Eddy Current and Quantum Well Effect Eddy Current Field Measurement of Carbon Fibre Raw Materials and cured parts in the Aerospace Industry

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Abstract. The composite industry requires a fast and couplant free NDT methodology. The C-Flux project spearheaded by M Wright & Sons Ltd (MWS) and TWI Wales, is tackling these requirements with the development of Eddy Current NDT system developed by ETher NDE and quantum well effect eddy current field measurement (QW-ECFM) NDT system developed by AHS. FAR UK and MWS are supplying to the project standard and flawed carbon fibre composite parts up 20mm thick to refine these electromagnetic techniques. TWI is developing automated apparatuses to deploy these NDT systems for the aerospace industry.

1. Introduction

The excellent strength-to-weight ratio of modern composite materials mean they are playing an increasing role in future aircraft construction, but they perform very differently to the metals traditionally used in the industry. Carbon fibre composites are anisotropic, with laminar construction and can fail suddenly without visible deterioration. Manufacturing defects, such as damaged or misaligned fibres, voids and delamination, can lead to reduced material performance. Integrating non-destructive evaluation (NDE) techniques into manufacturing processes provides important surety that each component meets required mechanical properties. However, meeting NDE requirements currently takes up approximately 10% of manufacturing time [4], so significant efficiency savings could be made if NDE testing could be accelerated.

Existing NDE techniques are costly and complex, ultrasonic inspection techniques require a couplant which adds moisture to the manufacturing environment [2], X-ray and laser testing are hazardous and expensive for a shop floor applications. Other techniques such as acoustic emission require the application of multiple sensors across the structure and thermal imaging has problems accessing confined spaces. Both acoustic emission and thermal imaging require the part to be lightly loaded

2. Current NDT Technology

Manual ultrasonic testing is the most commonly used technique, with top speeds of around 1m^2/h. Attempts have been made to introduce automation but it has proved difficult due to the sensitivity of the process, requiring fluid couplant and highly-skilled operators. iPhoton and Tecnatom have collaborated on an air-coupled ultrasonic system but with limited take-up. At a cost of well over £2.5 million and speeds of only 6m^2/h, even Boeing have been unable to find a cost benefit in these systems [3].

Phased array ultrasonic systems perform well and are suitable for deployment on robotic arms, but still require a couplant.

Techniques developed in the C-Flux project have the potential to work at 30m^2/h, 30 times faster than manual ultrasonic NDE, and eight times faster than an ultrasonic gantry system. Eddy currents in particular do not need to be in contact with the sample surface, they are safe to operate, sensitive and can detect variation in fibre volume fraction and flaws in the weave architecture. However the signal to noise variation, vibrations, constant stand-off, and equipment integration are areas that need developing to make eddy current a viable NDT technique. Quantum Well Effect Eddy Current Field Measurement (QW-ECFM) is predicted to scan 6m^2/hr at 0.5mm resolution but the sensors are robust and can be used in adverse operational conditions and small enough to reach most areas. Eddy current and (QW-ECFM) uses magnetic induced events to check for flaws with in the sample inner structure. Eddy currents cannot identify flaws which are parallel to the probe [1].

2.1. NDT for 3D wovens

MWS are experts in 3D woven carbon fibre fabrics for aerospace and will be providing all of the fabric materials for the project,

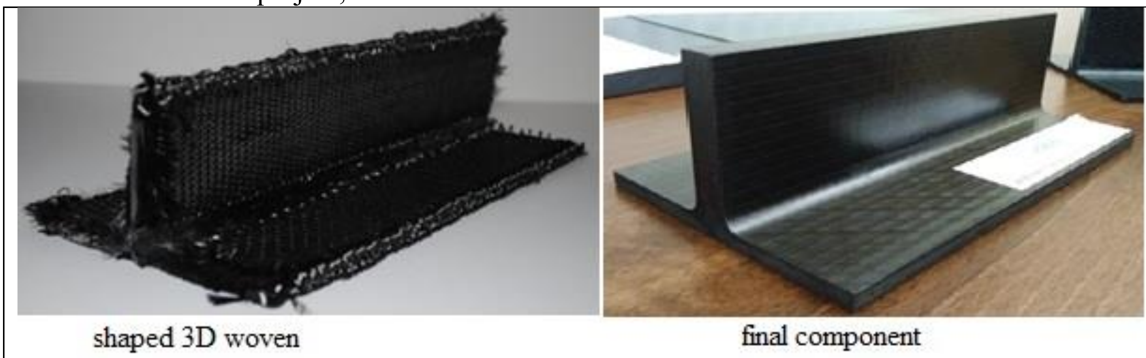

Figure 1 typical 3D woven shaped fabric/composite

3D wovens composites are thick and complex structures where flaws are difficult to scan via Ultrasonic NDT systems[6].

Ultrasonic NDT are suitable for thin composites and sandwich structures but is less suited to thick 3D woven composites. Another NDT technique available is radiographic testing (X-rays) which are known to be suitable in scanning thick complex structures like 3D wovens composites [6]. However X-rays work well with 3D wovens composites but they are hazardous to use on the shop floor and therefore expensive. In cases where no other solution is available, as is the case of 3D wovens composite structures, the overall cost is a factor in considering the selection of material. The development of other NDT methodologies is therefore required.

2.2. NDT Electromagnetic devices for carbon fibre composites (CRFP)

The development of eddy currents and QW-ECFM in the C-Flux project means that now they are capable of analysing carbon fibre composites. These methods use the conductivity of the carbon fibre tows in a carbon fibre composite to create an electromagnetic field. The measurement of the variations of eddy current allows the NDT scanning of 3D woven composite.

Figure 2 ETher NDE eddy current scanning equipment

Figure 2 shows the scanning device with attached eddy current probe designed by ETher NDE scanning carbon fibre fabric in through transmission mode.

While the scanning device from AHS , operating in reflection mode, has a unique technology using Quantum Well Hall Effect sensors leading to a highly sensitive NDE method for 3D woven fabric inspection,

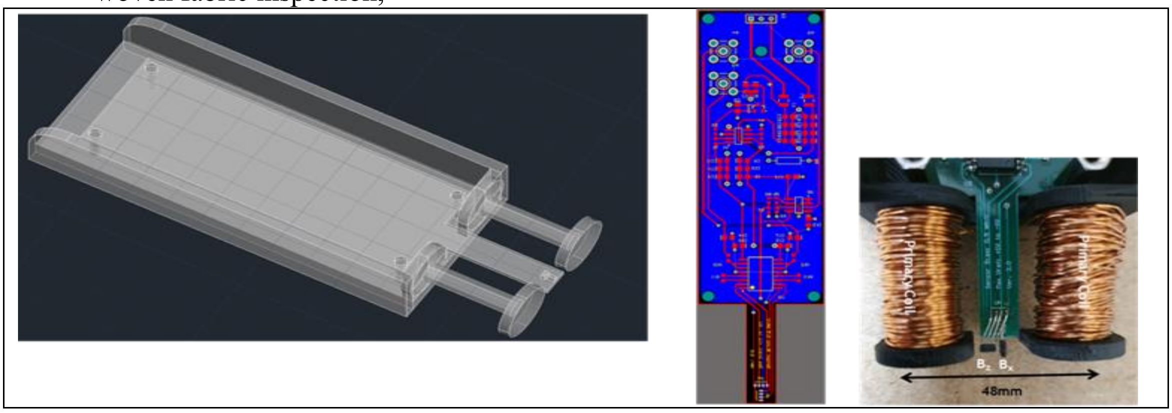

Figure 3 AHS Quantum Well Hall Effect Eddy Current Field Measurement (QW-ECFM) scanning head

Figure 3 shows the scanning probe designed by AHS for carbon fibre fabrics.

3. Sample scan results from both X-Ray and Eddy current techniques

MWS are the lead partner in CFLUX project, they design and manufacture a flat 3D woven fabric preform for preliminary scan tests. The composite manufacturing facilities at MWS allowed them to infuse 4 sections of 3D woven flat fabric. Before and during the infusion flaws were introduced in 3 of 4 sections.

Using the facilities available at TWI Wales it was possible to analyse the 4 sections of the flat 3D woven carbon composite samples made at MWS. A comparison between X-ray and eddy current is shown in fig 4.

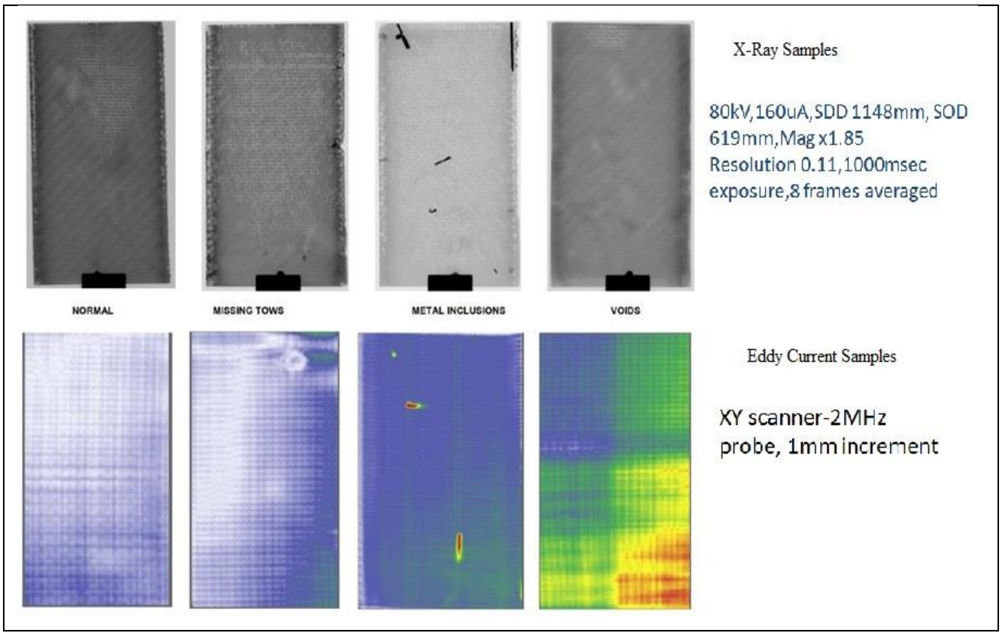

Figure 4 X-Ray and Eddy current scans of 4 flawed 3D woven samples

The initial samples from MWS were subjected to X-ray analysis in order to verify the artificial flaws which had been created in each part. In figure 4 we can see the initial samples with missing tows, metal inclusions and voids as flaws. It should be noted that some variation in volume fraction (ratio of carbon fibres to resin), exists in all manufactured carbon fibre parts, this is a result of the varying tension on the tows during manufacture and infusion. In some instances this variability is important to quality control. Inspection by automated conventional eddy current techniques was also carried out, the weave is visible, as were the scissor stab and metal inclusions, however voids were not detected. There was good correlation between the X-ray and eddy current results.

A comparison between the, eddy current and QW-ECFM was also completed and is shown in figure 5.

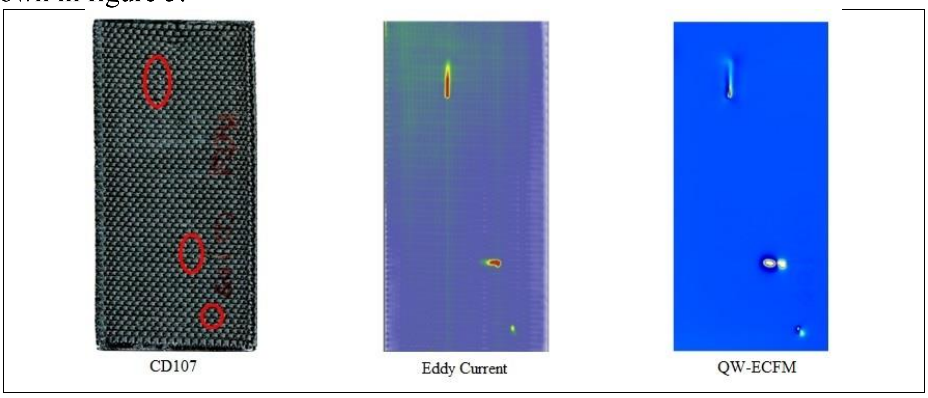

Figure 5 A 3D woven sample analysed by both eddy current and QW-ECFM

From the left, an optical photograph of the composite, CD107 refers to the MWS internal name for that particular fabric. In the middle and to the right are the scans with eddy current and QW-ECFM showing the metal flaws included in the composites. Both techniques work well in detecting metal flaws.

MWS created 4mm and 15mm reference sample panels from woven carbon fibre material. In figure 6 it is possible to see these reference samples with defects, TWI designed and machined the flaws in the reference samples. The size, distancing and depth of cut of the flaws, machined using a flat nose cutter, simulate carbon fibre composite delaminations in the parts. The 4mm and 15mm panels had 6mm and 3mm square pockets machined into them at differing spacing, sizes and depths. The pocket patterns design was the results of numerous years of research accumulated by TWI in studying and understanding materials failure modes. This understanding was aided by their expertise in material destructive and non-destructive testing. These reference samples will enable evaluation of the new eddy current and QW-ECFM technology in relation to resolution of the size and depth of flaw detectable.

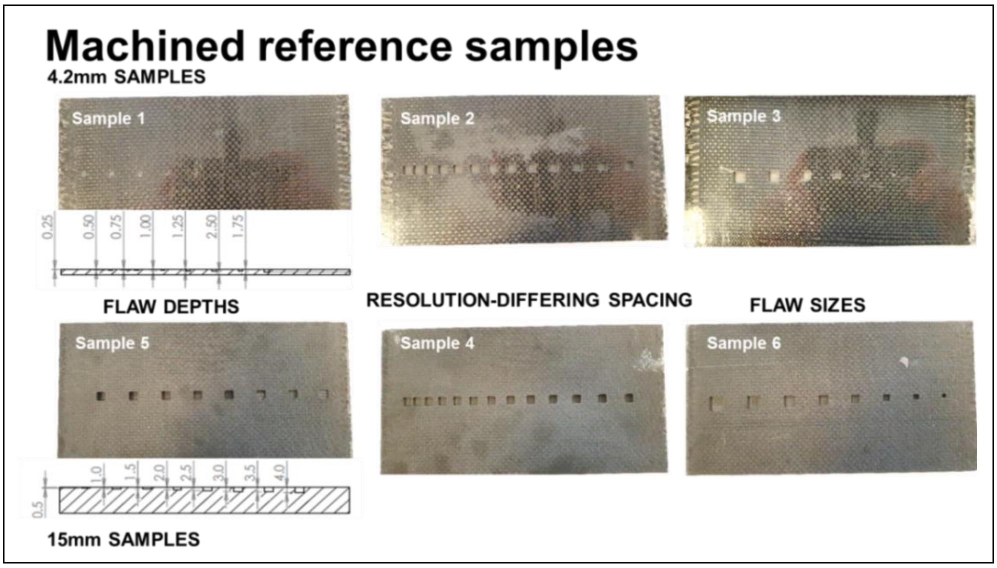

Figure 6 The reference samples made for this project

4. Sample scan results from eddy current and QW-ECFM

Preliminary results of the various types and frequencies used for eddy current inspection are promising, the weave of the carbon fibre material is clearly visible, has are some of the machined flaws. There are some issues with the undulations in the part surface, which is varying the standoff of the probe, this is shown as white areas.

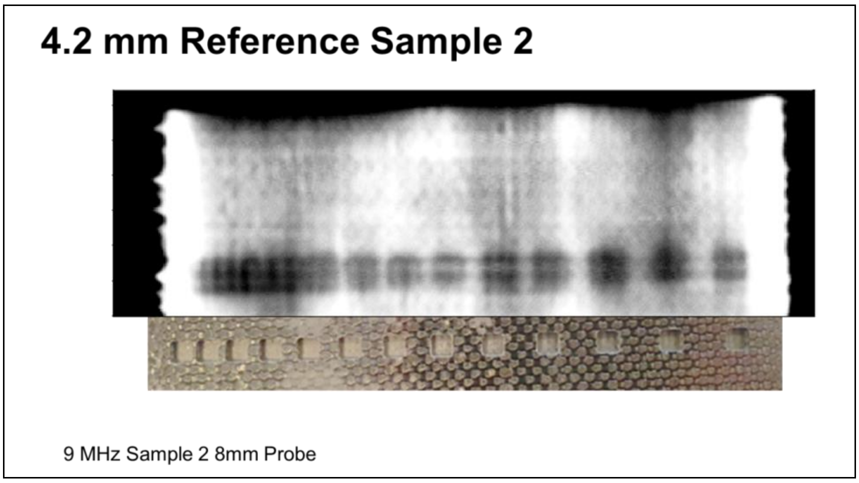

Figure 7 Reference Sample 2 scanned with eddy current

Figure 7 shows the 4.2mm thick sample with constant flaw size (6mm x 6mm) but with the flaw distance decreasing. This is a scan at 9MHz with 8mm with a thru transmission probe test.

This test was designed for resolution testing, it shows great promise, and the results have been filtered using a bespoke algorithm created by ETher NDE. The definition between the machined pockets becomes clear once the space between pockets reaches 4mm.

The Quantum Well Effect Eddy Current Field Measurement also tested the 4.2mm but it was not possible to get an image output from the QW-ECFM analysis at this stage because the system it is still in development. It was possible however to get a line scan signal output of the weak fields.

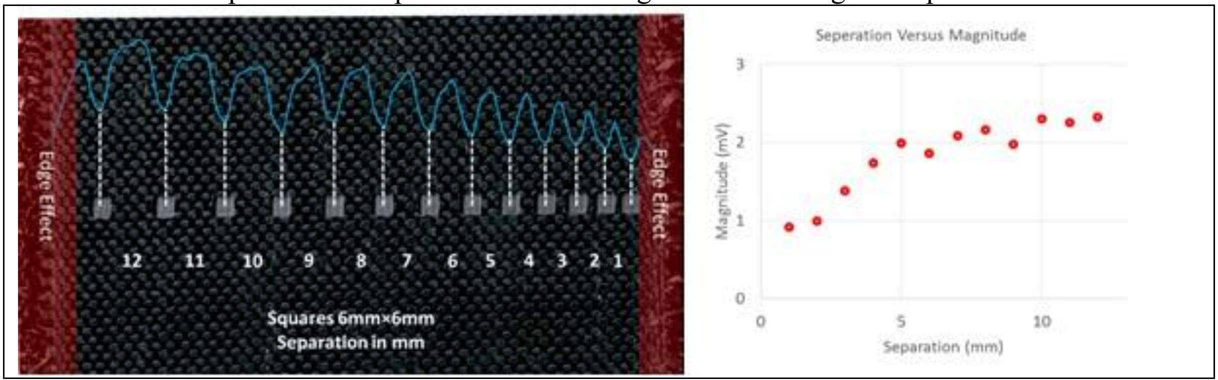

Figure 8 Reference Sample 2 scanned with QW-ECFM

In figure 8 sample 2, 4.2mm thick is shown with constant flaw size (6mm x 6mm) where the distance between flaws is decreasing. The signal output graph clearly shows a correlation between the position of the flaws and position of the minimum values on the graph. Also the number of minimum values is the same as the number of flaws present in the sample. This is again a remarkable result for a NDT system normally used for analysing metal components.

The results for both techniques are quite encouraging.

5. Automation of scan operation.

TWI have integrated a robotic arm with 6 axis movement, with a mounted eddy current NDT yoke and probe assembly. TWI has designed the eddy current attachment to the robot and they have created a 3 axis path for the robot to follow. The component used to set up the 3 axis path, is a compressor blade shaped object. This was select by FAR UK for the complexity of the shape itself. The complexity of the object was required to ensure that robot tool path and eddy current sensor could be used on a realistic component. On the left hand of Figure 9 we can see TWI CFLUX software plotting the scan results from the eddy current probe outputs, interpolated to the positions of the flaws on the part. A 3D scan mesh is produced which can be overlaid onto a CAD representation of the original part.

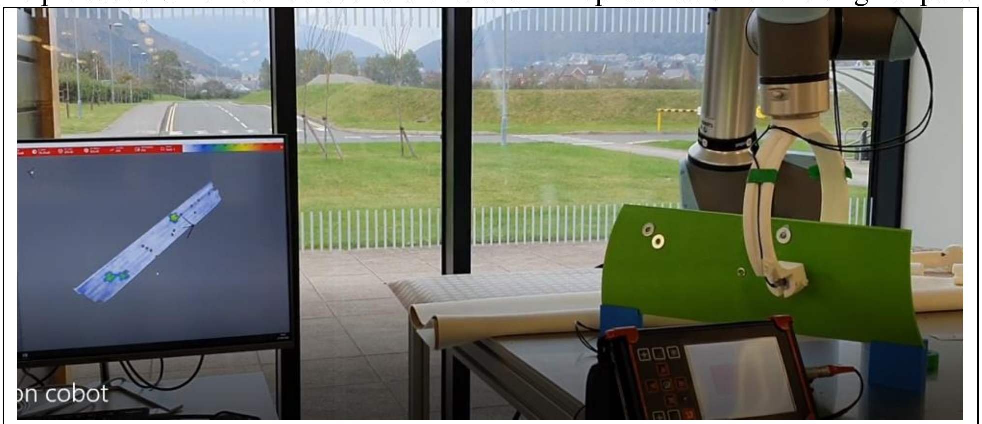

Figure 9 robot setup with curved 3d printed sample and robot programming software

On the right hand side of figure 9 shows the robot arm with attached sensor yoke. A 3d printed version of the curve component select by FAR UK has been used to programme the robot tool path.

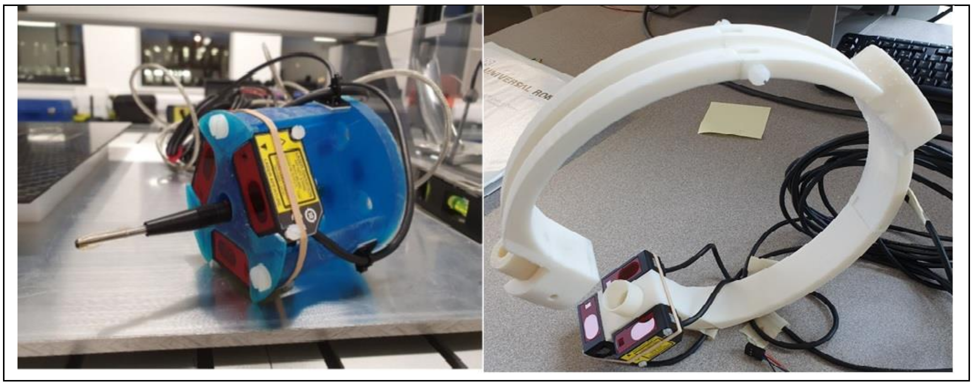

Figure 10 Eddy current sensors holder designed by TWI

Figure 10 shows the eddy current probe and laser yokes designed by TWI.

5.1. Curved sample selection for robot software

FAR UK are using their expertise of complex finite element analysis (FEA) modelling, testing and tooling manufacture, to correlate the effects of flaws on real life components. FAR UK selected the chosen component based on the requirements of TWI to write a complex 3d path for the robot. It was decided then that there was enough information available to model a CAD file of the compressor blade CFM56 aero engine.

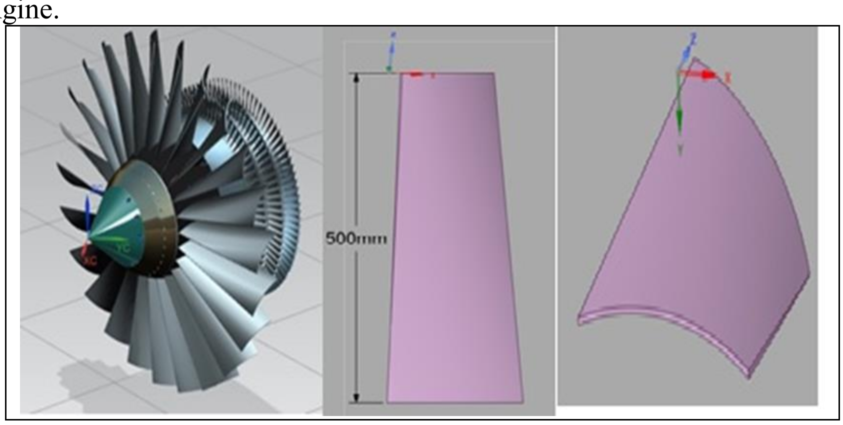

Figure 11 CFM56 engine compressor blade schematics

This part of the engine tends to be quite a complex part with curves in both the width and length direction. Figure 11 shows the FAR UK chosen component. The final components will be 500 mm in length and 200mm wide. This will be manufactured using a 3D woven fabric which will then be infused with epoxy resin in tool with the component shape.

FAR UK also developed FEA of the blade demonstrator to assess the effects of flaws

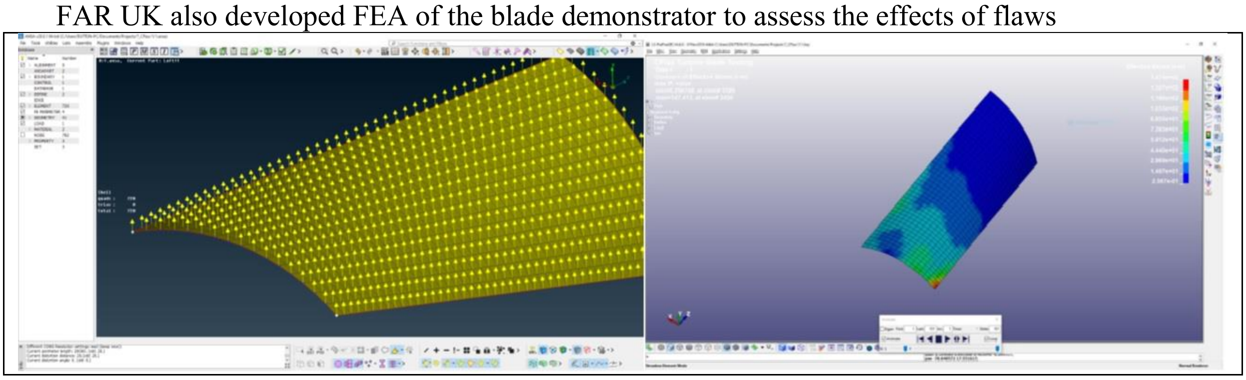

Figure 12 FAR UK finite element analysis of blade demonstrator

In figure 12 we see the FEA analysis made by FAR UK, this is at the moment basic because there no flaw positions to add to the part. With the model in place it is relative easy to insert flaws into the model and assess the detrimental effect of the flaws on the strength of the part.

6. Conclusions

The work presented in this paper shows the current status of the C-Flux project. At the moment the development of eddy current and quantum well magnetic flux leakage (QW-ECFM) for carbon fibre composite NDT is developing rapidly. Significant step results from both ETher NDE and AHS are reported regularly in the project website [5]. The paper also shows that eddy current can be used to scan carbon fibre composite with the similar detail to X-ray techniques.

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