Energy Harvesting for Structural Health Monitoring

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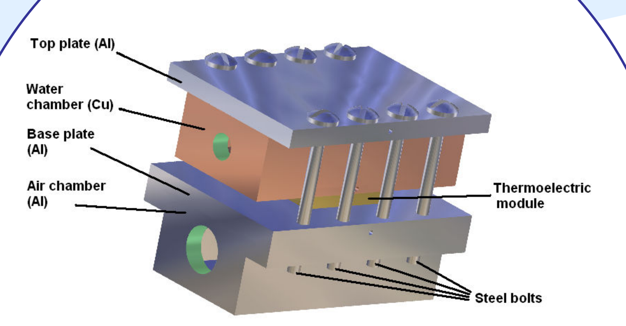
Research Background

Aerospace manufacturers are currently developing a new generation of all composite aircraft for civilian and commercial use, in an attempt to reduce weight and hence emissions. Although composite materials have excellent mechanical properties there is an increased risk of structural damage due to small impacts, such as bird-strike, or even the dropping of tools during maintenance. In order to ensure safe operation and to assess the structural integrity of composite aircraft structures during long service lives, there is a need to develop an integral Structural Health Monitoring (SHM) system that can continuously monitor composite structures for damage. One such approach to SHM uses arrays of active and passive acoustic emission (AE) sensors, physically wired to a central processing unit. A problem with this approach is the excessive weight and cost associated with the wiring required to power such sensors and collect data. A solution to this problem is the use of wireless autonomous sensor nodes, powered from harvested energy. This poster reports on a series of investigations at Cardiff that forms part of a much larger TSB project (SHeMS).

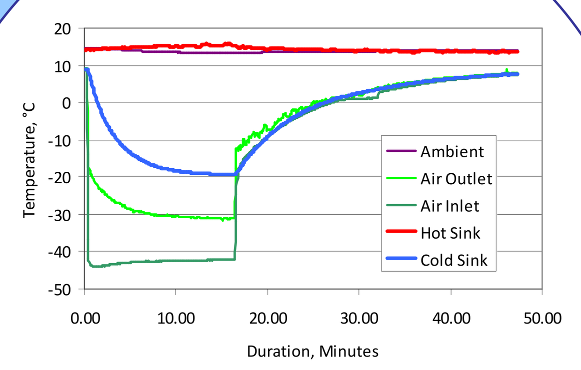
Passive and Active Monitoring

AE is the most sensitive form of non-destructive testing (NDT) and relies on the detection of stress waves emitted by damage as a component is undergoing stress by an array of sensors. The most attractive aspect of AE monitoring is the ability to detect, identify and locate damage as it is occurring, however the sizing of damage can be difficult. Active monitoring, that utilises the same sensors, in a pulse and receive manner can offer a real solution to sizing problems, with phased array being one technique that can be employed. Initial investigations have demonstrated that the same sensor set can be used to continually monitor a composite structure acoustically and that post impact damage the active technique can give an indication of damage size.

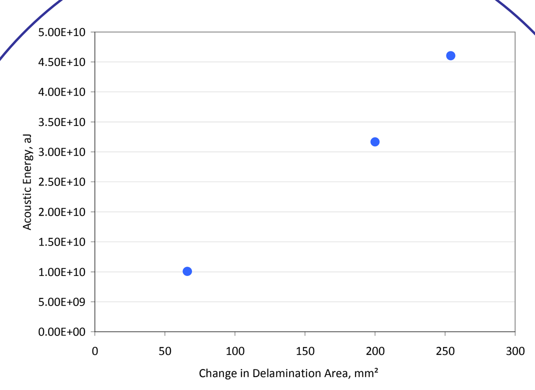


Thermoelelectric Energy Generator (TEG) Test Rig
Cold air supplied by a vortex tube and a cold water supply are used to generate temperature differences for testing the power output and efficiency of devices. TEG units can be sandwiched between the skin and fuel tank to generate desired energy levels.

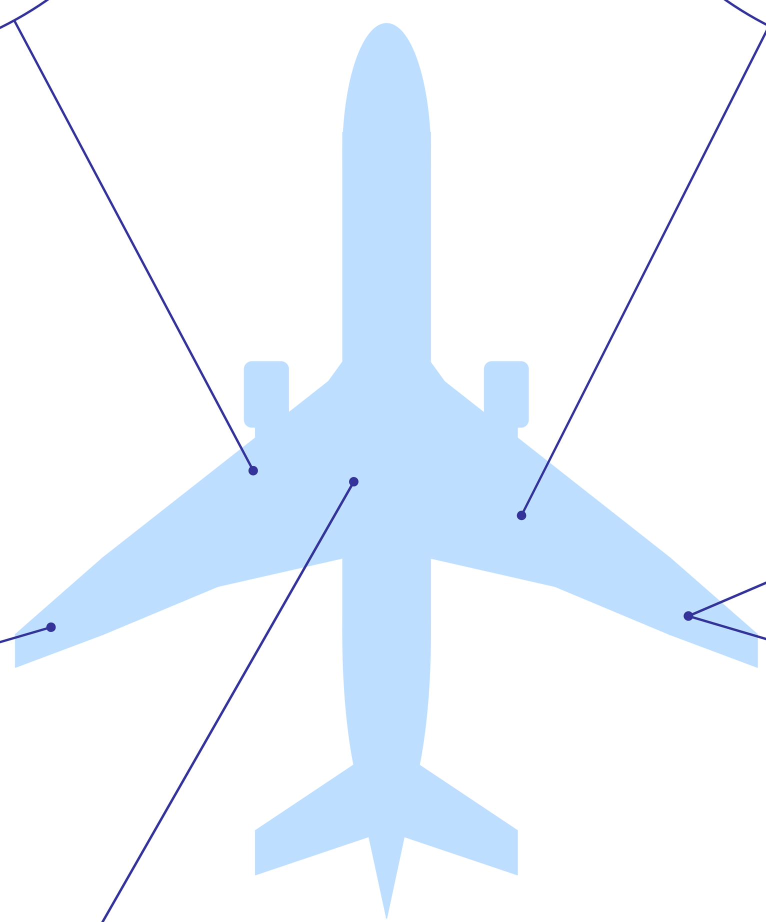
System Integration
To fully realise an SHM system utilising energy harvesting further areas of research are being completed at Cardiff. The energy efficiency of fundamental system components is being investigated whilst the transmission of data through light weight and low cost acquisition systems in carbon fibre wings is being researched.

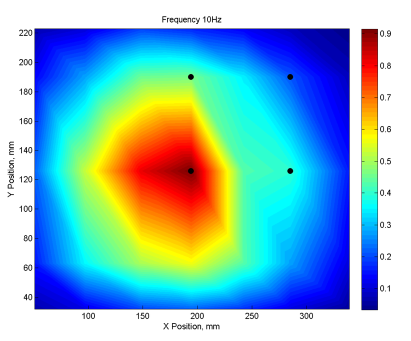


Thermoelectric Energy Generator (TEG) Test Results
Using the in-flight temperature profiles it was possible to generate 1 V which can be boosted to 3.5 V, enough voltage to power an AE sensor. Average power generated during a typical test cycle is 50 mW.

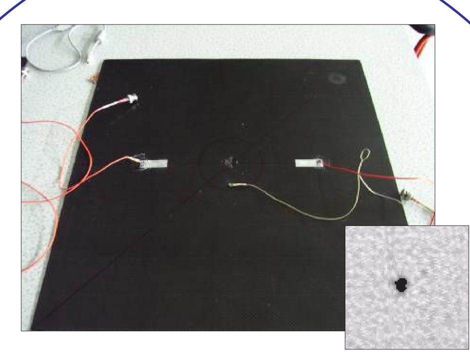


Acoustic Emission Monitoring Results
Utilising data recorded during the impact process it was possible to determine a correlation between the energy of the detected signal and the disbond area as measured using a C-scanner. Further investigations assessing location accuracy will be completed.

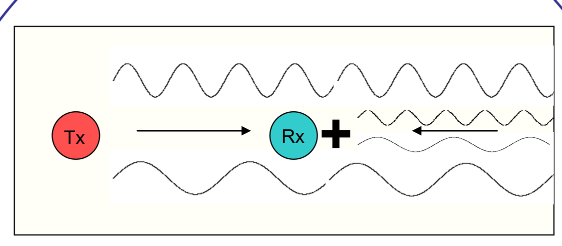




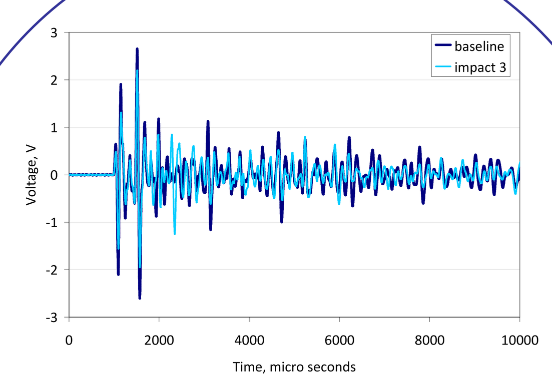
Passive Vibration Energy Generation
A bespoke test rig to test the efficiency of Quick-pack devices has been developed. Measurements of energy output by four devices at varying points on a stiffened panel have been tested against known frequencies and deflections (above). Results show that it is possible to generate 4 mW of power.



Active and Passive Monitoring
A series of investigations to assess the viability of using the same sensors for active and passive monitoring have been completed. Carbon fibre panels manufactured in an autoclave were subjected to impacts and actively and passively monitored.



Active Vibration Energy Generation
By generating and guiding surface vibrations (Lamb waves) from positions where power is available (fuselage) to areas where wiring would be prohibitive (wing tips) it is possible to enhance passive energy harvesting. Detailed experimental and numerical modelling investigations have revealed that the position of receivers is fundamental due to wave superposition and cancellation from reflections.



Acousto-ultrasonics Monitoring Results
Utilising a cross correlation technique it is possible to determine the onset of damage. A comparison of a transmit/receive wave before damage with the same wave after damage can reveal any change in the structure (above). Further techniques such as phased array will be explored.

Passive and Active Energy Harvesting

Three methods of energy harvesting have been considered, passive and active vibration and thermoelectric. Passive vibration using cantilever piezoelectric devices is relatively well established however this research programme has utilised novel Quick-pack devices due to their low profile nature and weight. Trials have shown that it is possible to harness 4 mW of energy for vibration levels associated with commercial flights. Active vibration utilises similar devices, however the natural ambient vibration of the aircraft is supplemented with forced vibrations that can be transmitted from positions where power already exists. Investigations have demonstrated that power can be transmitted but device position is critical due to wave superposition. Finally thermal harvesting offers real opportunities for generating the power levels associated with SHM systems. Trials have demonstrated that it is possible to achieve an average power of 50 mW for a typical commercial flight. Further work is being completed to find new thermoelectric materials and improve device performance.

System Integration

To realise a full SHM system further areas of research are required. The use of low power wireless data transmission systems is being investigated whilst the efficiency of all system components is being considered to ensure all harvested power is fully realised. Furthermore issues surrounding energy storage need to be investigated. With the use of chemical battery storage devices being prohibited the use of solid state batteries and capacitors are being considered.

Conclusions

The use of energy harvesting for SHM systems can offer distinct advantages to the designers of future aircrafts. Work completed at Cardiff under a TSB project (www.shemsproject.co.uk) has shown the techniques outlined offer an excellent solution to aid in the reduction of aircraft weight and emissions.

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