

NDT&E Complex Geometry Composite Impact Damage Assessment with Associated Coupled FEA Structural Modelling.

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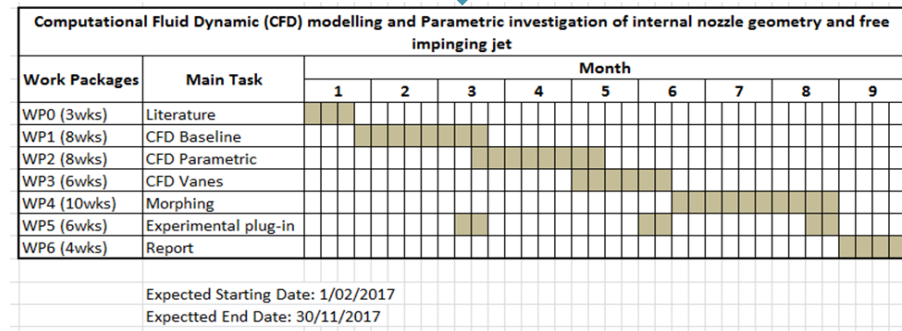
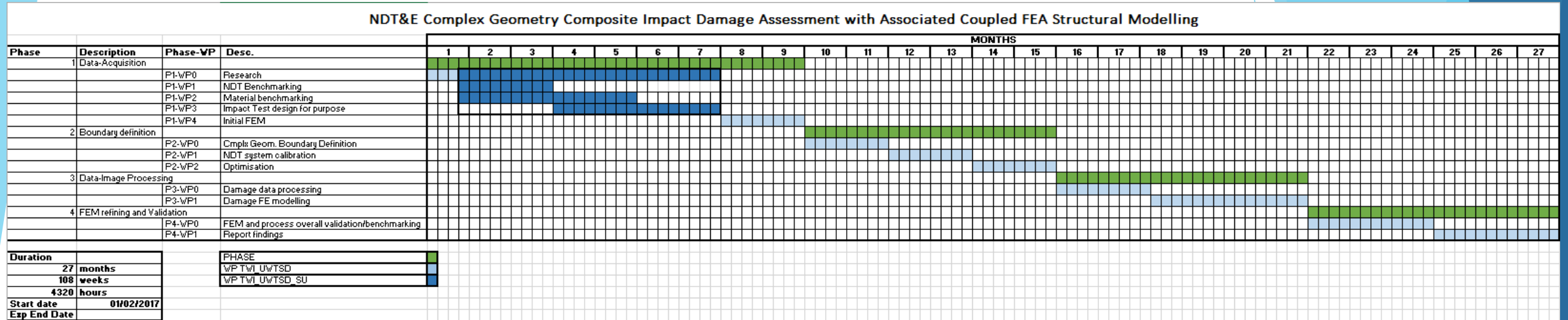
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- Finite Element Analysis (FEA) and Composite materials.
- Benchmarking, improving university's test capabilities.
- Real-life geometry-independent damage data acquisition/ processing and FEA Coupling for residual strength assessment.
- Possible impact of project outcome and TWI past developments.

Project aims/overview :

- Acquire in a reliable way induced impact damage data on composite complex geometries by means of advanced NDT&E (Non destructive testing and evaluation) technique development (e.g. advanced ultrasonic phased array methods, etc.), signal processing and optimisation.
- Consider damage inspection of complex laminae configuration and combined failures (matrix/fibre cracking and/or delamination).
- Data processing through Python and Matlab from NDT acquisition in order to implement real-life damage into ABAQUS Finite Element (FE) models.
- Define accurate coupling and integration between FE models and real damage NDT data sets.
- In-house validation of FE models of damaged and undamaged specimens.
- Determine the structural integrity to assess the viability of continued use of damaged structures.

Time plan:



Prifysgol Abertawe
Swansea University



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University of Wales
Trinity Saint David



Composite Materials:

Generally, **composite materials** can be defined as a **combination of two or more materials** that results in **better properties** than those of the individual materials alone [1].

Carbon fibre-reinforced polymers (CFRP)
Glass fibre-reinforced polymers (GFRP)
Aramid products (e.g. Kevlar)
Wood-plastic composites (WPCs)
...And many others....



This is a composite! ←

The main constituents of a composite are a **reinforcement** and a **matrix**.

The **reinforcement** is the fibres and is used to fortify the matrix in terms of strength and stiffness.

The **matrix**, normally a form of resin, keeps the reinforcement in the desired orientation. It protects the reinforcement from chemical and environmental attack, and it bonds the reinforcement so that applied loads can be effectively transferred.

1-Department of Defence Handbook, 'Composite Materials Handbook, Volume 3: Polymer matrix composites - Materials usage, design and analysis', MIL-HDBK-17-3F, Volume 3, 17 June 2002. Currently available as Composite Materials Handbook CMH 17.

Comparing composites to commonly used materials:

Why are composites so attractive?

Carbon-fibre reinforced composite can be:

5X stronger than 1020 grade steel
1/5th of the weight

7X stronger than Al 6061, and still
nearly half the weight.

The main advantages of composite materials are their high strength and stiffness, combined with low density, when compared with ordinary materials (Steel, aluminium etc.).

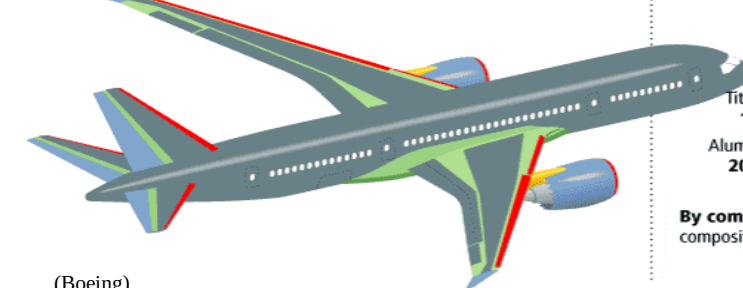
They allow
us to do
cool stuff!



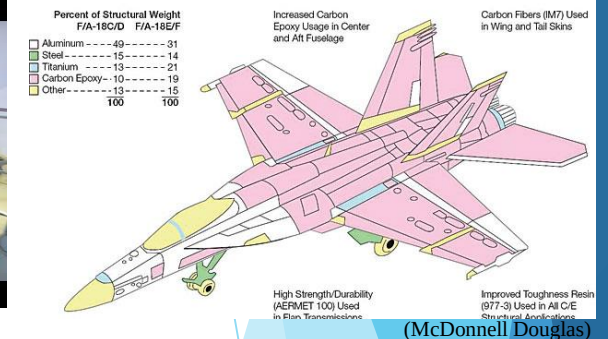
(Koenigsegg Automotive AB)

Materials used in 787 body

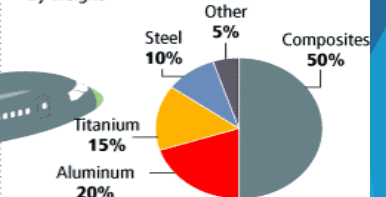
- Fiberglass
- Aluminum
- Carbon laminate composite
- Carbon sandwich composite
- Aluminum/steel/titanium



(Boeing)



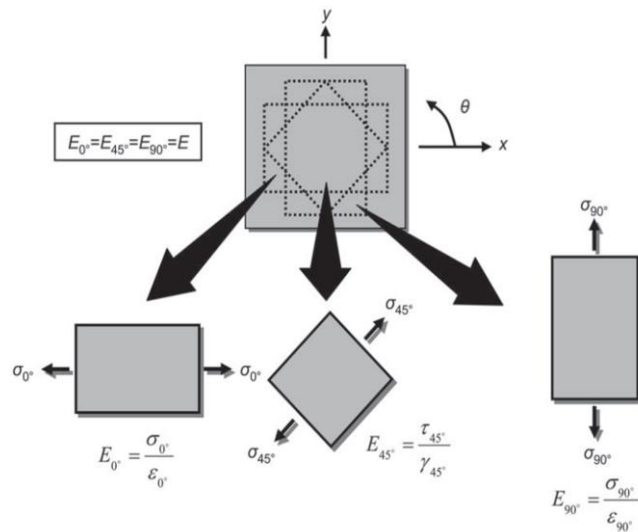
Total materials used By weight



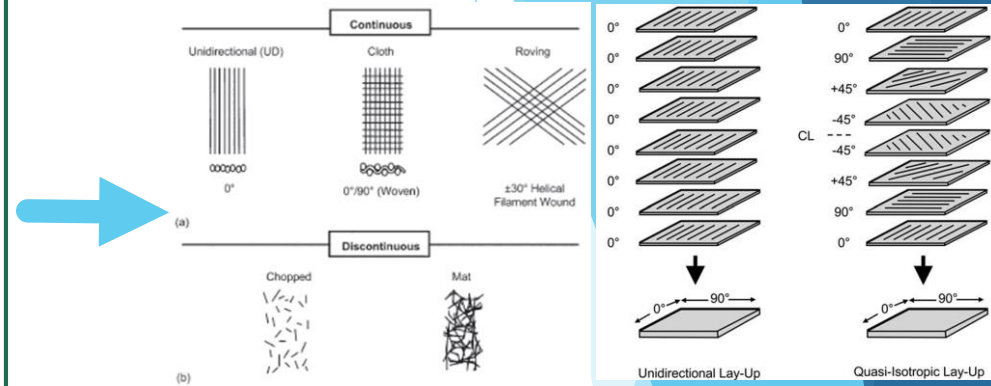
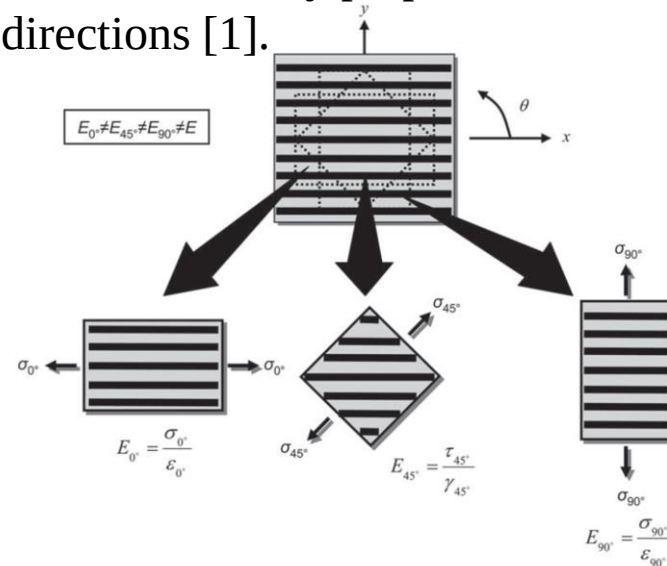
By comparison, the 777 uses 12 percent composites and 50 percent aluminum.

Comparing composites to commonly used materials:

Most of the materials such as Aluminium, Steel, Copper etc. can be defined as Isotropic.



Composites, in the majority of the cases are Anisotropic, and Orthotropic, which means that have properties that are different in three mutually perpendicular directions [1].

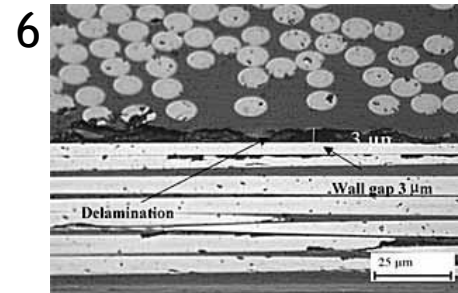
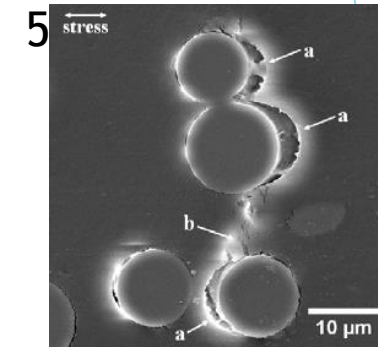
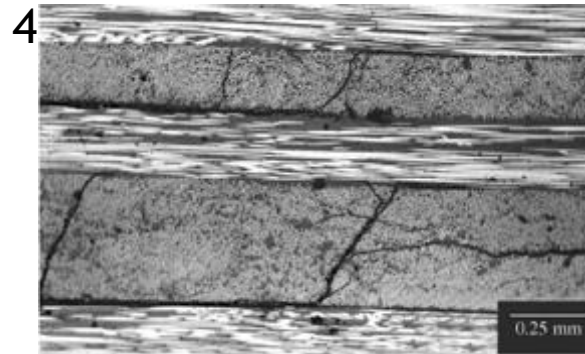
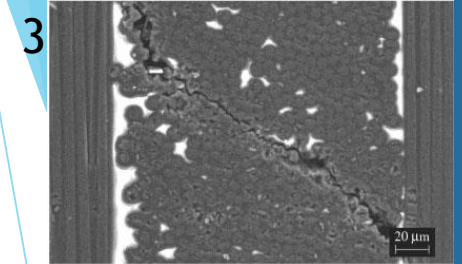
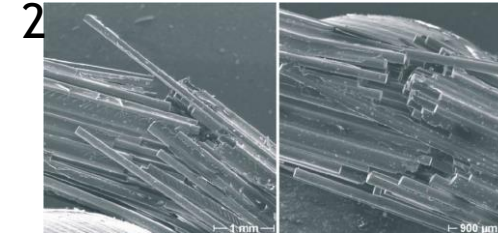
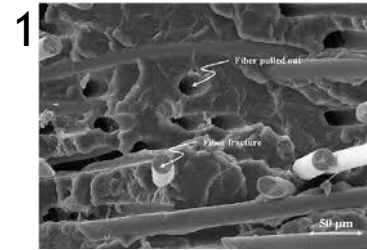


Engineers can potentially tune composite parts to withstand loads in specified directions just by varying the number of plies and their orientation layup!

1-Department of Defense Handbook, 'Composite Materials Handbook, Volume 3: Polymer matrix composites - Materials usage, design and analysis', MIL-HDBK-17-3F, Volume 3, 17 June 2002. Currently available as Composite Materials Handbook CMH 17.

Failure modes overview:

- Fibre breakage.
- Fibre pull-out.
- Matrix crazing.
- Matrix cracking.
- Fibre de-bonding.
- Delamination...Only this occurs in 3 different modes!
- Many others...[2]



It can be understood how modelling these materials accurately is still a big challenge. As precise as the manufacturing process can be there will always be a degree of discontinuity.

2-Hosseinzadeh R., Shokrieh M.M., Lessard L., Damage Behaviour of Fiber Reinforced Composites Reinforced Plates Subjected to Drop Weight Impacts, Composites Science and Technology, 2006, 66, p. 61-68.

Impact damage (This study)

What happens if a composite laminate is impacted?
A wing, for example, is a laminate structure...All the damage modes listed in the previous slide are likely to appear if impacted!

(Please do not consider being shot down by a minigun, you'd have other things to worry about then!)

Impacts in Aerospace?

Bird strike.

Hail.

Foreign object damage (FOD).

Dropped tools and other maintenance incidents.

Ground support equipment (GSE).

Assembly line.

...similar for Automotive, Marine and Energy industries!



(Airbus)



(Boeing)

Impact damage (This study)

The main issue is represented by impact damage classified as **BVID** (Barely Visible Impact Damage) [3].

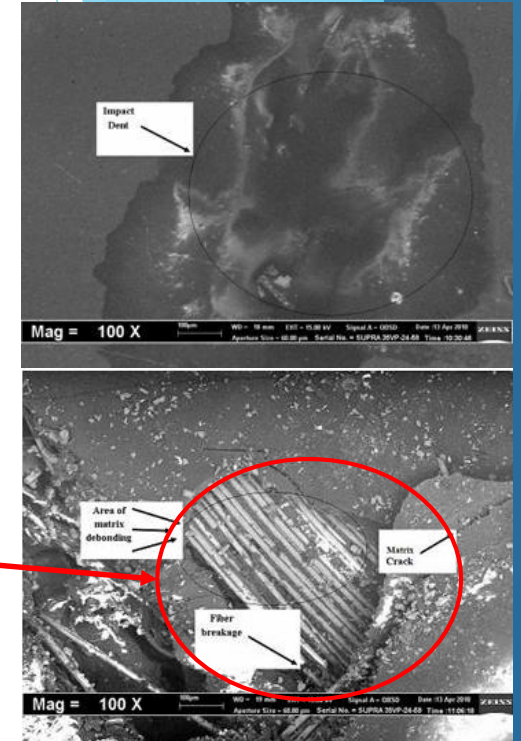
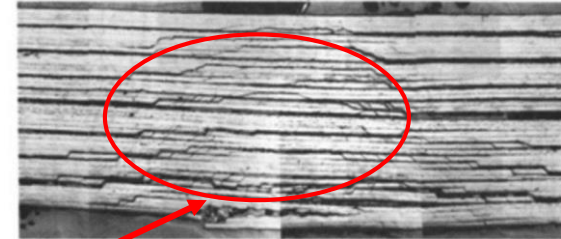
Unlikely to be detected with naked eye inspection.
Can appear with any low velocity/energy impact.

Again, if shot (Hi velocity/energy) the engineers and/or maintenance team will have an easy life when inspecting the structure. The **damage is clearly visible and can be assessed.**
...Hopefully!

What we see?

What really is there? Beneath the surface.

Barely nothing on the impacted surface



Repair/substitute!
But how do we deal with BVID?

?

The study then needs to answer 2 main questions.

- How can we detect the damage if we can't see it?
- Once the damage is detected, how can we quantify the remaining strength of the structure in a reliable and cheap way?

(British Airways would not be happy to have a plane grounded for a few weeks as every component gets physically tested)

Which then leads to:

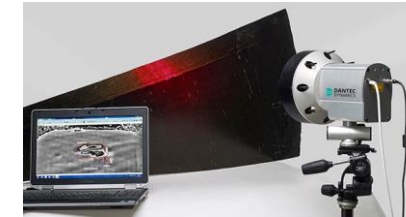
How can these answers be integrated in one single system/process?

How can we detect the damage if we can't see it? Applying Non Destructive Testing and Evaluation (NDT&E) to composites.

Multiple NDT Methods like Ultrasound, X-ray, Thermal Imaging, Laser Based and Optical Surface Inspection are used in today's industry for; component inspection
Material properties characterisation and recently, composite structural health monitoring/damage assessment.

Ideally we want a 'portable system' that can be utilised with a 1-side-only access. Thus, radiographic techniques may not be ideal. It can be seen that **image/data processing** needs to be carried out extensively to achieve accurate results.

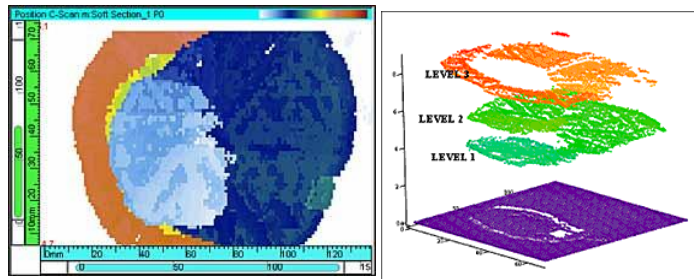
In this study various NDT&E Techniques will be assessed in order to quantify and benchmark their capabilities.



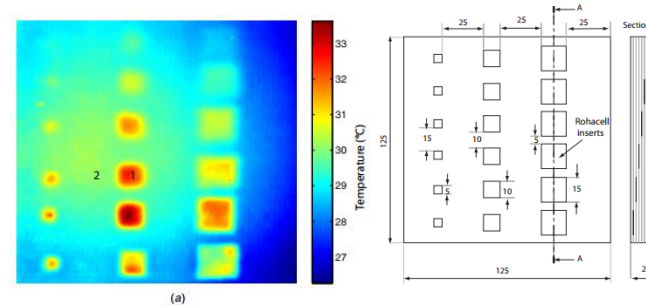
Shearography



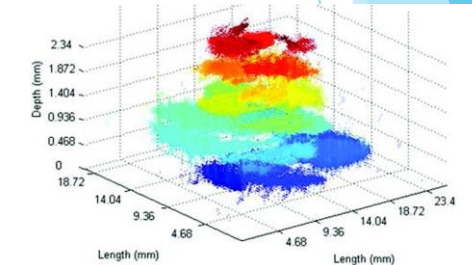
Active thermography



Processed C-scan data (Ultrasonic) of impact damage. [4]



Pulsed thermography of artificial delamination for calibration purposes and material properties definition.

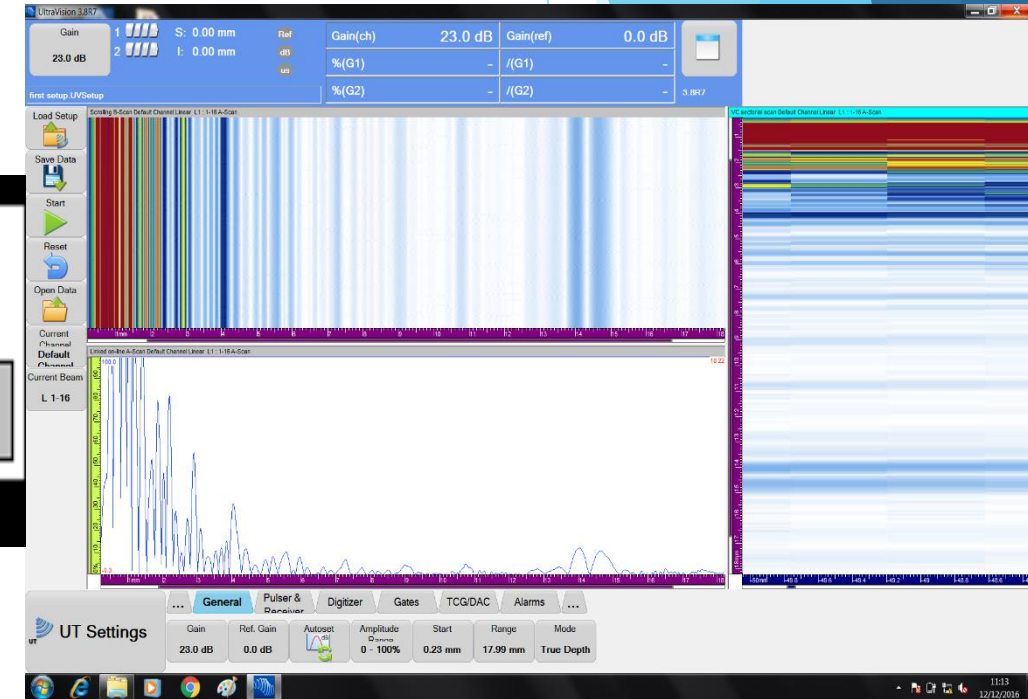
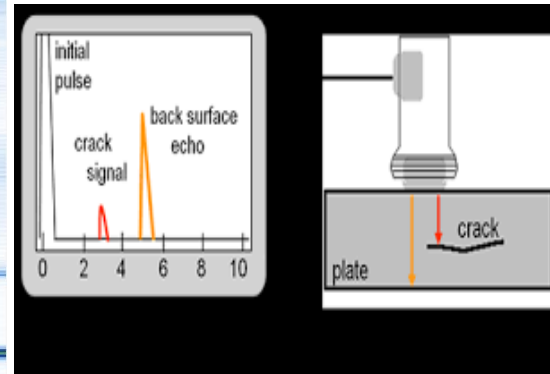
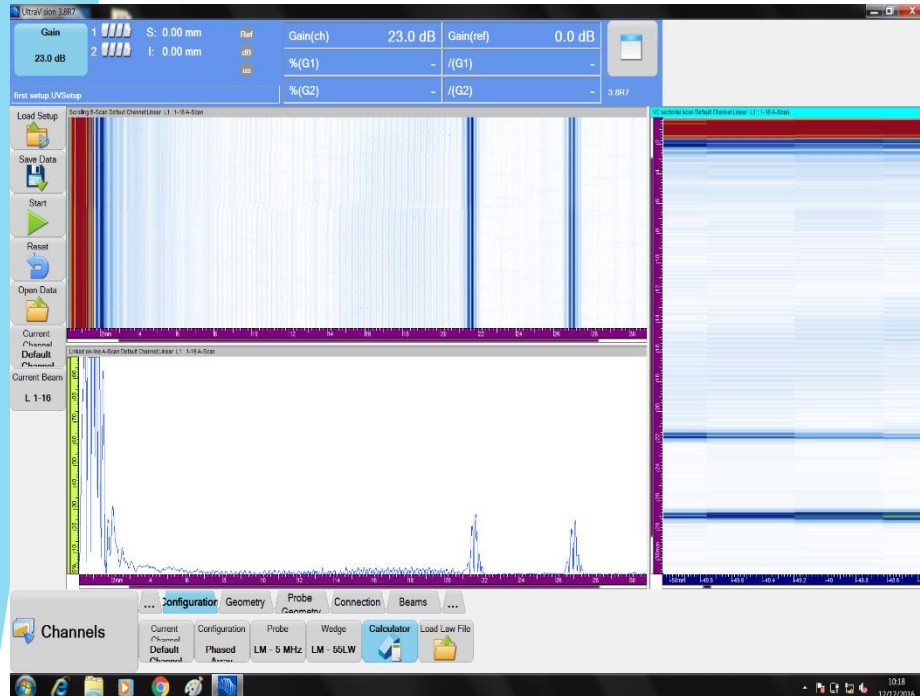


Microfocus X-ray computed tomography scans showing delamination after impact through a quasi-isotropic CRFP plate [5]

4-Channa Nageswaran, Colin R Bird and Reiko Takahashi, Phased array scanning of artificial and impact damage in carbon fibre reinforced plastic (CFRP), TWI, Paper presented at the BINDT conference in September 2005
5-National Aeronautics and Space Administration, Method of Non-Destructive Evaluation of Composites, Using trapped energy analysis to characterize hidden damage, NP-2014-11-1284-HQ

Applying Non Destructive Testing and Evaluation (NDT&E) to composites.

Why image and data processing are needed? Both images are showing a UT inspection, same defect type...

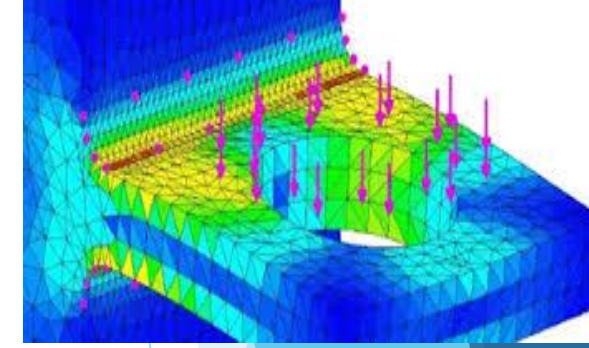
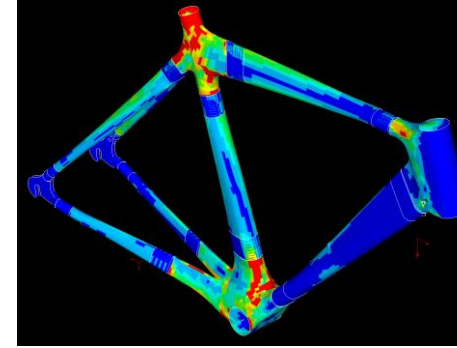


CFRP or Steel?

Once the damage is detected, how can we quantify the remaining strength of the structure in a reliable and cheap way?

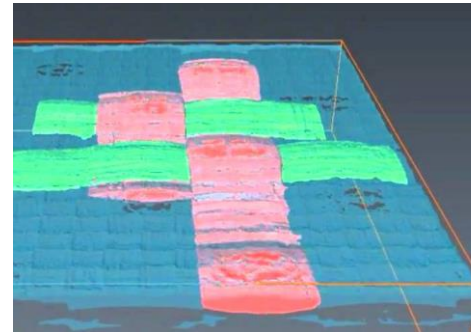
Finite Element Analysis (FEA) and Composite materials

The description of the laws of physics for space- and time-dependent problems are usually expressed in terms of *partial differential equations* (PDEs). For the vast majority of geometries and problems, these PDEs cannot be solved with analytical methods. Instead, an approximation of the equations can be constructed, typically based upon different types of *discretization*. These discretization methods approximate the PDEs with *numerical model equations*, which can be solved using numerical methods. The solution to the numerical model equations are, in turn, an approximation of the real solution to the PDEs. The *finite element method* (FEM), more commonly known as Finite Element Analysis (FEA) is used to compute such approximations.[6]

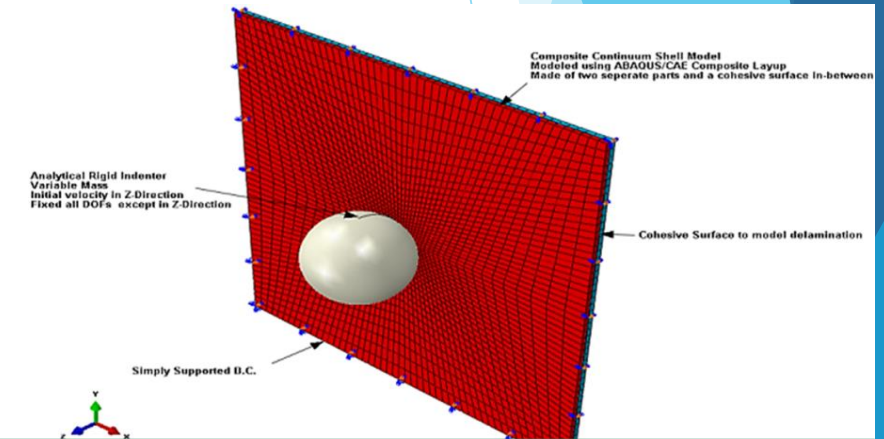


Issues with composites:

Multiple failure modes occurring at same time. A suitable damage model needs to be tested and implemented. Ply interaction; how do different laminae carry and transfer in-plane and through thickness loads. Which elements do we use?



Consider matrix and fibre properties separately?



How can a model be defined as reliable?

6-COMSOL Simulation software, COMSOL News Magazine, Multiphysics Simulation Magazine, 2016 by COMSOL Inc.

Benchmarking.

Data collection and physical tests need to be designed and carried out in order to define related FEA simulations as reliable.

Design tests.

Material properties and Impact testing equipment, designed considering complex geometries by means of laminate and component geometry.

Data collection

Define material mechanical and bulk properties.

Carry out physical tests.

Utilise different NDT&E methods to assess damage.

Optimise NDT&E.

Multiple NDT&E methods can be used simultaneously for validation purposes.

Data validation

Simulate (FEA)

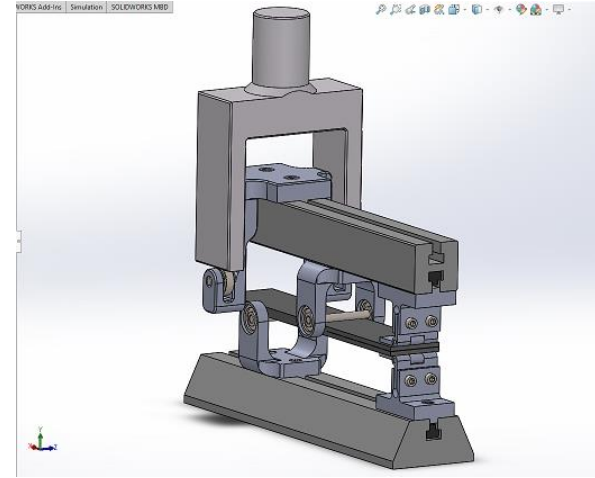
Optimise FEA, test different modelling approaches.

Have a Reliable material and damage FE model.

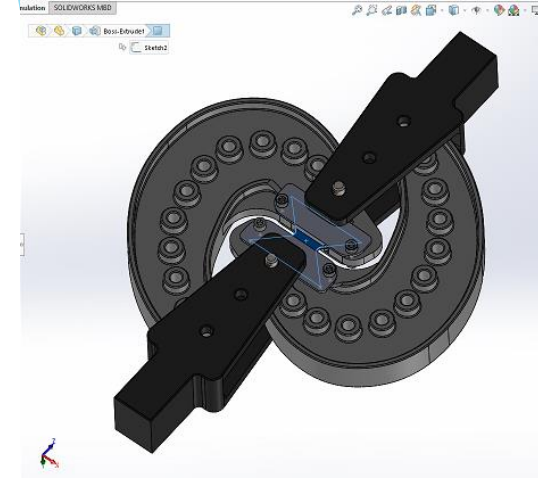
Improving Universities Composite testing capabilities.

Composite testing equipment will be designed and manufactured according to ASTM/ISO standards.

Other equipment, author's designs:

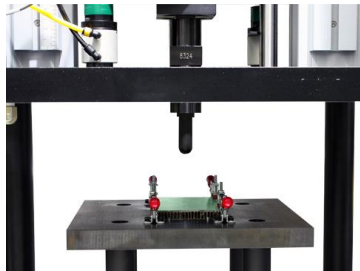


Modified Mixed Mode Bending test



Modified Arcan Fixture

Impact test machine and CAI (Compression after impact) rig. The first one is used to **induce damage**, the second one is to **evaluate residual strength of the laminate**.

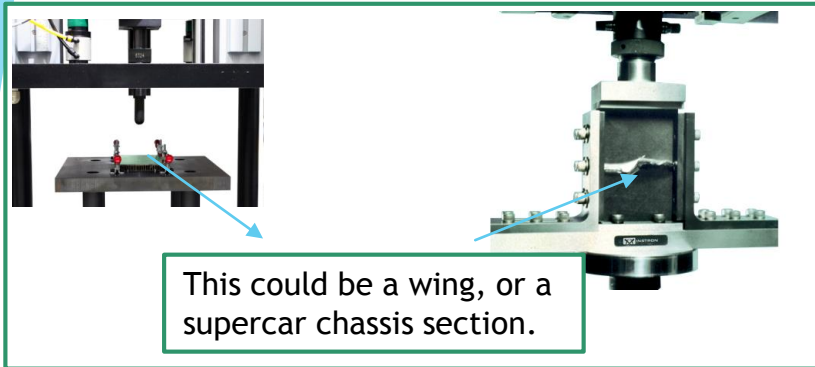


These will need to be adapted then to allocate specimens with non conventional geometries.

Finally:

Real-life geometry-independent damage data acquisition/ processing and FEA Coupling for residual strength assessment.

Let's go back a second... Classic Residual Strength testing.



This is really expensive!

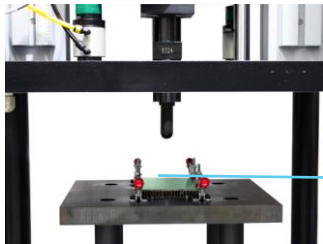
<https://youtu.be/rak2HldVp9M>

This is really cheap!

Ideally the whole process would be automated

The component can be assessed without being disassembled, and broken!

So what if...



Damaged part... Still an expensive component

Data acquisition:

- NDT&E
- Optimised method capable of exporting accurately the damage and its location regarding the whole structure.
- laminate configuration
- Some systems allow to input CAD geometries.

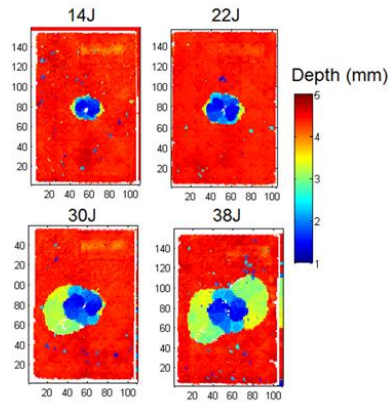
Utilise MATLAB/Phyton to process the data (Damage C-scans etc.), relating the damage to geometrical boundaries and coding it in order to output a Finite element MESH of the damage Compatible with the Previously validated FEA Simulation which will be compiled in ABAQUS.

FE model running with the real-damage included.

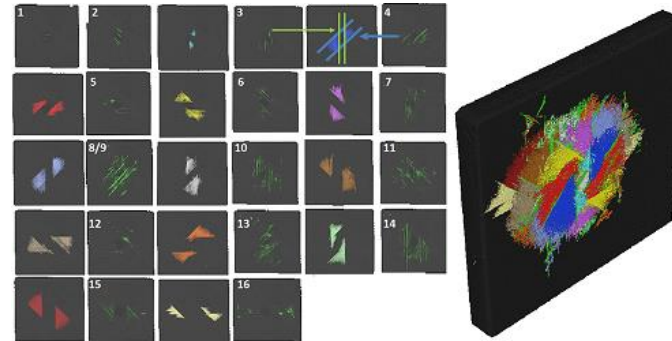
It is important that the simulation has been validated previously!

Possible impact of project outcome and TWI past developments.

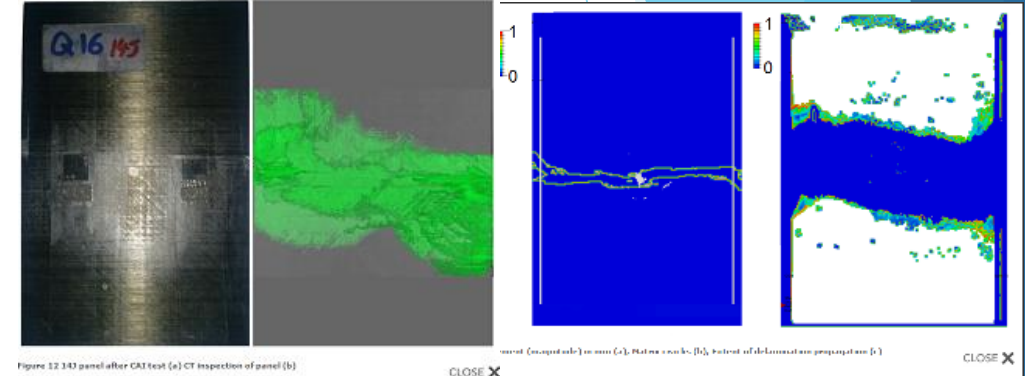
UT C-scan data of impact damage



Meshing single ply real damage.
Forming the FE laminate.



Physical test and FEA
Comparison



Limitations of initial TWI research, which this study will try to overcome:

- Single laminas are UD (geometrically uni-directional). Damage modes are easily recognisable.
- Laminate plate is Quasi-isotropic.
- Laminate is a simple flat plate, this process has never been implemented for complex geometries.

Possible outcome of project:

- Decrease 'dead time' for inspection in industries utilising composites components.
- Simplified and effective structural assessment.
- Reduce assumptions on how a damaged part would perform.
- Give a guideline to define effectively critical damage sizing.

Thank you for listening!



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