

Non-Destructive Testing & Evaluation

Opportunities for Interdisciplinary Research

Professor Peter Charlton
Senior Research Fellow in NDT

Overview

- Background to NDT Research at UWTSD
- Definition of NDT&E
- Why NDT&E
- Overview of Some Main Methods
- Probability of Detection
- Commercial Project Examples
- Postgraduate Research
- Collaboration Opportunities

NDT&E Research at UWTSD

Niche industry within the South Wales region with a number of companies that are involved in research (TWI), manufacturing (Silverwing Ltd) and service inspection (Oceaneering Asset Integrity). Other companies such as TATA, Calsonic, Team Precision, TIMET and others also utilise NDT technologies.

- Non-destructive testing research has been ongoing at UWTSD, Swansea since the early 1990's.
- During 2005 the university became the lead academic partner in the NDT Validation centre with TWI in EMC2, Port Talbot.

A number of KTC's have been delivered in recent times with the more recent involvement in the Advanced Sustainable Manufacturing Technologies (ASTUTE) project.

The responsibility of the NDT support within the ASTUTE project has rested with UWTSD and is continuing under the ASTUTE 2020 programme.

Further work has also been conducted under the Strategic Insight Programme (SIP)

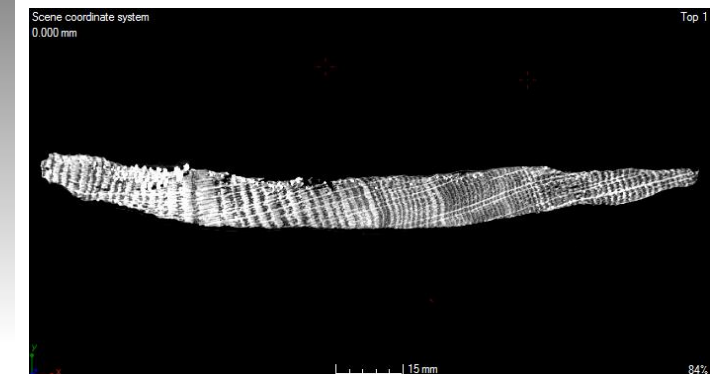
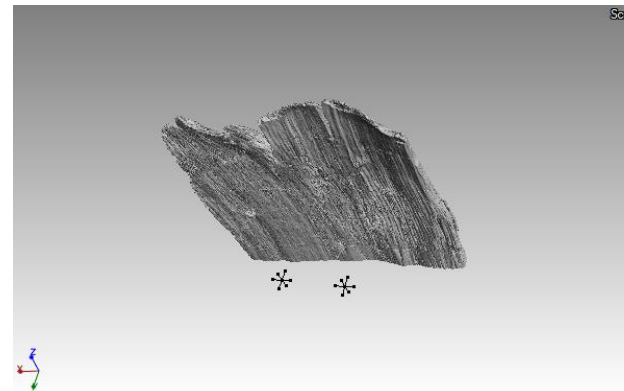
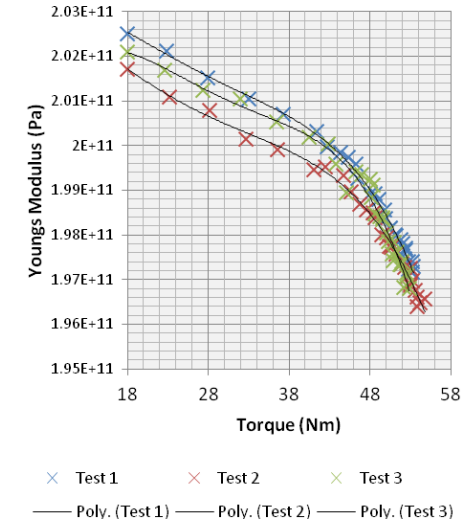
NDT&E Research at UWTSD

- NDT involves the application of physics, engineering (all disciplines), materials and computer science to determine the structural integrity and material properties in a wide range of industrial applications.
- The technology closely resembles the familiar medical imaging methods.
- To this end research can be/is undertaken across many disciplines

NDT&E Research at UWTSD

Some examples include:

- Applications in the automotive school where ultrasonic methods have been used to evaluate stresses on connecting rod installations.*
- Application of CT Radiography as a means of the improved dating of archaeological wood samples (Newport Ship) in partnership with Professor Nigel Nayling, School of Archaeology, History and Anthropology.*



NDT&E Research at UWTSD

Additional challenges:

- The increasing use of composite materials
- The development and growth of additive manufacturing processes

It is paramount that consideration of resulting material and structural properties are considered.

Definition of NDT

**The use of noninvasive techniques to
determine the integrity of a material,
component or structure
or
quantitatively measure some characteristic
of an object.**

i.e. Inspect or measure without doing harm.

Aerospace Industry

Aloha Airlines Flight 243 April 28, 1988 from Hilo to Honolulu in Hawaii

The Boeing 737- 297 suffered extensive damage after an explosive decompression

The aircraft landed safely at Kahului Airport, Maui

Only one fatality, a flight attendant who was ejected from the plane and 65 passengers and crew injured.

The investigation determined:

- The weather had no role in this accident.
- The quality of inspection and maintenance programs were deficient.

Findings: the fuselage failure initiated in a lap joint along S-10L;[3] the failure mechanism was a result of multiple site fatigue cracking of the skin adjacent to rivet holes along the lap joint upper rivet row and tear strap disbond which negated the fail-safe characteristics of the fuselage. Finally, the fatigue cracking initiated from the knife edge associated with the countersunk lap joint rivet holes; the knife edge concentrated stresses that were transferred through the rivets because of lap joint disbonding.



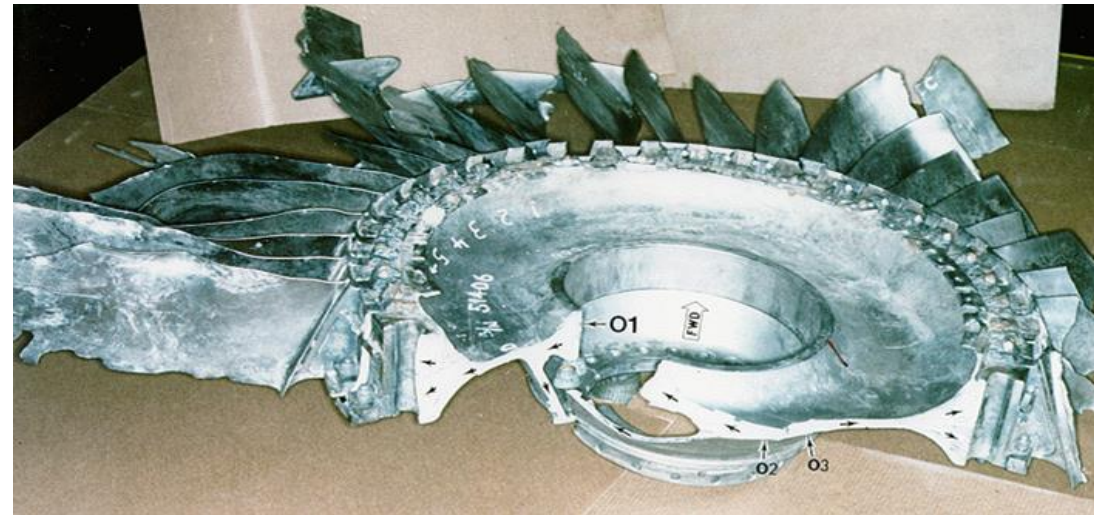
Aerospace Industry

United Airlines Flight 232 July 19, 1989 from Denver to Colorado in the US

Suffered a catastrophic failure of its tail-mounted engine leading to the loss of all flight controls

Of the 296 people on board, 111 died in the accident and 185 survived.

Investigators found that a defect that went undetected in an engine disk was responsible



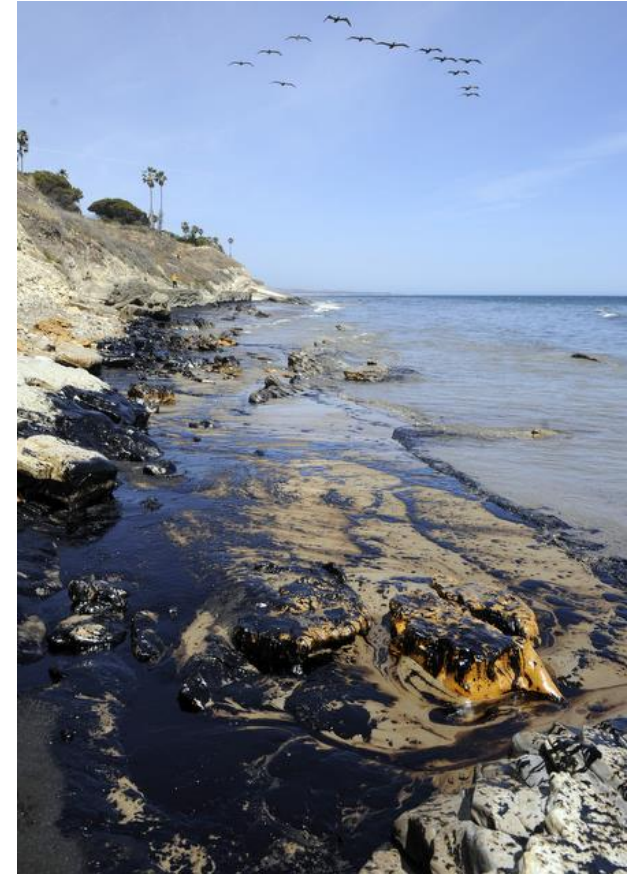
Petrochemical

Refugio oil spill

The oil spill, located immediately north of **Refugio State Beach** in, **Santa Barbara County, California** originated in a 2 feet (61 cm) diameter underground pipeline named Line 901 owned by Plains All American Pipeline.

The oil quickly spread along 7 miles (11 km) of the coastline from Arroyo Hondo Creek to the west to El Capitán State Beach on the east. The slick reached four marine protected areas that have significant for their ecological or cultural significance: Naples, Kashtayit, Campus Point and Goleta Slough. Culturally significant land and artefacts to the Chumash people are also found in this area.

Before the spill, an inspection of the 28 year old Line 901 pipeline found extensive corrosion problems resulting in thinning pipeline walls. The pipeline did not have an automatic shut-off valve that would have been required on an intrastate pipeline as Line 901 is categorized as an interstate pipeline. Officials from Plains All American Pipeline claimed that installing a new valve would present other potential dangers.



Railtrack

The **Hatfield rail crash** was a [railway](#) accident on 17 October 2000, at [Hatfield, Hertfordshire](#), UK. It was caused by a [metal fatigue](#) induced [derailment](#), killing four people and injuring more than 70.

A preliminary investigation found a rail had fragmented as trains passed and that the likely cause was "[rolling contact fatigue](#)" (defined as multiple surface-breaking cracks). Such cracks are caused by high loads where the wheels contact the rail. [\[12\]\[13\]](#) Repeated loading causes [fatigue](#) cracks to grow. When they reach a critical size, the rail fails. Portions of the failed track at Hatfield were reassembled and numerous fatigue cracks were identified; these contributed to [spalling](#) of the running surface to around five millimetres (0.20 in) deep and 100 millimetres (3.9 in) long.



Methods of NDT

Visual

Tap Testing

Microwave

Thermography

Magnetic Particle

Acoustic Microscopy

X-ray

Acoustic Emission

Magnetic Measurements

Liquid Penetrant

Replication

Ultrasonic

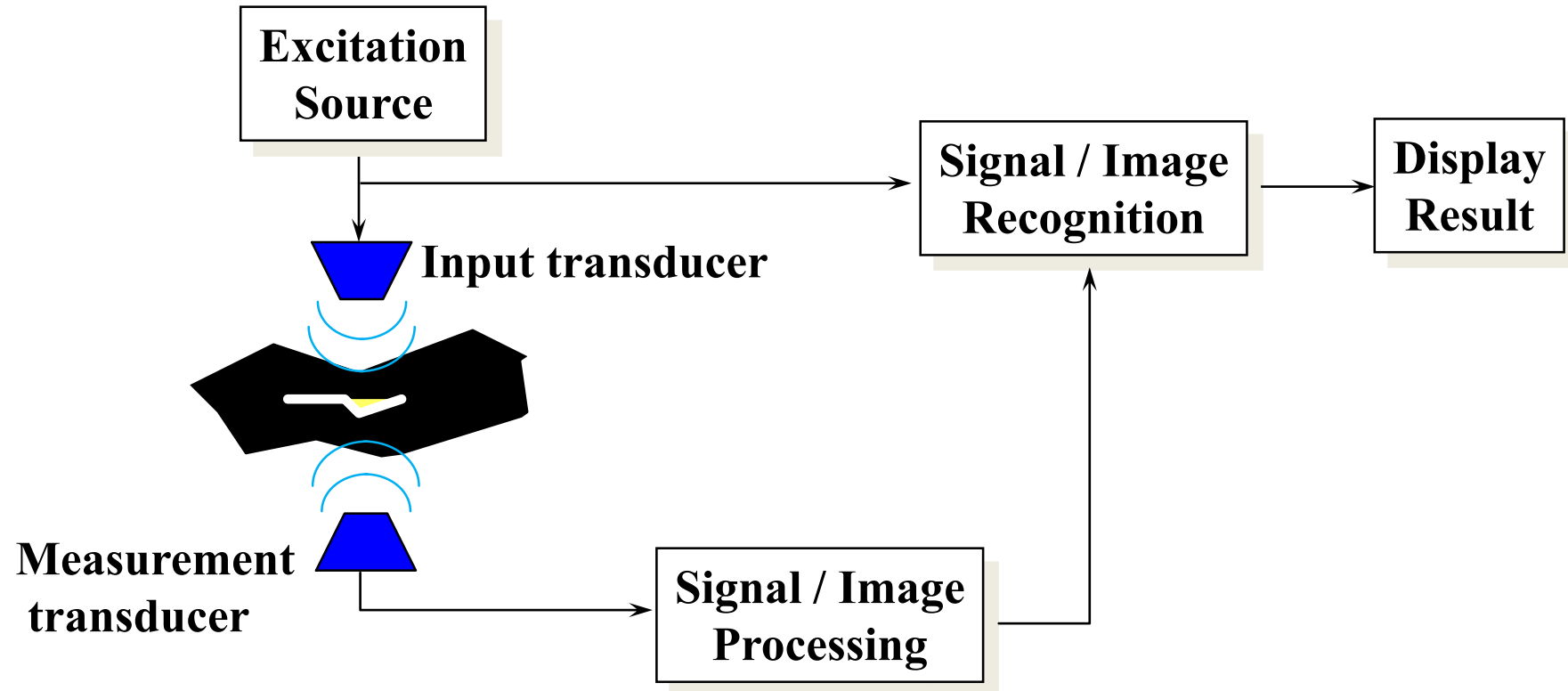
Laser Interferometry

Eddy Current

Flux Leakage

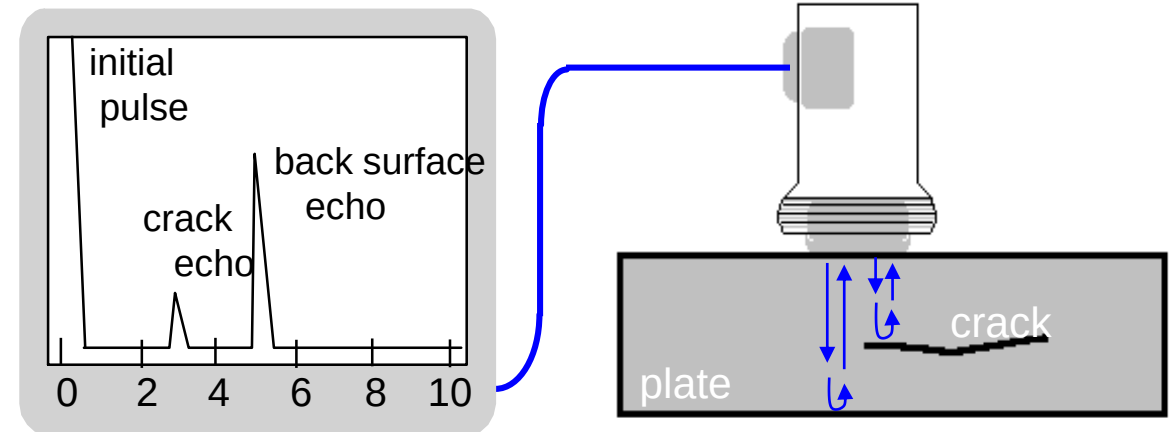


Sensor Based Inspections : Principle



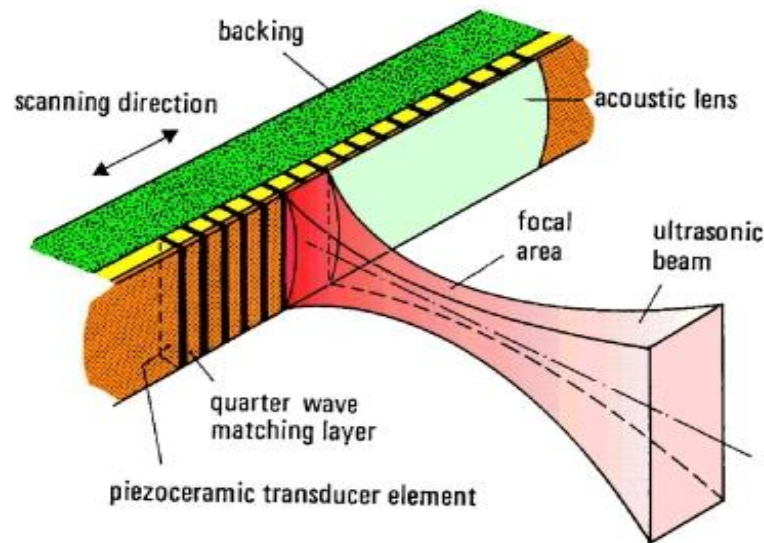
Ultrasonic Inspection

- High frequency sound waves are introduced into a material and they are reflected back from surfaces or flaws.
- Reflected sound energy is displayed versus time, and inspector can visualize a cross section of the specimen showing the depth of features that reflect sound.



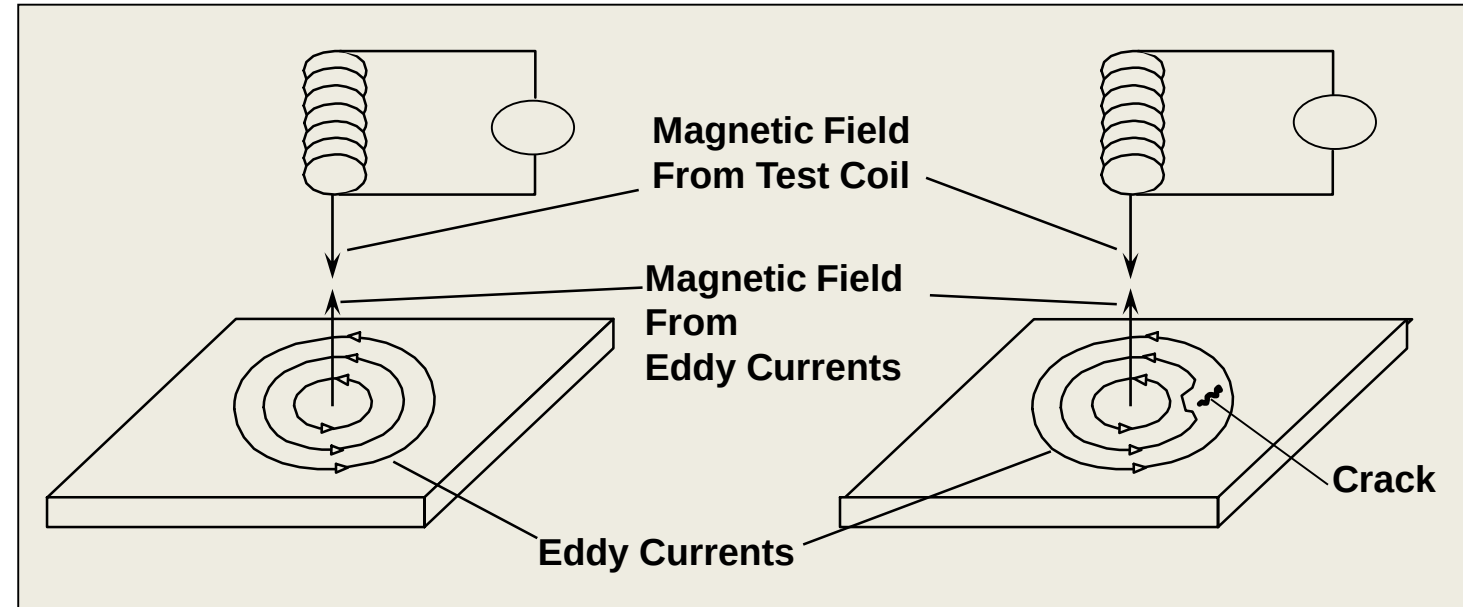
Ultrasonic Phased Array Imaging

- Phased Array (PA) ultrasonics has applications in industrial nondestructive testing
- The PA image shows the defects hidden inside a structure or weld

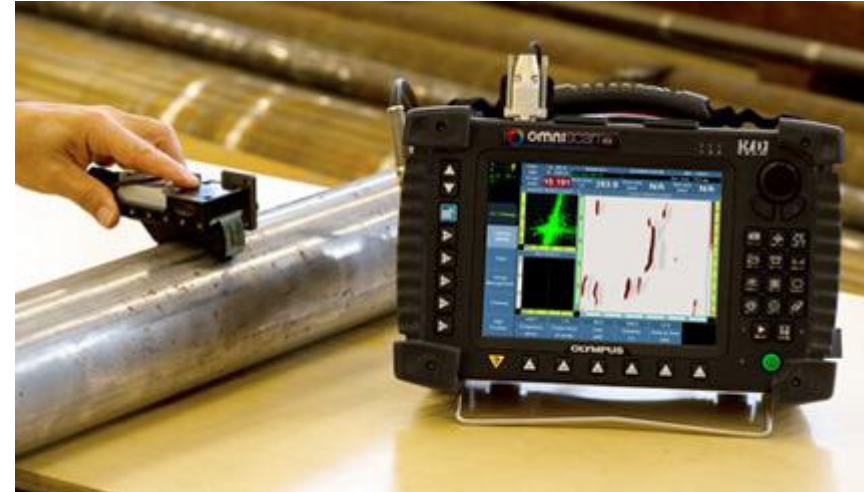


Eddy Current Inspection

- Eddy currents are induced electrical currents that flow in a circular path. They get their name from “eddies” that are formed when a liquid or gas flows in a circular path around obstacles when conditions are right.
- Defects cause a disruption in the circular flow patterns of the eddy currents and weaken their strength.
- This change in strength at the crack location are detected through the process of mutual inductance resulting in impedance changes in the test coil.



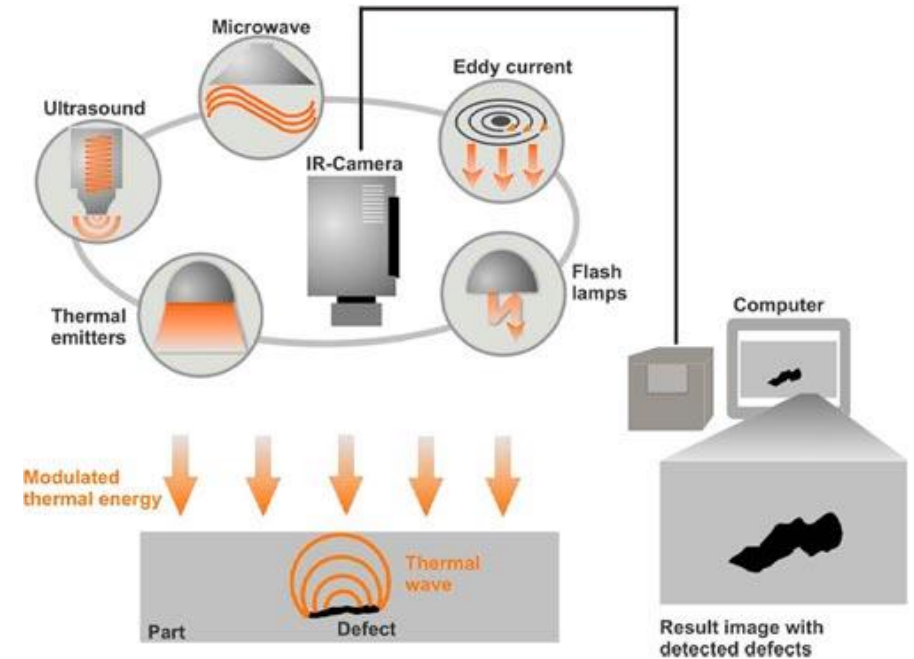
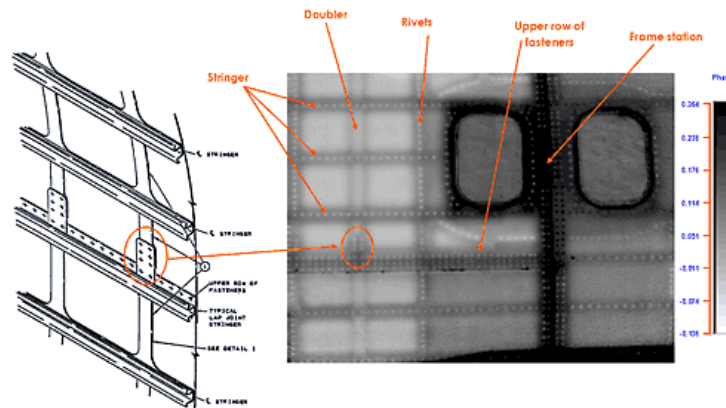
Eddy Current Array Imaging



Thermography

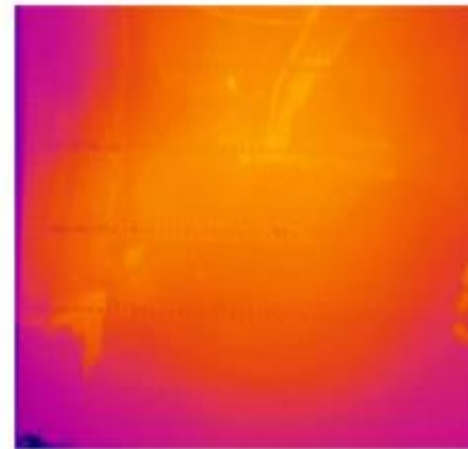
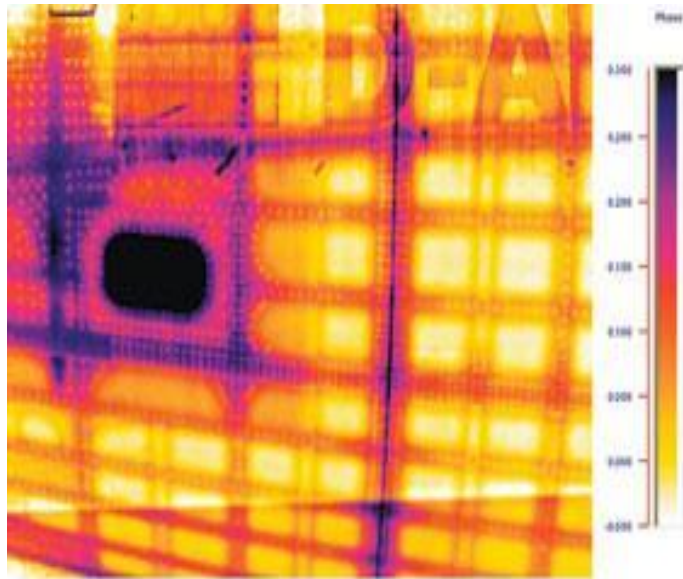
Two methods are used :

- Passive, in which the features of interest are naturally at a higher or lower temperature than the background
- Active, in which an energy source is required to produce a thermal contrast

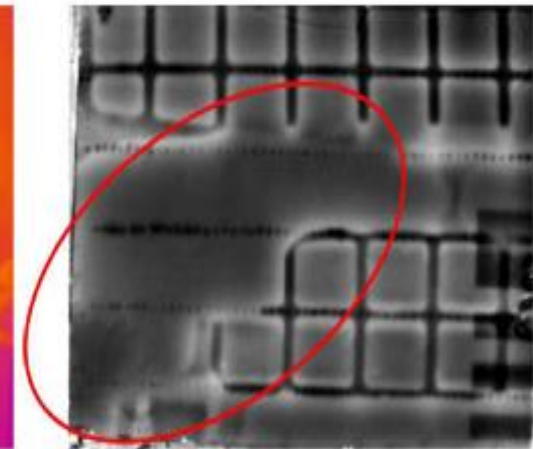


Thermography

Fuselage inspection of Boeing 737

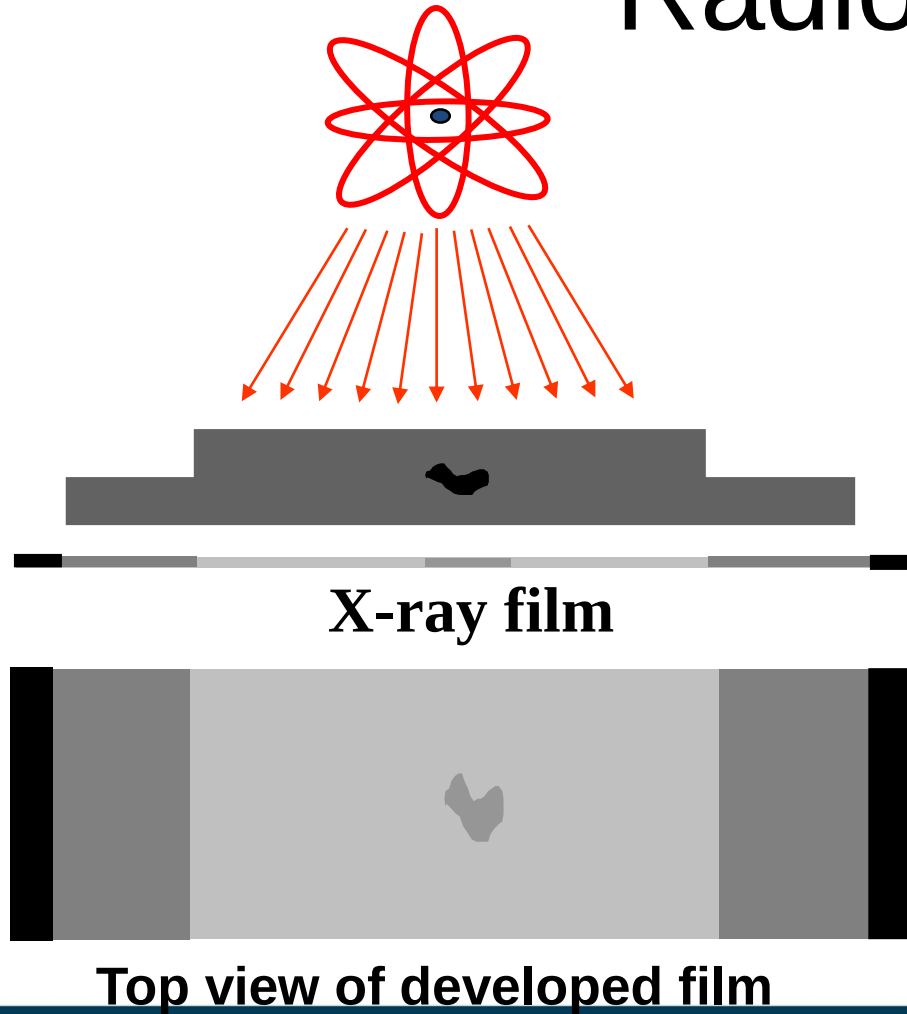


Infrared image of 737 hull



Resulting image shows disbondings clearly identified.

Radiography



The film darkness (density) will vary with the amount of radiation reaching the film through the test object.



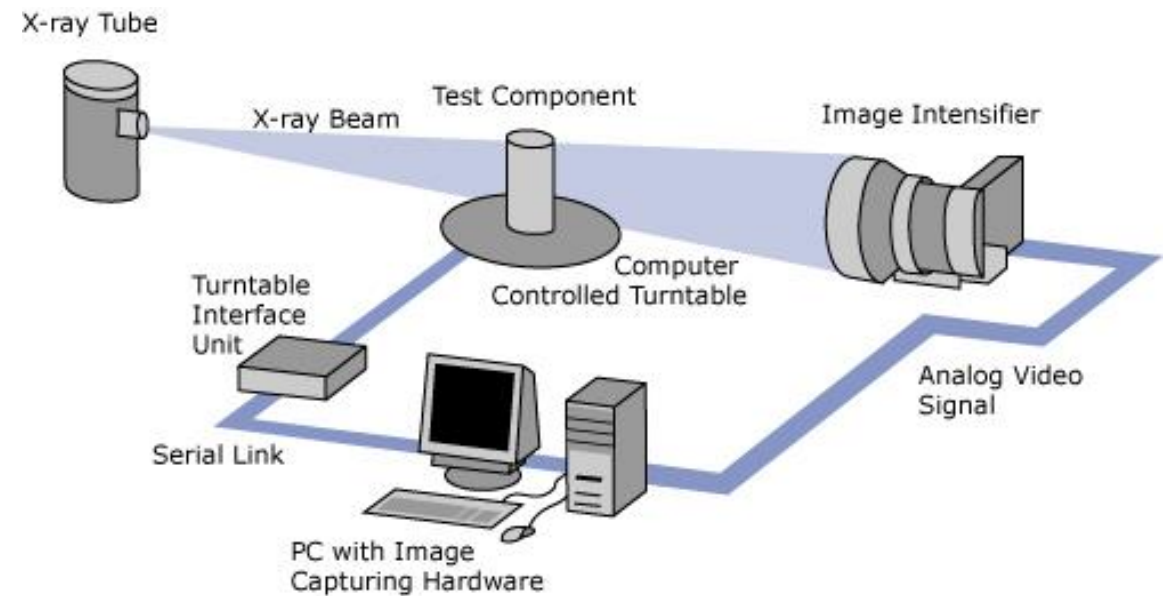
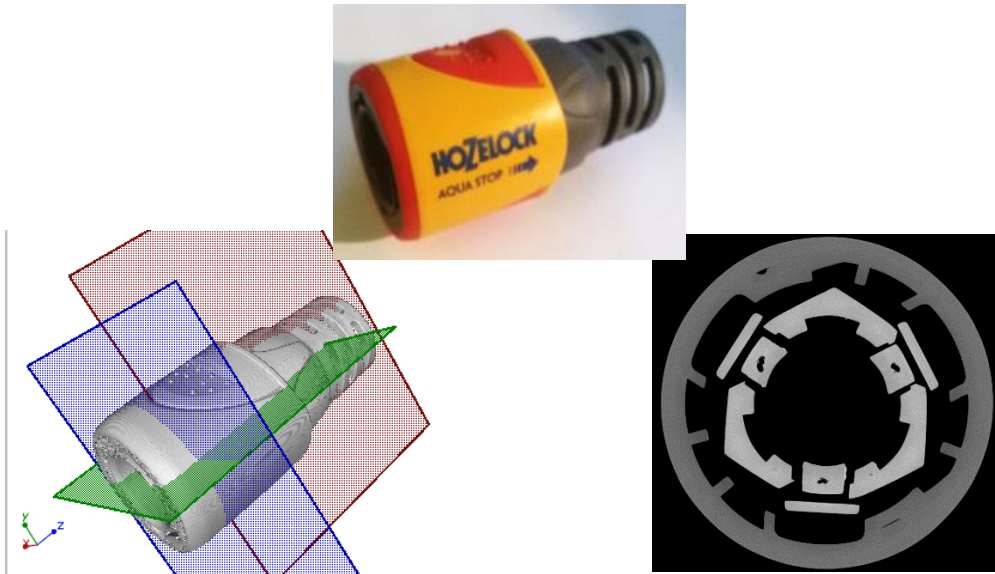
= less exposure



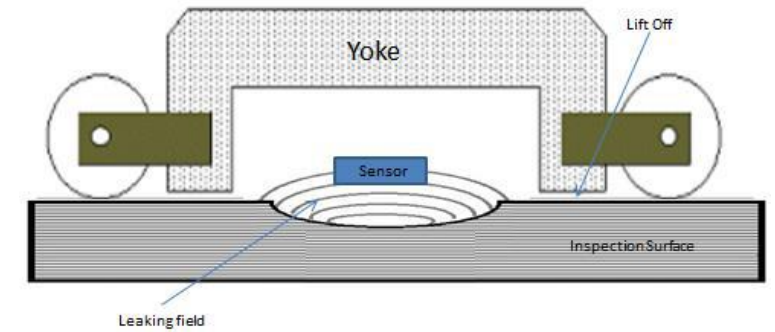
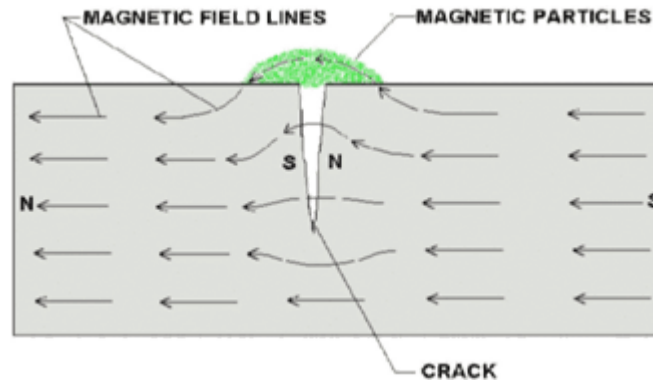
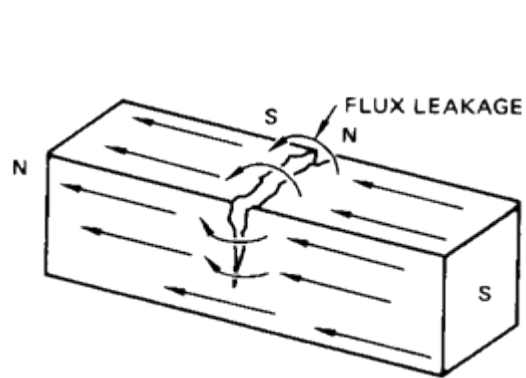
= more exposure

CT Radiography

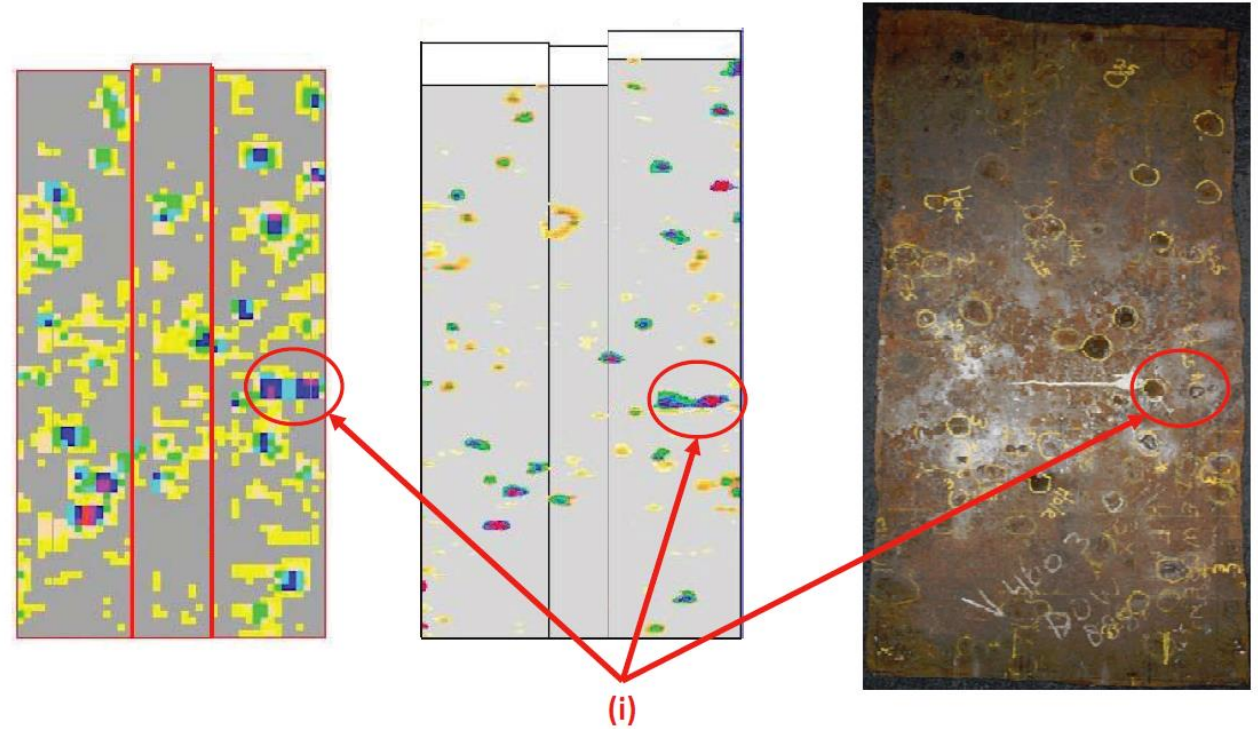
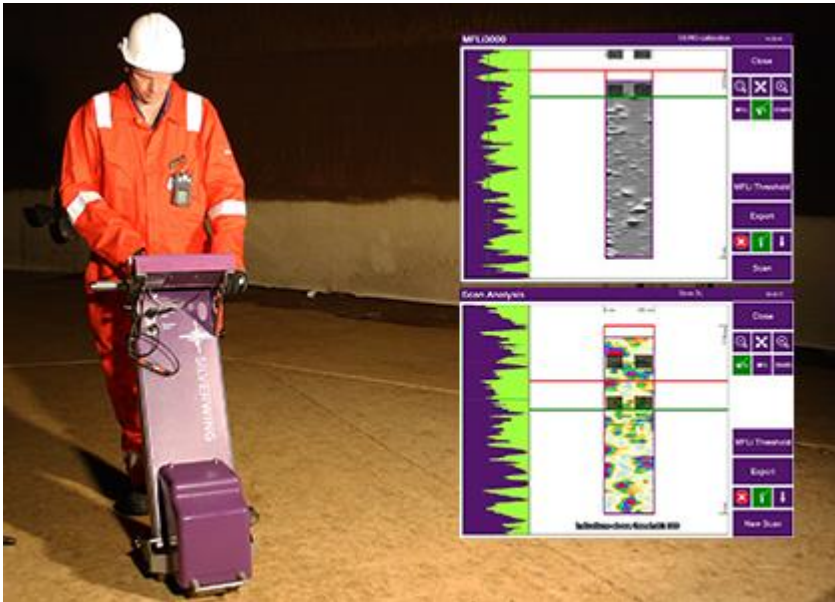
Computed Tomography (CT) uses a real-time inspection system employing a sample positioning system and special software.



Magnetic Flux Leakage



MFL Imaging

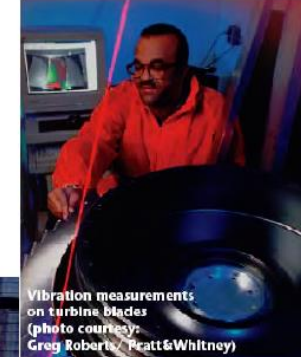
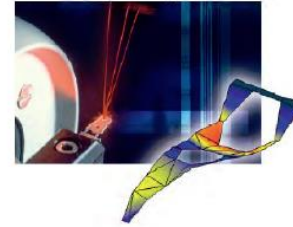


Laser Doppler Vibrometry

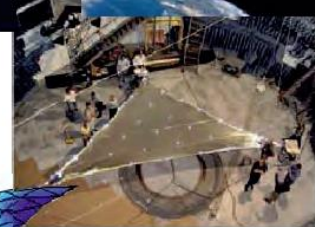


Some Applications

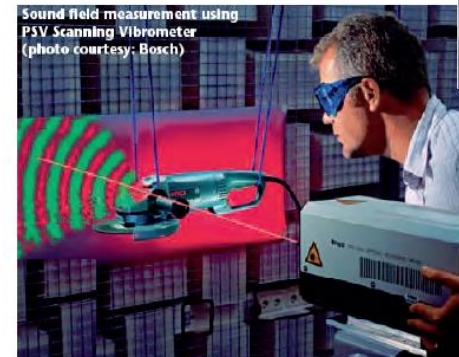
3-D vibration measurements for modal test on a disk drive suspension



Vibration measurements on turbine blades (photo courtesy: Greg Roberts, Pratt & Whitney)

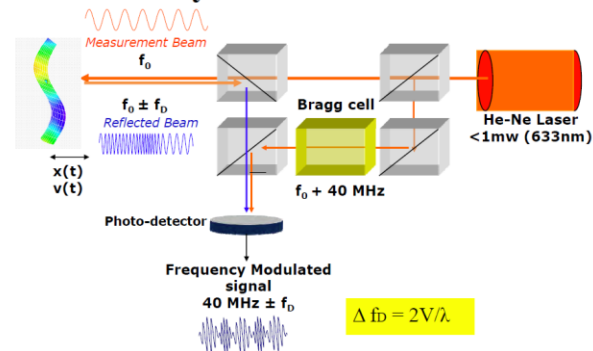


Modal tests for validation of a solar sail design (photos courtesy: NASA)



Sound field measurement using PSV Scanning Vibrometer (photo courtesy: Bosch)

The Heterodyne Interferometer



Assessment of Reliability of Nondestructive Testing

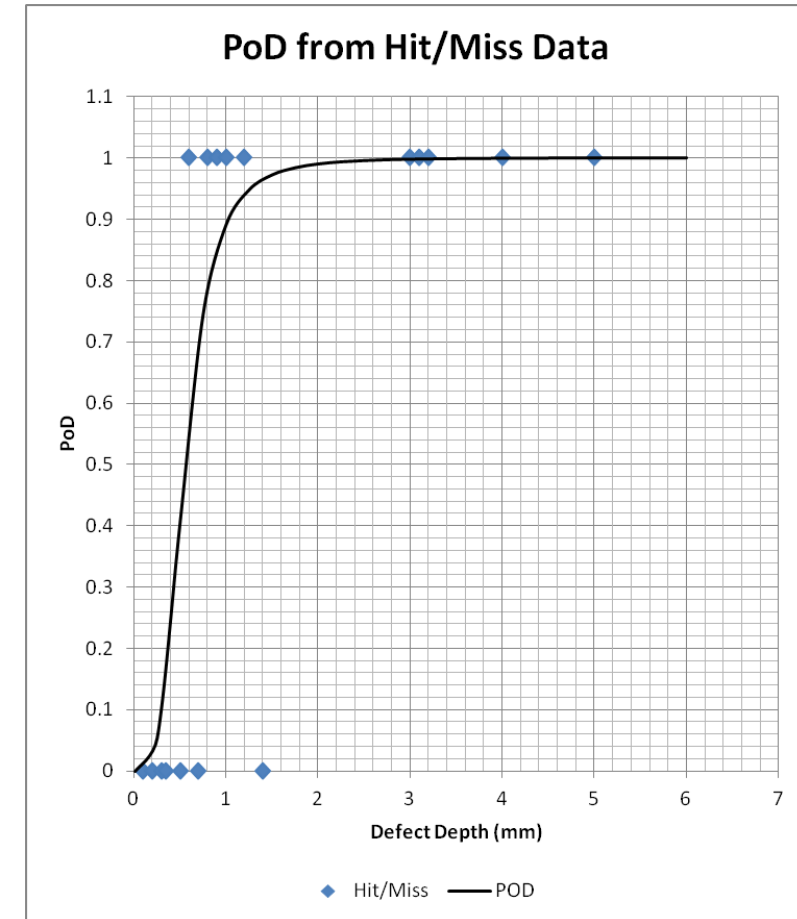
Detection Uncertainty

1. Detection uncertainty relates to whether or not a flaw has been found. This is in itself is a controversial topic.
2. What constitutes a flaw? If we consider that any deviation from a pure condition constitutes a "flawed" item then even the smallest crystal dislocation in a metal structure could be interpreted as a "flaw". Not many (probably not any) components would be considered "unflawed" if the definition was taken to this extreme.
3. Flaw detection must therefore take on some practical considerations. Detection of flaws in NDT is by indirect means and whether or not a flaw is detected therefore depends on a variety of factors. These factors include:
 - i. the nature of the flaw itself
 - ii. the test method used
 - iii. the sensitivity of the test method used and,
 - iv. human factors.

Assessment of Reliability of Nondestructive Testing

Example Hit/Miss Data – Defect Depth used as defect parameter

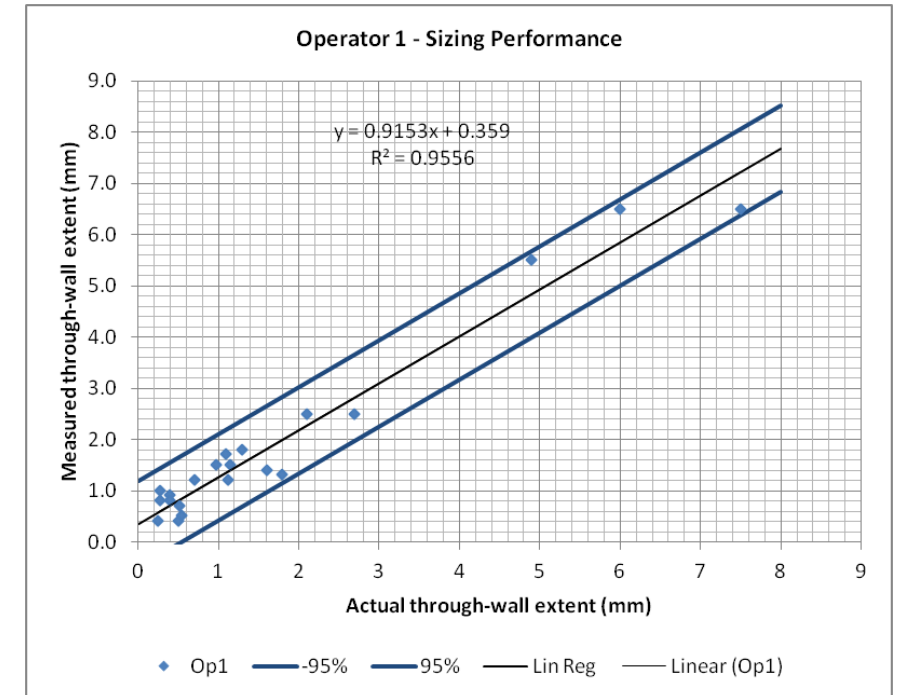
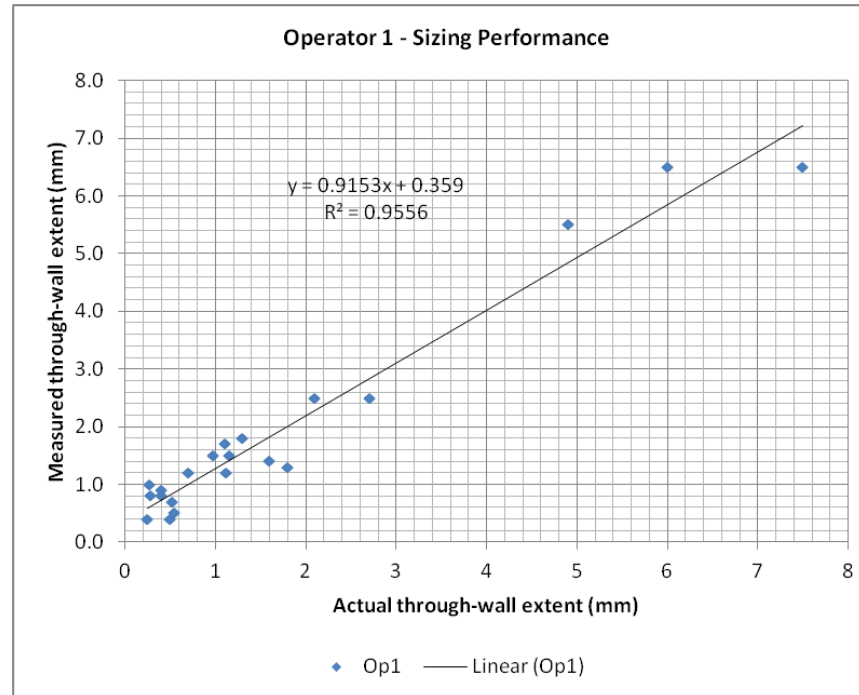
Defect	Depth (mm)	Hit/Miss
A	0.1	0
B	0.2	0
C	0.3	0
D	0.35	0
E	0.5	0
F	0.6	1
G	0.7	0
H	0.8	1
I	0.9	1
J	1	1
k	1.2	1
l	1.4	0
m	3	1
n	3.1	1
o	3.2	1
p	4	1
q	5	1



Assessment of Reliability of Nondestructive Testing

Sizing Accuracy Estimation

Defect	true size	Estimate
1	0.25	0.4
2	0.27	1.0
3	0.28	0.8
4	0.4	0.9
5	0.4	0.8
6	0.5	0.4
7	0.52	0.7
8	0.55	0.5
9	0.7	1.2
10	0.98	1.5
11	1.12	1.2
12	1.15	1.5
13	1.1	1.7
14	1.3	1.8
15	1.6	1.4
16	1.8	1.3
17	2.1	2.5
18	2.7	2.5
19	4.9	5.5
20	6	6.5
21	7.5	6.5



Commercial Project Examples

Strategic Insight Programme (SIP)

Matilda's Planet

Thermographic Investigation to determine energy efficiency and directivity characteristics of a novel Thermal Radiation heater Panel

Silverwing UK

Optimisation of Variable Reluctance Magnet Bridge for Magnetic Flux Leakage Inspection Tool

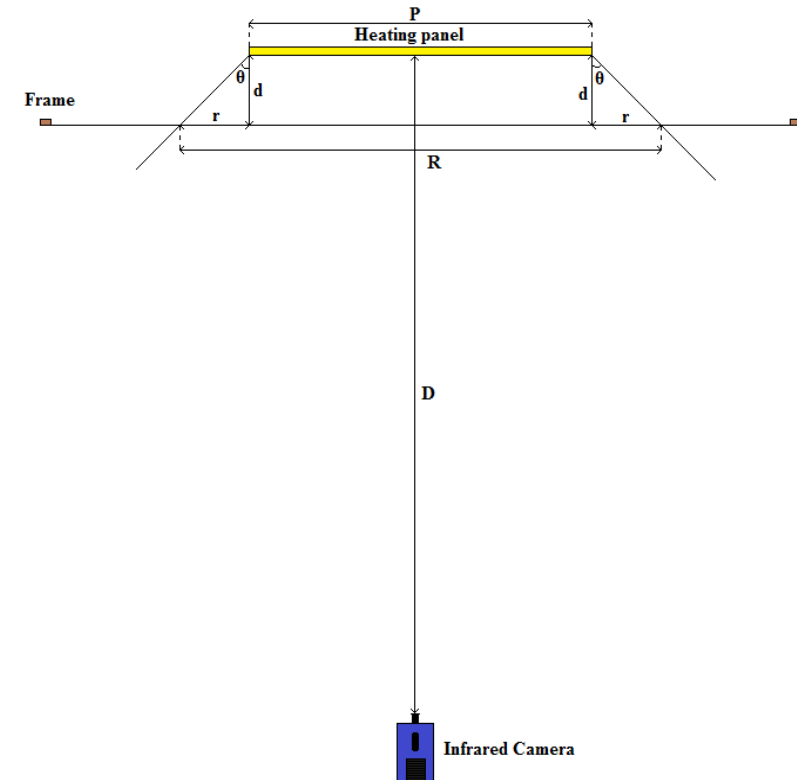
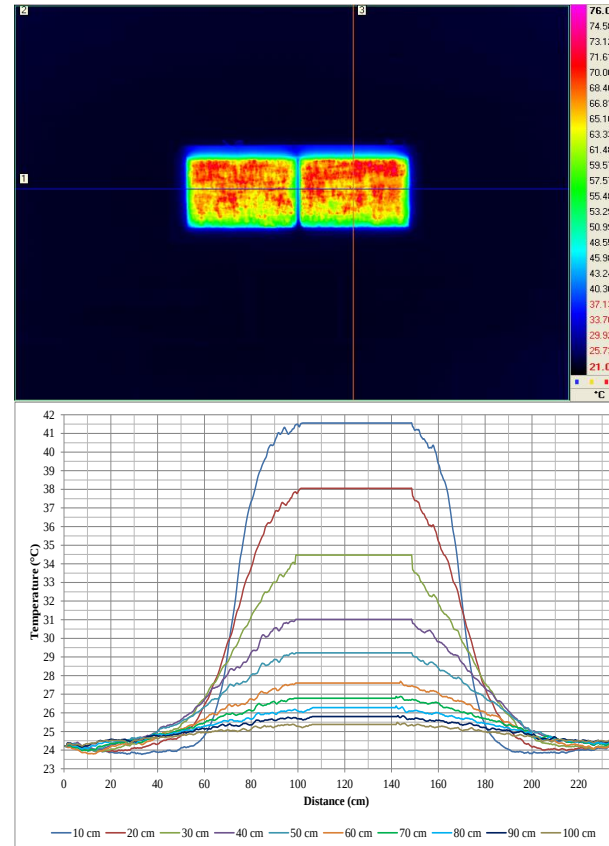
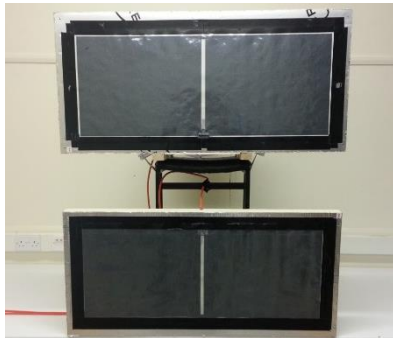
Oceaneering Inspection Services

Ultrasonic Curved Phased Array Optimisation and statistical analysis for Microbial Attack Pipe Inspection

Commercial Projects

Matilda's Planet

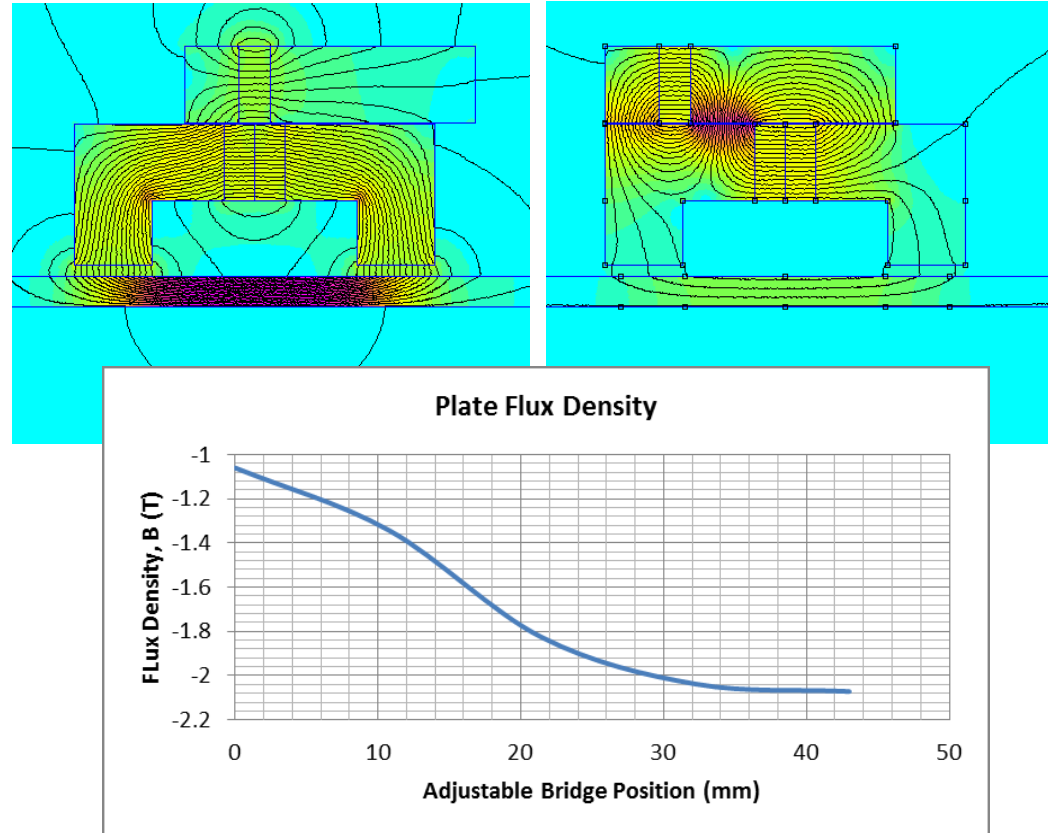
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Commercial Projects

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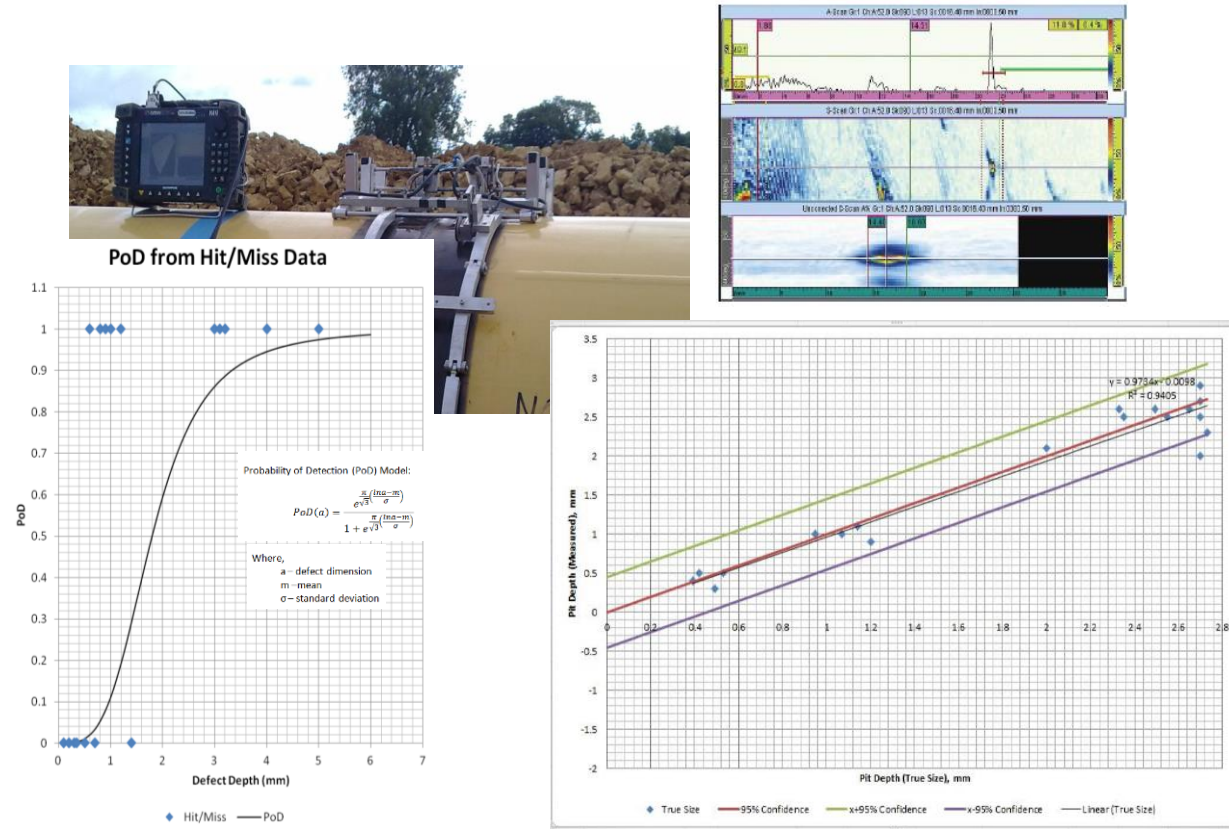
Optimisation of Variable
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Commercial Projects

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Completed Postgraduate Research

MSc in NDT&E Research Projects – 17 Completed with Industrial Partners

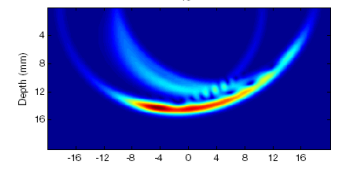
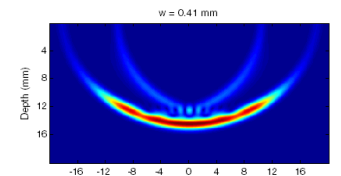
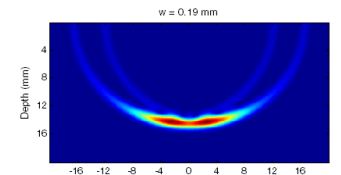
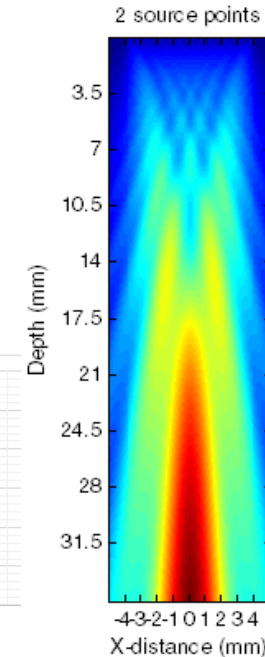
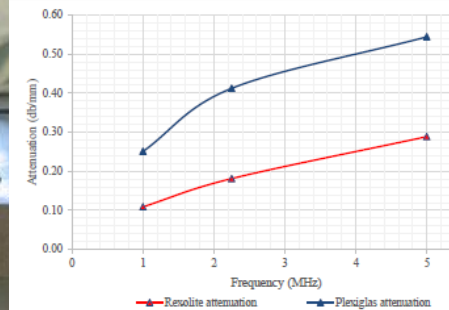
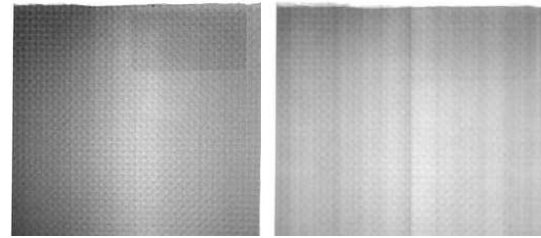
Examples:

2015, Chris Rowden, Optimisation of Digital Radiographic Parameters for CFRP Component Evaluation

2015, Rhodri Jones, Investigation into the Suitability of 3D Printed Ultrasonic Wedges

2014, Michael Wood, Non-linear Ultrasonic Evaluation of Kissing Bonds in CFRP Composites

2013, Anja Hamblyn, Ultrasonic Diffraction Pattern Calculations for Synthetic Aperture Focussing Architectures



Completed Postgraduate Research

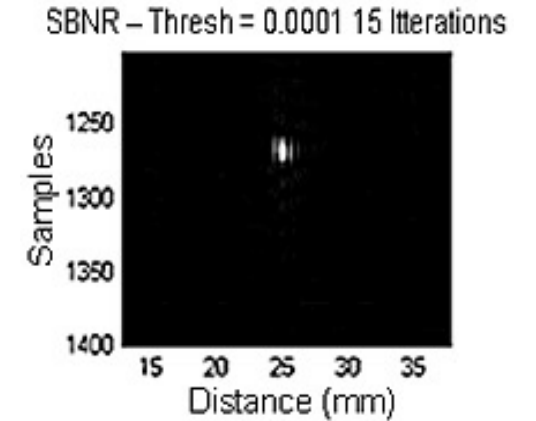
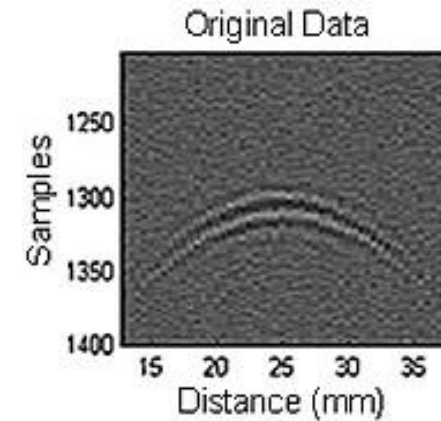
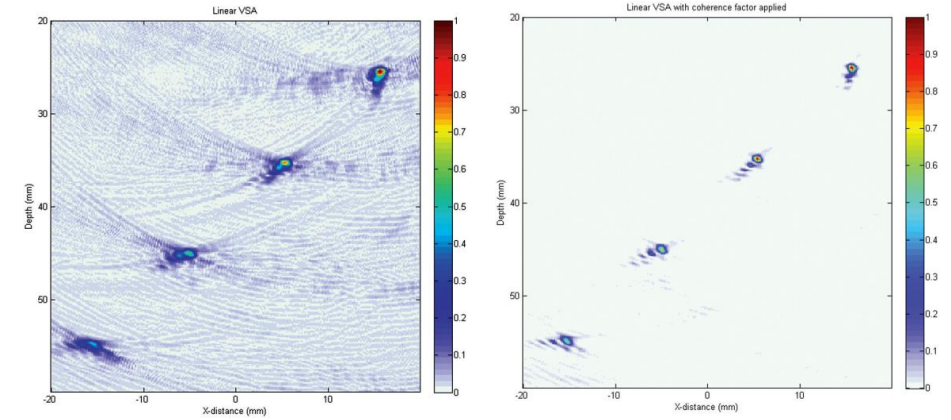
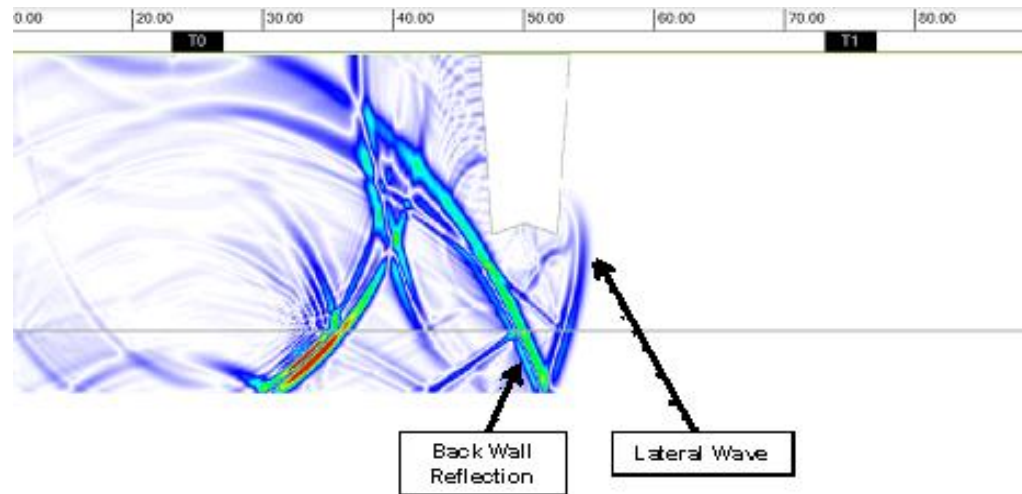
- 3 PhDs Completed in Advanced Ultrasonic Imaging
2015, Mark Sutcliffe - An Investigation into Time Critical Synthetic Transmit Aperture Ultrasound Imaging
2013, Stephen Mosey - Resolution Enhancement of B-Mode Ultrasound Images
2011, Paul Sinker - An Enhanced Ultrasonic Time-of-Flight Diffraction Technique using Sparse Transducer Arrays

Advanced Array Ultrasonic Real-Time High Resolution Imaging Methodologies

High resolution ultrasonic medical imaging capabilities to the industrial imaging sector.
Ultrasonic simulation – Integral and Differential Methods
Signal and Image Processing Development

Research Specific Areas:

- Multiple Virtual Source Aperture (MVSA) Ultrasound Imaging
- Deconvolution and Beam Weighted Synthetic Aperture Focussing
- Sparse Array Transducer Configurations for Time of Flight Diffraction (TOFD) Weld Inspection Imaging



Centre for Applied Innovation in Non-Destructive Evaluation (CAINDE)

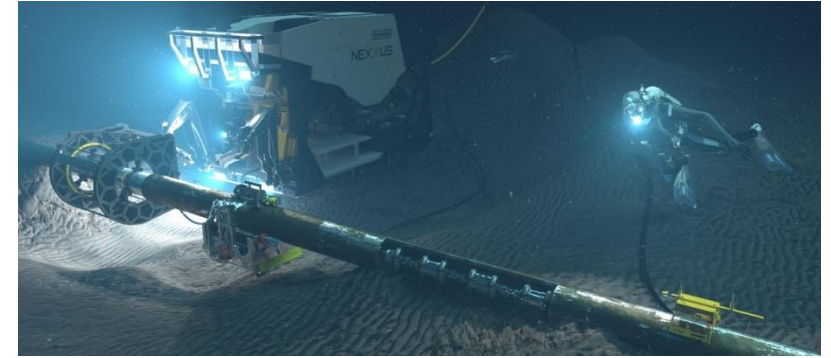


Partnership between UWTSD, TWI (Wales), Oceaneering
Inspection Services and Silverwing Ltd



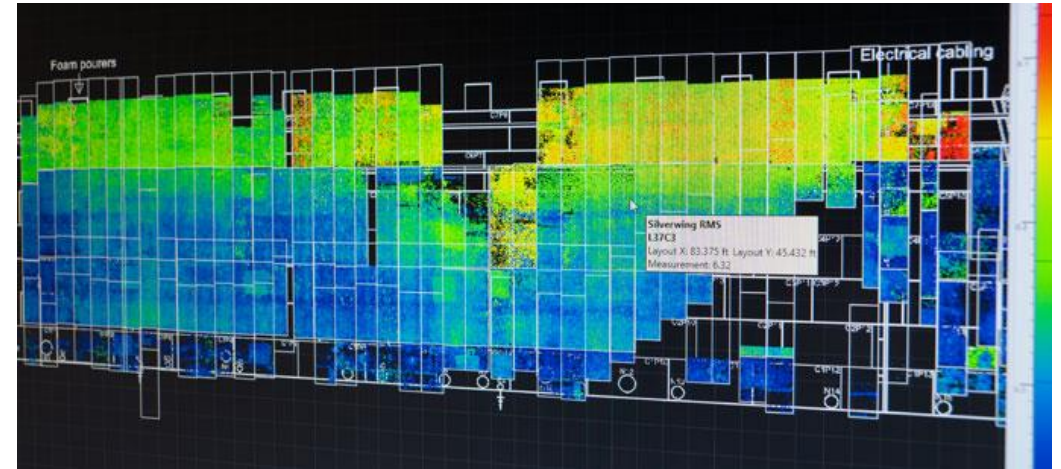
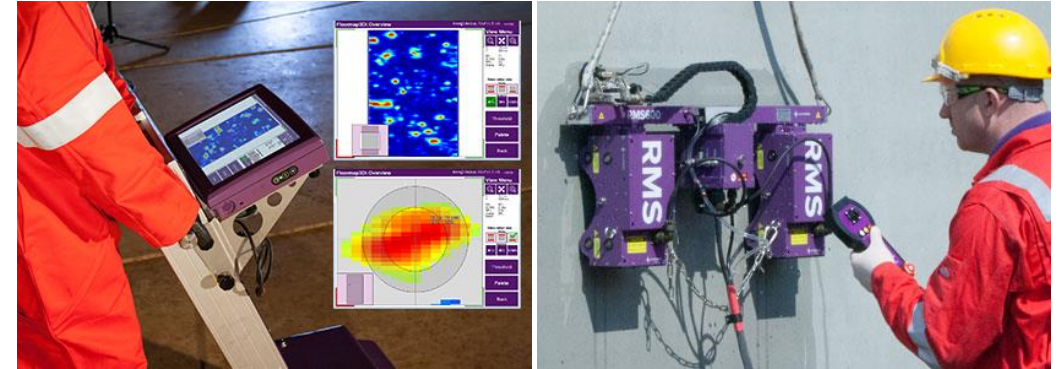
Oceaneering Specialist Inspection Services

- A global oilfield provider of engineered services and products primarily to the offshore oil and gas industry.
- Largest Offshore Inspection Company in the world
- Based in Swansea



Silverwing (UK) Ltd

- The leading manufacturer of NDT equipment for storage tanks, vessels and pipeline inspection within the oil, gas and petrochemical industries.
- Based in Swansea – Software, electronic, electrical and mechanical design and development all in house.
- 30 years' experience in the design, development, manufacture and sales of advanced, seamless NDT inspection equipment ranging from MFL tank floor scanners to advanced UT corrosion mapping system.



TWI Technology Centre - Wales

- One of the world's foremost independent research and technology organisations with expertise in materials joining and engineering processes as applied in industry.
- TWI Technology Centre (Wales) specialises in the development and application of state of the art non-destructive testing (NDT) methods.
- Through applied research and development in response to requests for assistance from member companies we provide real world solutions to inspection challenges across a broad range of industries.
- Undergoing further expansion - Advanced Engineering Materials Research Institute (AEMRI)



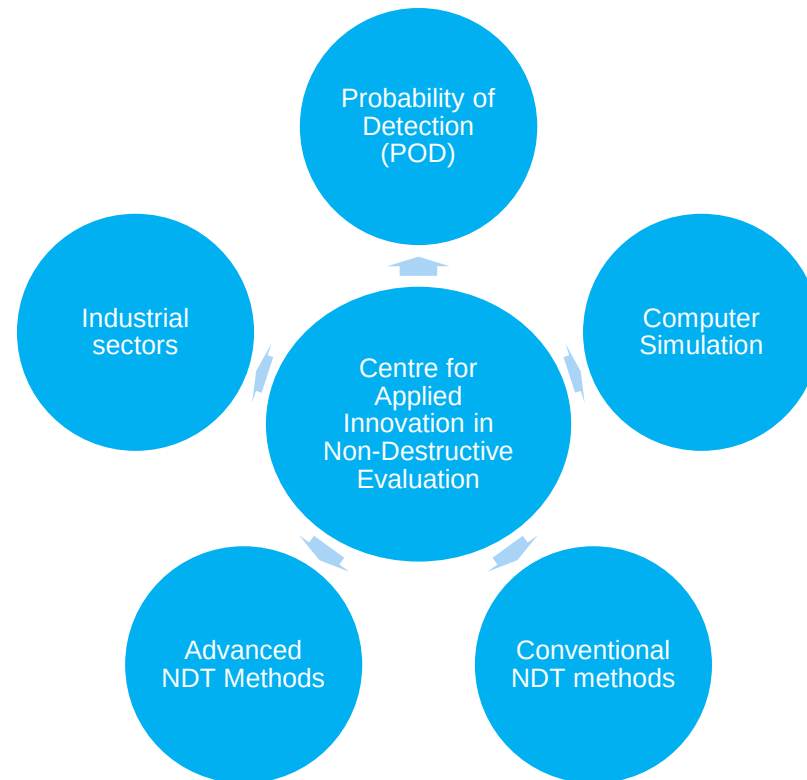
Centre for Applied Innovation in Non-Destructive Evaluation (CAINDE)

- A central academic research 'Centre' in Wales to provide a focus for industrially steered collaborative Non Destructive Testing and Evaluation research activities.
- Build on the continuing applied collaborative research activity that has been fostered between UWTSD and its industrial partners.
- The 'Centre' will also provide cross faculty and inter-disciplinary research opportunities where NDT applications are appropriate:
Engineering, Archaeology, Built Environment, Applied Computing and Industrial Design

CAINDE Focus

- Close to Market Research and Development;
- Student Work Experience and Internships;
- Generate income via funding, grants and commercial activity and research;
- Commercialisation of jointly developed ideas;
- New Academic Programme Proposals;
- Accreditation of staff development programmes;
- CPD training for industry incorporating innovative work-based learning approaches.

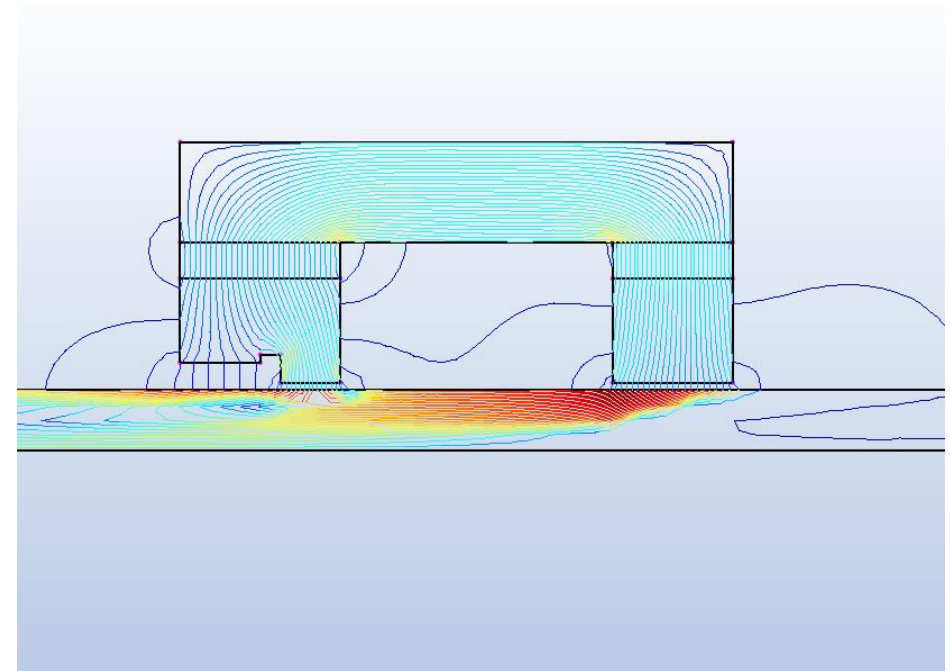
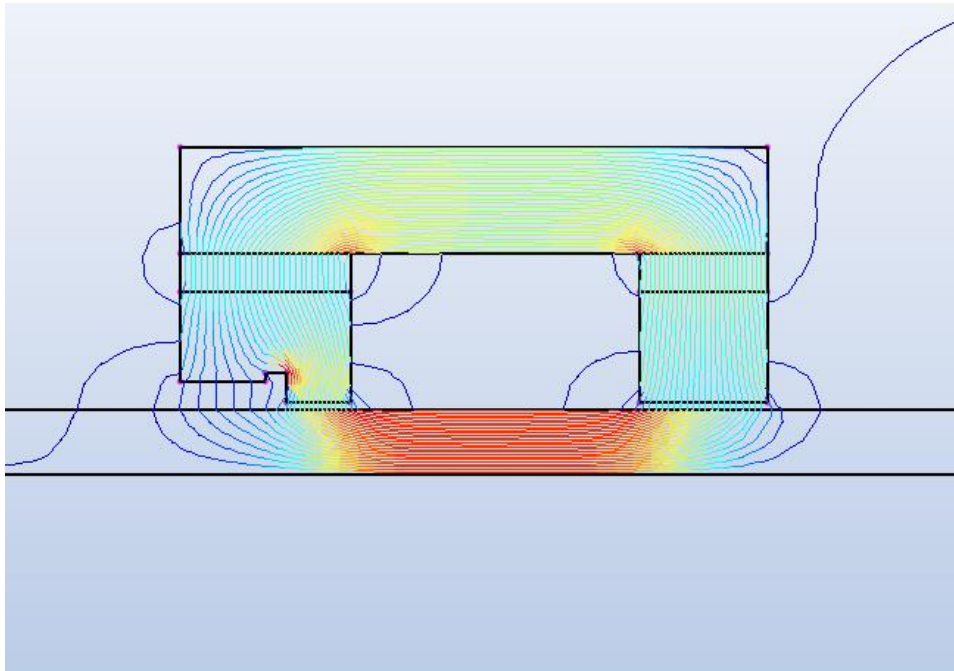
Centre for Applied Innovation in Non-Destructive Evaluation (CAINDE)



Current Postgraduate Research

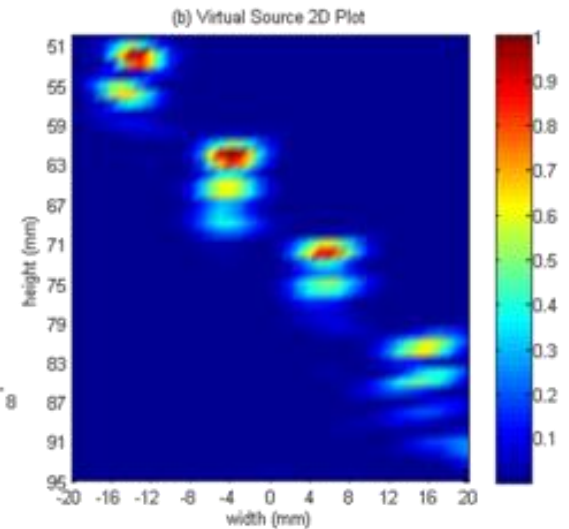
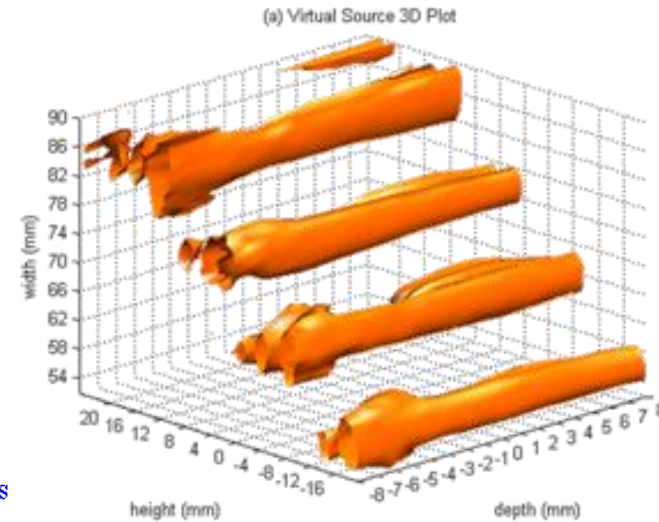
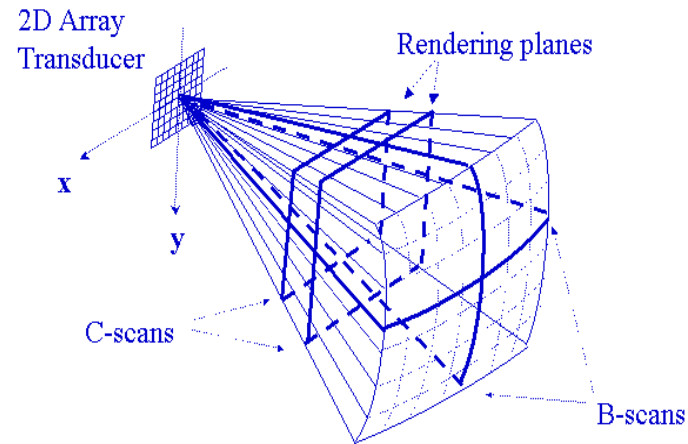
- KESS PhD Studentships
 - Ashley Pullen – Enhanced Magnetic Flux Leakage Analysis
Silverwing Ltd
 - Ewan Hoyle – Advanced Virtual Source Aperture Ultrasound Imaging for NDT
 - Owen Lloyd-Rees – Electromagnetic Acoustic Transducer Optimisation
TWI (Wales)
- Joint Industrial PhD Project (JIPP) Studentship
 - Liam Penaluna – Integration of Advanced Focused Phased Array Ultrasonic Inspection Techniques,
Oceaneering Inspection Services
- Industrial Funded Part-time PhD Studentship
 - Ralf Lieb – Real-time Solutions of the Inverse MFL Problem
Silverwing Ltd
- ASTUTE Research Project
 - Luca Pagano – NDT&E Complex Geometry Composite Impact Damage Assessment with Associated Coupled FEA
Structural Modelling, ASTUTE/UWTSD/TWI (Wales)

Ashley Pullen - Enhanced Magnetic Flux Leakage Analysis, Silverwing Ltd
Supervisors: P. Charlton, N. Whitehead



Ewan Hoyle - Advanced Virtual Source Aperture Ultrasound Imaging for NDT, TWI (Wales)

Supervisors: P. Charlton, J. Rees



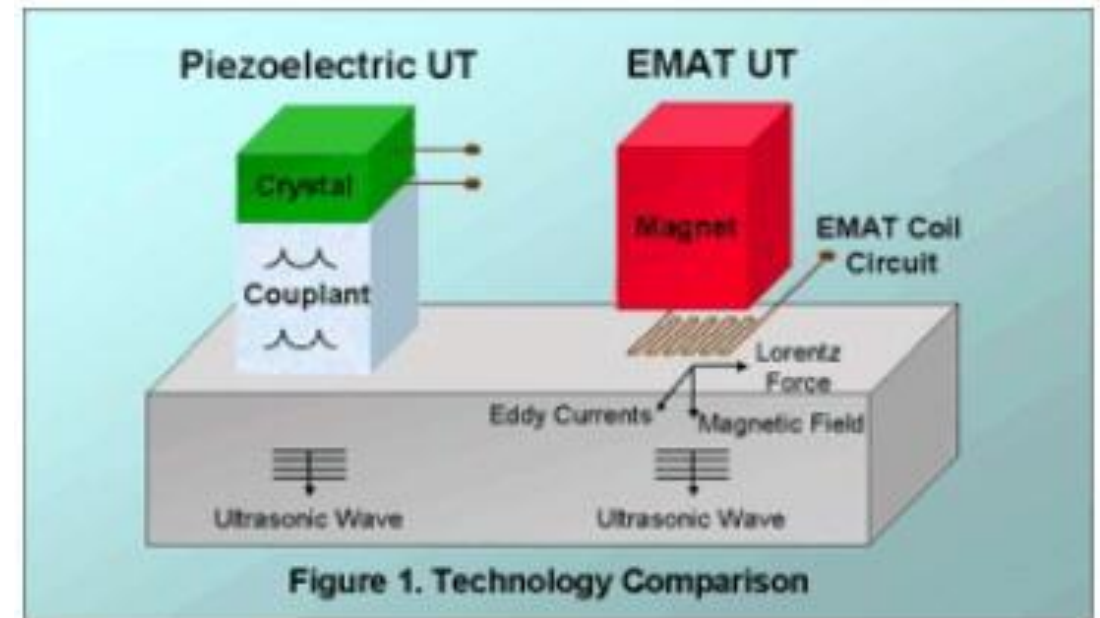
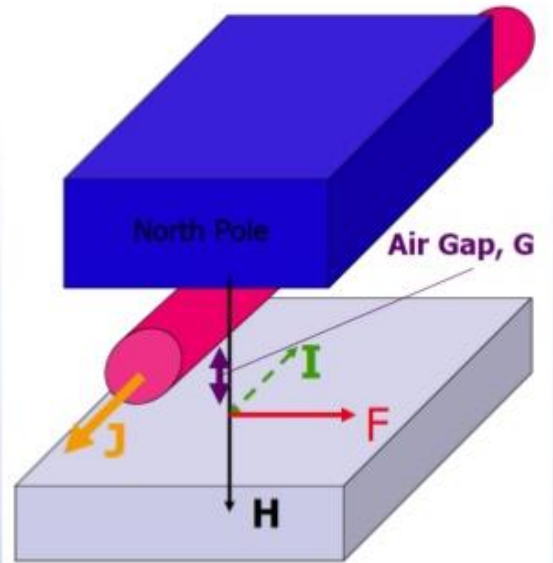
Owen Lloyd-Rees - Electromagnetic Acoustic Transducer Optimisation, TWI (Wales)

Supervisors: P. Charlton, S. Mosey

What is an EMAT?

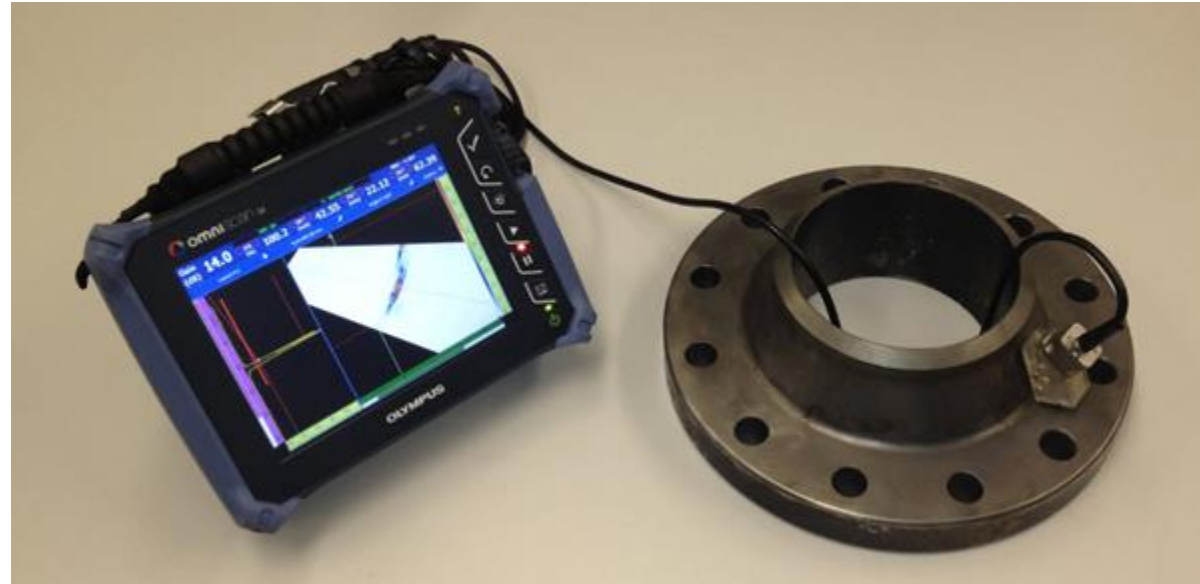
A magnet, a wire, an air gap and a metal surface.

- like an eddy current probe
- Transmission of a sound wave:
A current J in the wire induces an eddy current I in the metal surface across the air gap G .
The eddy current I + magnetic field cause a force F to launch a sound wave in the metal surface.
- Receiving a sound wave:
A sound wave moves the surface in the magnetic field to generate an eddy current that induces a current J in the wire



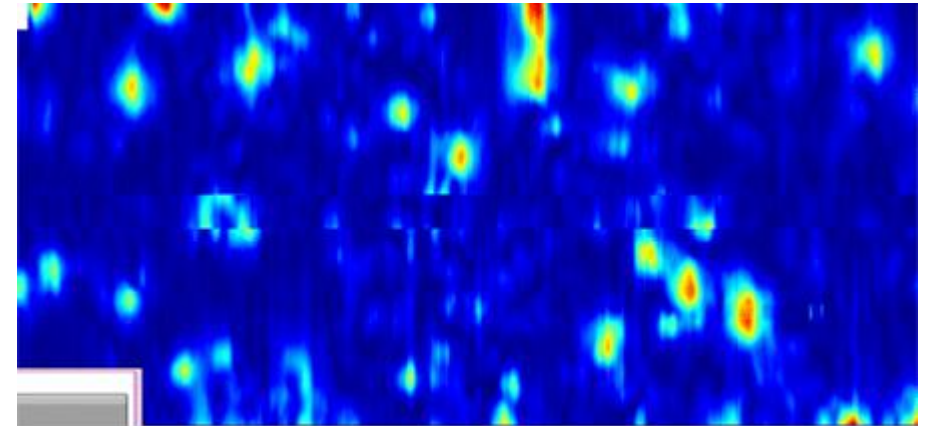
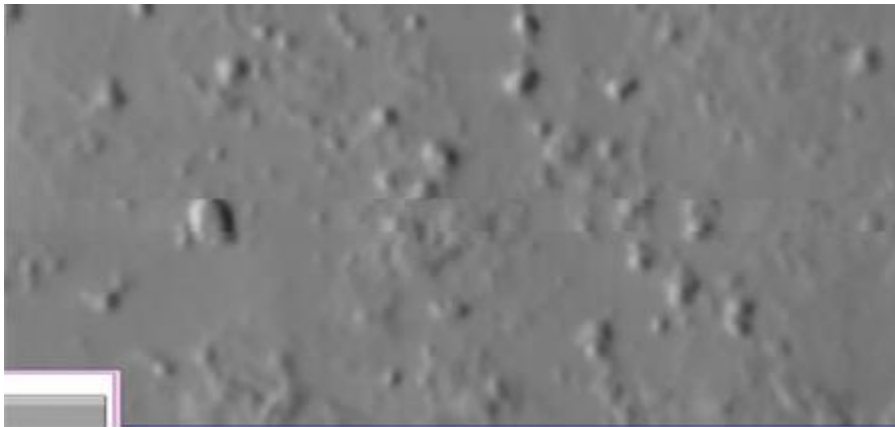
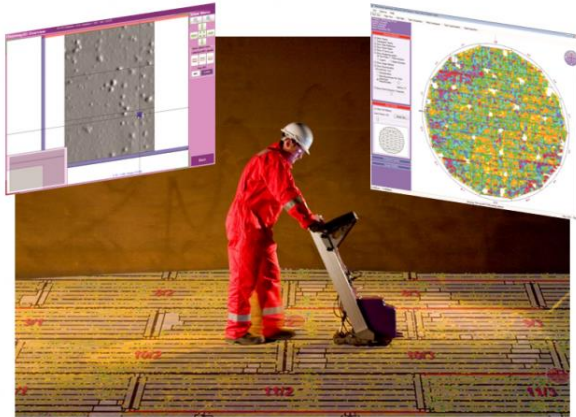
Liam Penaluna - Integration of Advanced Focused Phased Array Ultrasonic Inspection
Techniques, Oceaneering Inspection Services
Supervisors: P. Charlton, S. Mosey

See later.....



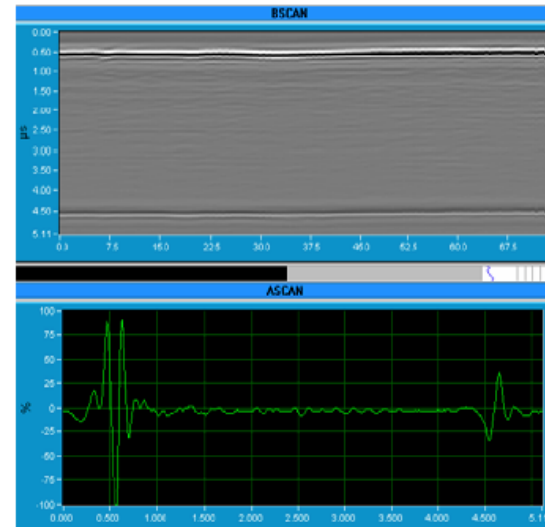
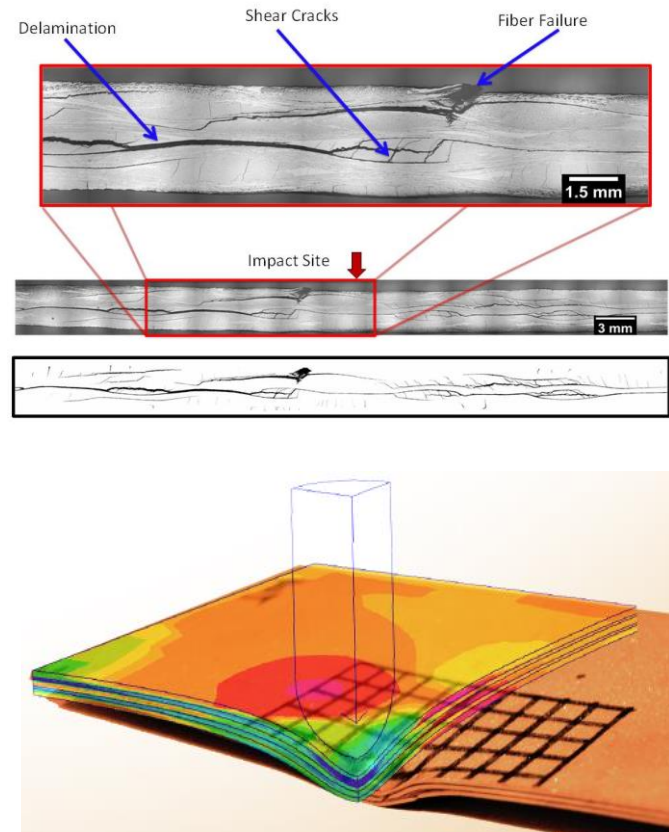
Ralf Lieb - Real-time Solutions of the Inverse MFL Problem, Silverwing Ltd

Supervisors: P. Charlton, G. Jones

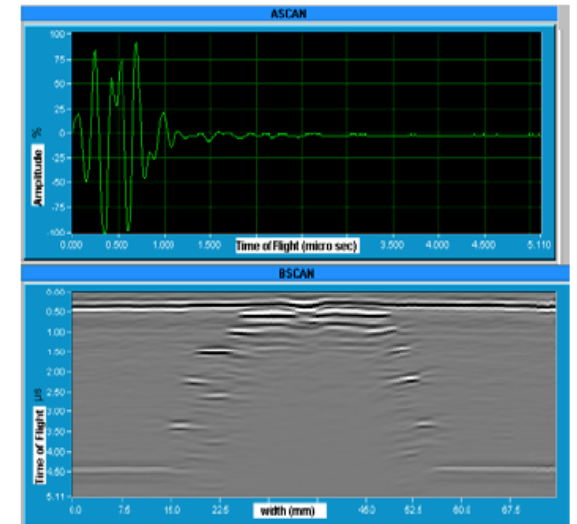


Luca Pagano - NDT&E Complex Geometry Composite Impact Damage Assessment with Associated Coupled FEA Structural Modelling, ASTUTE/UWTSD/TWI (Wales)

Supervisors: P. Charlton, K. Donne



(a)



(b)

Figure 1. A, B – Scans of (a) healthy and (b) impact damaged CFRP sample

Interdisciplinary Research

- Engineering
 - Physics
 - Computer Simulation
 - Digital Signal Processing
 - Data handling and visualization
 - Instrumentation and Control
 - Automation/Robotic Manipulators
- Built Environment
 - Thermography, Ultrasound, Acoustic Emission
- Archaeology
 - CT Radiography, Adaptation of technology for sub-sea inspection
- Industrial Design
 - Additive Layer Manufacture - Evaluation of Material and Structural Properties