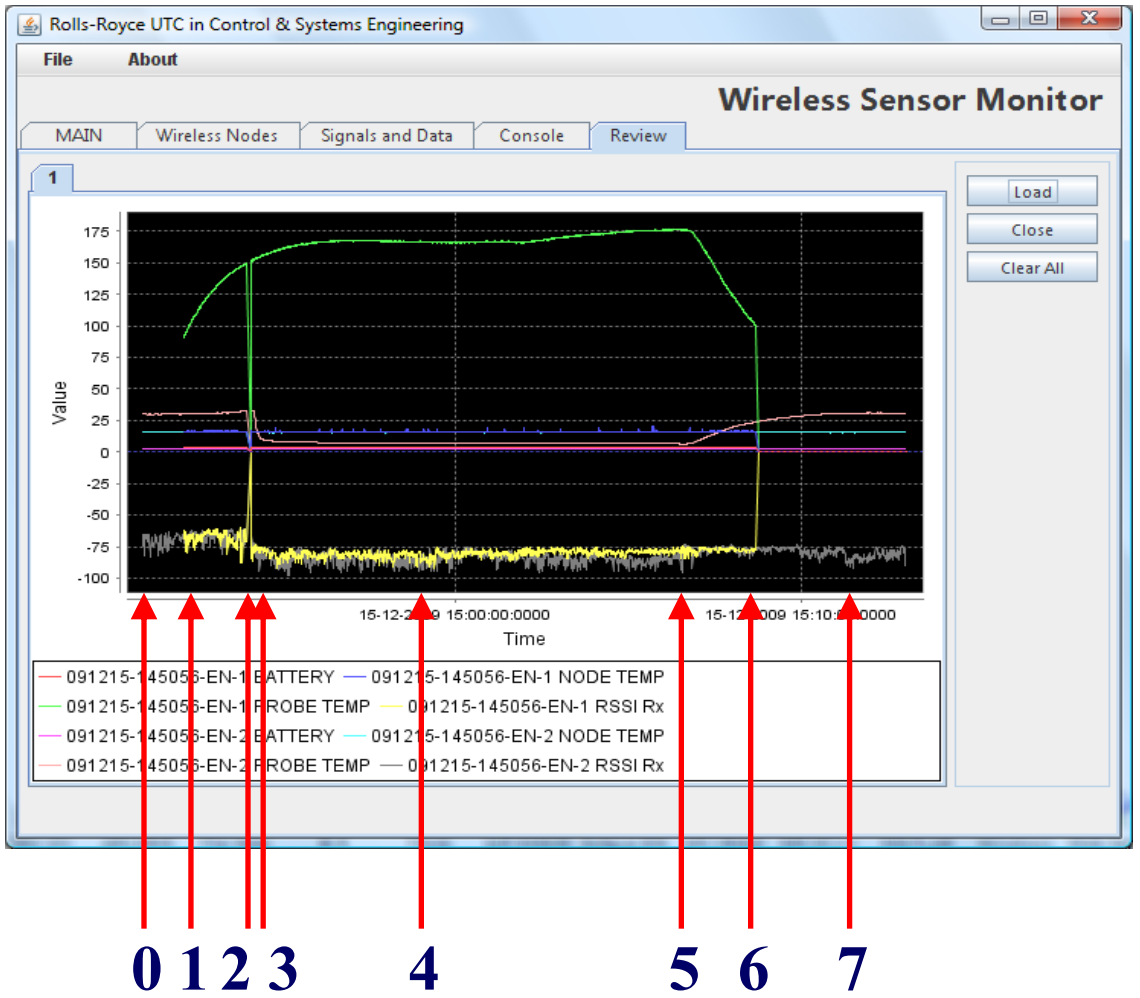
- Micropelt Seebeck device combined with sensor attached to combustor casing

Thermally Powered Wireless Thermocouple Test

- Wireless Sensor 1
  - Powered by TEG harvester via 3.3-V voltage regulator
  - Measures **hot-side** air temperature
  - Range: 0-1000 deg C
- Wireless Sensor 2
  - Battery powered
  - Measures **cold-side** air temperature
  - Range: -20 to 125 deg C
- Wireless Receiver
  - Connected to laptop PC (not shown here)
  - Located in remote monitoring room



Timeline of Events



0: Hot air flow begins

Only Sensor-2 is active

1: Minimum required temperature difference is achieved

3V output activates

Sensor-1 activates powered by harvester

2: Steel door closes

Wireless signal temporarily lost, but regained almost instantly as wireless *channel agility* kicks in

3: Cold air flow begins, cold-side temperature drops rapidly

4: Temperatures stabilise

Up to **2 Watts** of energy is harvested

5: Hot and cold air flows are stopped

6: Temperature difference reduces

Sensor-1 cuts off as temperature difference is lost

7: Sensor-2 continues to monitor heat-soak on cold side when no flow is present

University Technology Centre
supported by Rolls-Royce

Concluding Remarks

- Most sensor types can be implemented. Need fast onboard processing if doing vibration monitoring and considerably more power
- Need very small space envelope and light weight
- Need to be low cost
- Need to work in hostile environment – the operating environment is a real challenge!
- Looking at 60GHz for mass data download on testbeds
- Batteries OK for test bed applications

  but for production systems with 25-30 year

  life would be huge maintenance overhead.

  Therefore energy harvesting is essential.