

Seeing through the problem...

...wiring deterioration made visible

The vulnerability and fragility of wiring looms will haunt the world of complex electronic circuitry as long as hard-wired connections exist. The consequences of failure range from inconvenient to catastrophic. Often in real structures the wiring is hidden from view and is difficult to access. But if it were possible to inspect what is happening to the wire and its insulation, by performing material checks, the world in which such devices are crucial could be a safer place. A project being managed by TWI could enhance non-destructive inspection of wiring beyond the current simple visual inspection and continuity checks, and also be able to inspect in some inaccessible areas.

In today's military and commercial aircraft, many miles of wiring are subject to heat, cold, moisture and vibration, which can make them brittle and fragile. Consequently such cabling becomes susceptible to cracking and abrasion, and can short circuit. Degradation and failure of aircraft wiring insulation in particular results in the failure of safety critical systems or even the risk of fire due to arcing (Figure 1).



Figure 1 Wiring inside aircraft structures is critical

So, there is a clear need to detect any degradation of aged wire before any malfunction takes place. Many developments have taken place on non destructive testing of the aircraft structure, but to date too little attention has been paid to aircraft wiring. Cabling defects can be as critical as structural defects and recently, aircraft manufacturers have been demonstrating increasing interest in the development of inspection techniques for wiring systems.

Typically wire inspection is carried out visually and/or with continuity checks and often after failure, in response to an instrument or system breakdown. Visual inspection will find the cracks and burns in easily accessible areas, but offers little quantitative information about the condition of insulated wires.

Two techniques, namely long range ultrasonic and Time Domain Reflectometry are more appropriate for inspection of inaccessible wires over distance, IR thermal imaging is ideal for examining small localised areas that may have been shown up by the other systems. The TDR system has been shown to detect small areas of insulation loss on certain wire pair patterns at distances of about 10metres, the Long Range Ultrasonics works at a shorter distance, primarily for thicker wire sections.

Three systems have been developed through the AWARE project, a project funded by the Technology Strategy Board and which embraces a total of nine partners.

Enhanced Time Domain Reflectometry (TDR) system

An Enhanced TDR technique has been developed at the London South Bank University (Faculty of Engineering, Science and Built Environment) which allows detection of insulation damage in electrical wires, and shield and braiding damage in coaxial and shielded twisted pair cables. The technique was developed for remote inspection of inaccessible wiring in aircraft, and can be applied to wires in excess of 10 meters of length. The TDR method is not new and has been in use for many years. It is however very attractive, since access to only one end of the wire system is required. The novelty of the new technique is in the selective use of the method, and in the arrangement and injection of successive pulses into the wire under test, which puts the new test procedure into a completely new perspective. Computer models of the technique were initially simulated using Vector Field software from Cobham Technical Services, before test procedures were created. Figures 2 and 3 show initial 3D models of insulation fault created in an 8 Amp figure of eight power cable, and an unshielded twisted pair cable respectively. Figures 4 and 5 show actual 10 mm damage created on the shield and insulation on one side of a coaxial cable (core conductor undamaged), and the corresponding fault detection using the ETDR technique respectively.

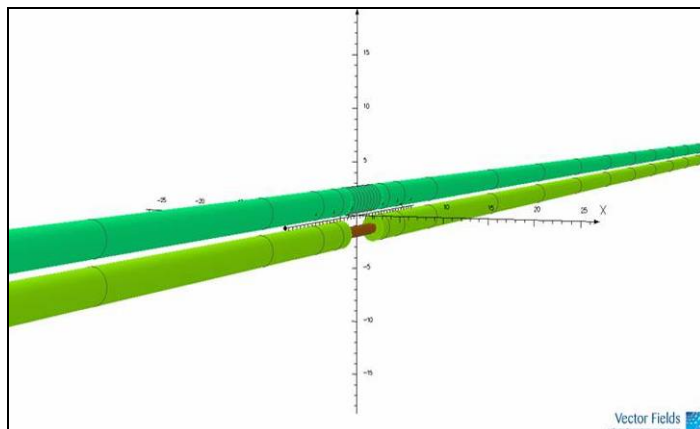


Figure 2 Computer model of a figure of eight power cable with 10 mm fault on one conductor insulation. This model was 10 meters long cable.

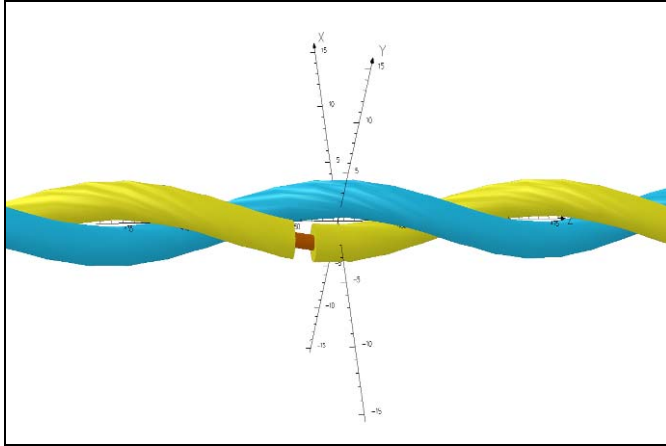


Figure 3 Computer model of an unshielded twisted pair cable with a 2.0 mm fault on one conductor insulation. This model was a simulation of a half a meter long cable.



Figure 4 Coaxial cable with a 10 mm damage created on the shield and insulation on one side with the core conductor undamaged. The fault was created near the middle of a 6 meter long cable.

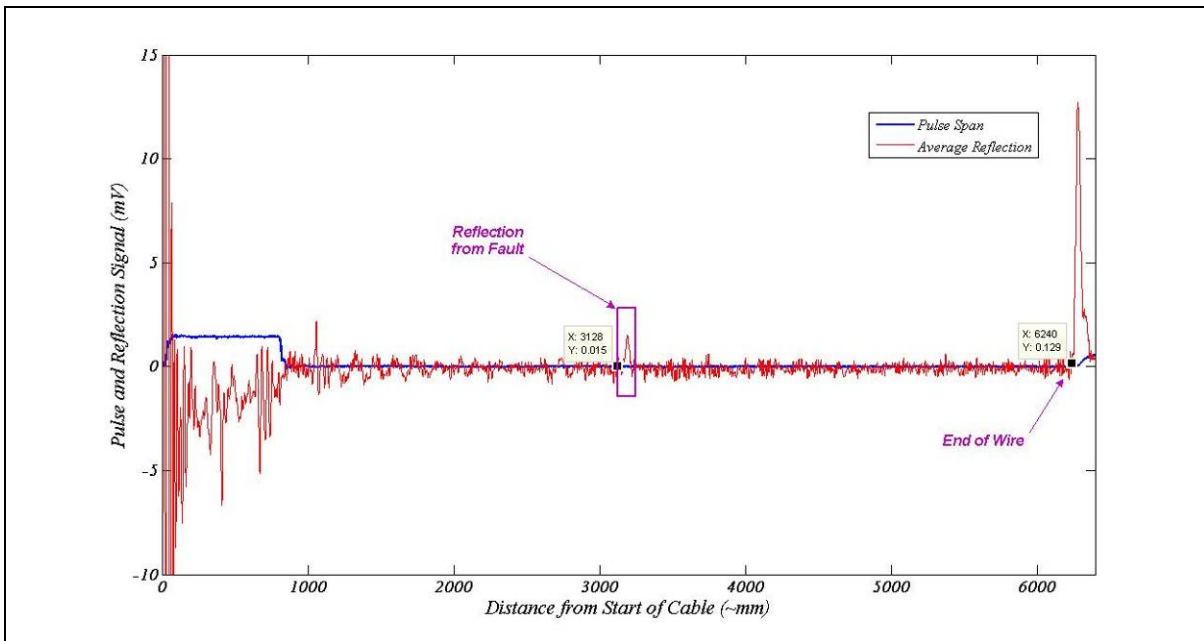


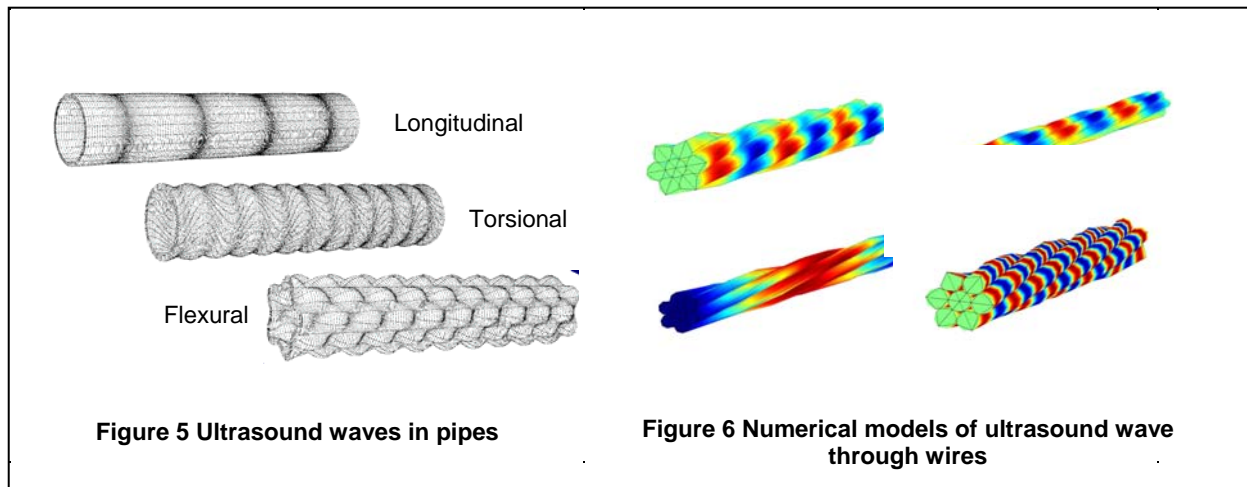
Figure 5 Shield fault detected for a 10 mm damage shown in fig 3, using the ETDR technique.

Long Range Ultrasonics system

The method utilises ultrasonic waves, pulsed along a wave-guide, which become reflected at discontinuities. In current LRU applications, the wave guide is a pipe and the discontinuity is corrosion, but most elongated components can propagate ultrasound over distances, perhaps 100m in some cases, as long as the cross-section is symmetrical; a rail is an example.

An aircraft wire can act as a wave guide for ultrasound, but there are important differences over wave propagation through pipes. These have presented the challenges that have been overcome in the AWARE project.

The first important difference is one of geometry. Pipes are cylindrical and hollow, while wires are solid. The wave modes are therefore quite different. Ultrasound wave propagation through pipes has been investigated extensively. There are three basic modes; longitudinal, torsional and flexural (Figure 5). For wires, new numerical models were developed in AWARE for investigating ultrasound wave propagation through not only single, but also multiple wire strands (Figure 6). They showed the viability of the method.



The second important difference is one of dimension. Wires have a much smaller diameter than pipes. Guided waves propagate most effectively if they are symmetrical. In a pipe, this can be achieved by surrounding a pipe with a ring of several ultrasound transducers. In AWARE, an alternative transducer has been developed, called a macro-fibre composite (MFC), which is flexible and the wire can be bed into the transducer to provide good contact.

A third important difference is that wires are always surrounded by insulation. Plastics are very attenuative of ultrasound, and even if the bulk of the ultrasound energy is propagating along the wire metal itself, the energy will 'leak' into the surrounding plastic insulation. The level of attenuation decreases with frequency and in AWARE it was found that adequate test ranges of several metres could be achieved at frequencies of about 20KHz, which is only just above the audible range. Indeed, the

propagation distances were much longer than expected and this has been attributed to the use of a polymer based transducer and consequently good 'acoustic impedance' matching between the transducer and the wire insulation.

Trials with prototype transducers in a simple clamp have been very successful (Figure 7). Test ranges of 6m have been achieved (Figure 8). A wide range of wire defects including abrasions, burns and cracks in single and multi-strand wires have been detected on long distances.

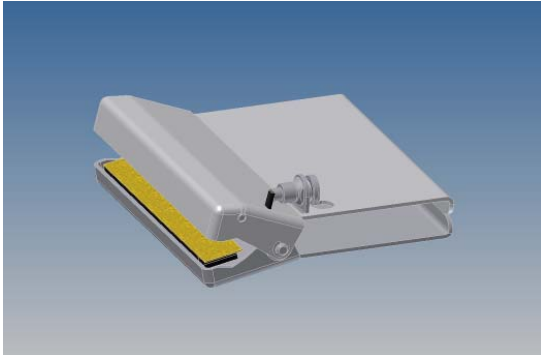


Figure 7 Prototype of the transducer clamp

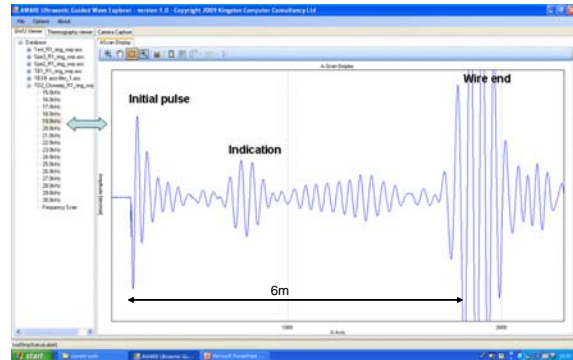


Figure 8 LRUT A-scan

Infra-Red thermal imaging system



The IR thermal imaging system developed at TWI uses a system comprising an IR camera (opposite picture) and a heating source.

The camera converts IR emitted from an object into a visual image that depicts thermal variations across the object. A heat source is necessary in this case because the amount of IR radiation increases when the temperature increases, and also because it allows the system to look at the heating/cooling time of the object.

If the insulation is defective, the defective area will have a different heating/cooling rate from the rest of the wire. So the defect effectively identifies itself. The visual image given by the IR camera is then sent to a PC and is analysed automatically and in real time using dedicated software, developed specifically for the AWARE project. The experimental work shows that the IR thermal imaging system used with an appropriate heating source can detect defects that are visually very difficult to see and in some cases that can not be seen visually (Figures 9 and 10). Ultimately it may be possible to distinguish wiring degradation by comparing the heating and cooling times of new and old wires.

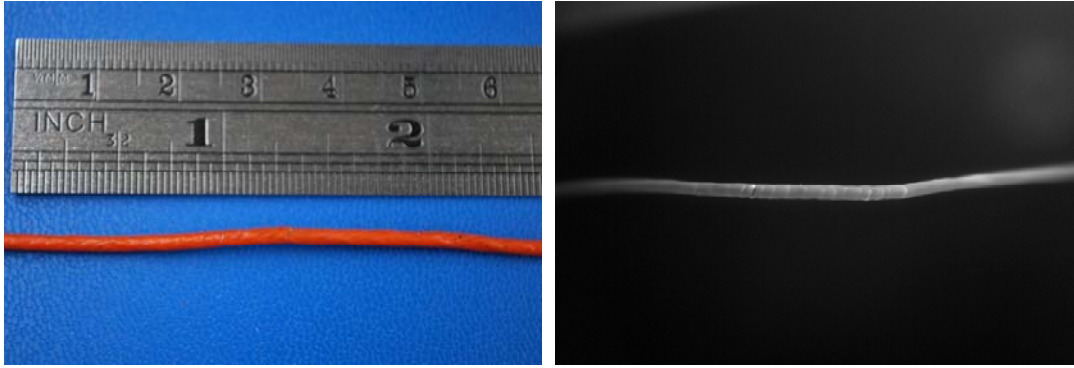


Figure 9 Wire inspected visually (left) and with the IR thermal camera (right)

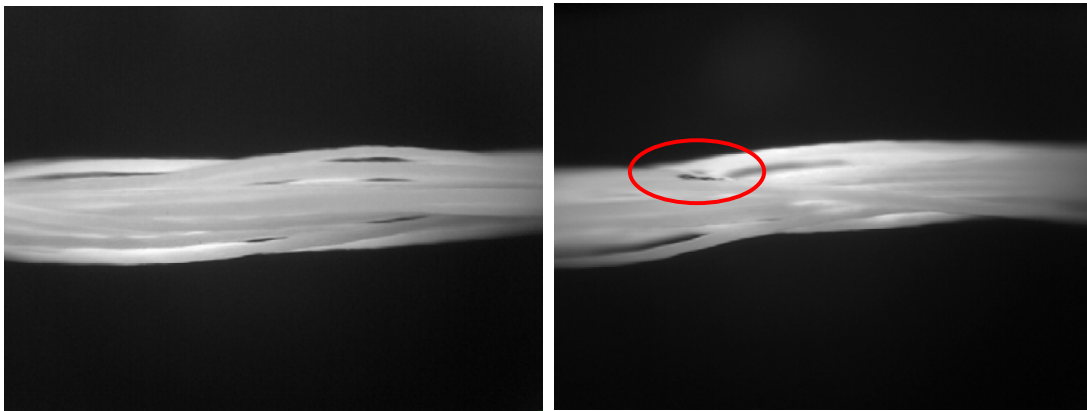


Figure 10 IR thermal imaging images. Non defective area (left) – area containing a defective wire (right)


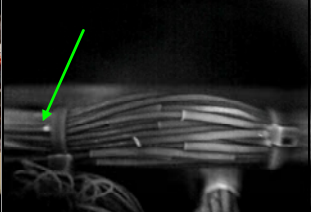
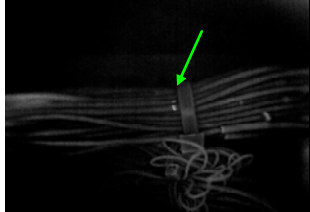
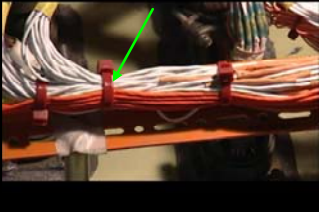
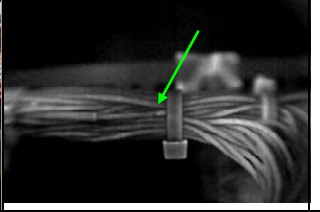
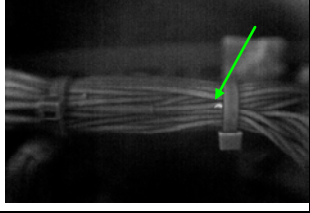
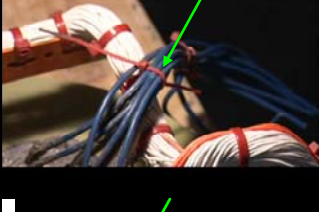
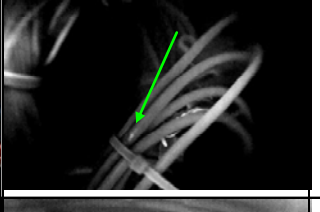
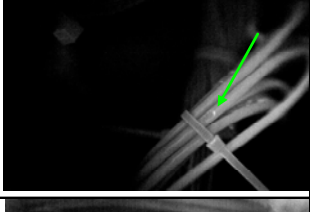
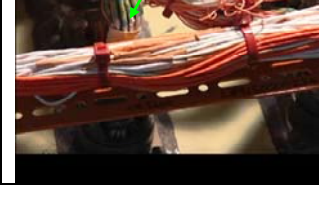


Wire and Flaw Number /location	Visual	Image Thermal Scan (Compressed data)	Still Image over flaw (Uncompressed data)
TB20-19vis-3thermo-orangewire-Insulation removed			
TB20-1.10vis-10thermo-whitewire-Insulation removed			
TB20-36vis-45thermo-bluewire-Abrasion			
TB20-14vis-1.11thermo-whitewire-Abrasion			

Figure 11 Tests on bundles of wires comparing visual inspection with IR thermal imaging inspection.

The major benefits of this technique are the portability of the infrared camera and the ability to examine large areas which are difficult to inspect visually because of the lack of light or because of the access. The system is relatively small and portable so an in-service inspection is feasible and both military and civil aircraft could benefit from this system during routine maintenance. Another interesting feature of the thermography system is that it is a non-contact technique allowing inspection of the surfaces of bundles of wiring in situ. Furthermore, it provides the added convenience of real-time imaging, thus reducing the time necessary for information retrieval or film development.

The finality of the system developed is to enhance detection of damages in aircraft wiring using IR thermal imaging and a dedicated custom built software (Figure 11).

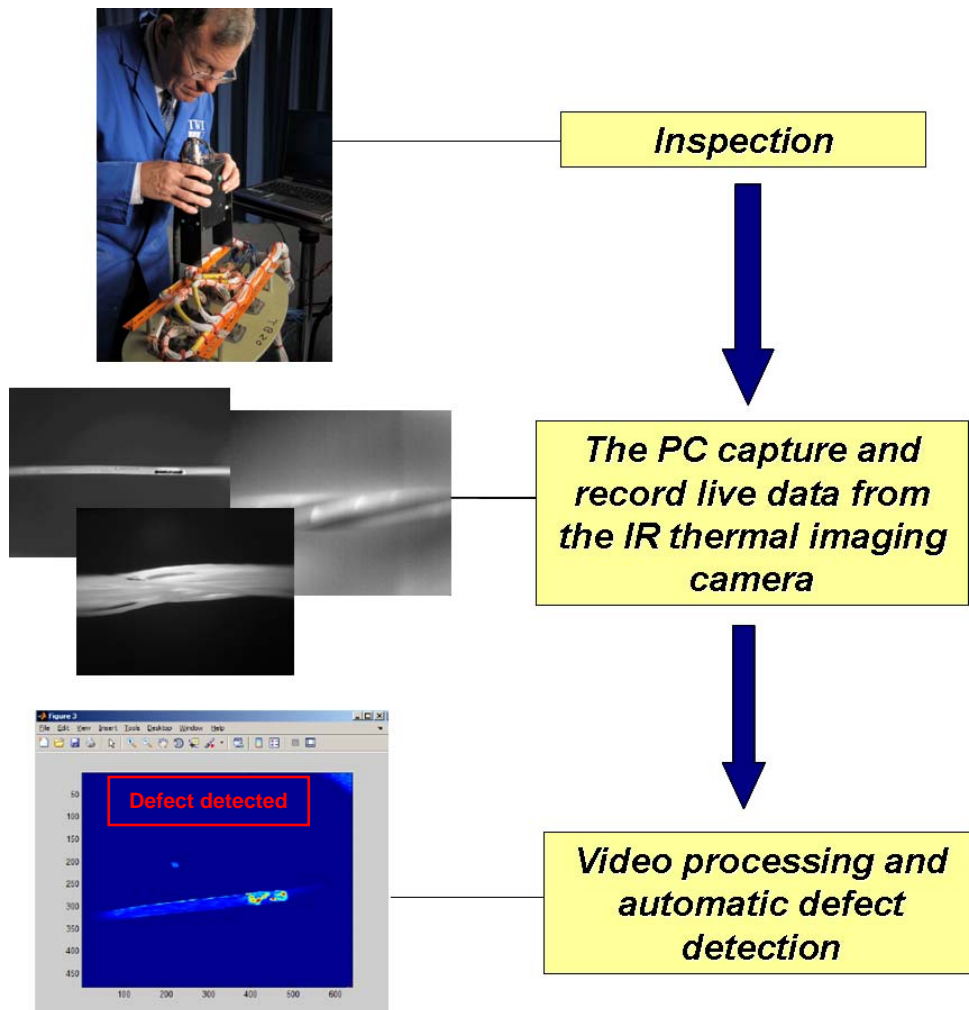


Figure 12 Inspection of defective wires using the thermal imaging system comprising the IR camera and the heating source. After recording the image given by the IR thermal camera, the AWARE integrated software allows automatic detection of defects on wiring.

One of the major economic benefits of those three techniques is the possible early detection of incipient flaws in the wiring system of the aircraft. The combination of the three systems allows rapid detection of defective insulation which can then be either repaired or replaced by a new wire. It is a financially attractive solution because it eliminates the need to rewire the entire aircraft. Although the maintenance time may be longer than visual inspection and the capital cost investments may be relatively high, the combined use of these systems in the long term could not only improve significantly the reliability of aircraft wiring but also be financially advantageous.

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