

## **ABSTRACT FOR THE GENERAL PUBLIC**

This project aims to develop a model based on a combination of **digital twin** (DT) technology and deep learning (DL) to identify failure problems and predict the fatigue life for adhesively bonded composite structures. The problem we are studying is the damage detection and **remaining useful life** (RUL) prognosis. The research specimen is adhesively bonded CFRP structures. The approaches used are hybrid models integrating DT and DL techniques. The training data is divided into simulation data and experimental data. The source of simulation data is the finite element model (FEM), and the experimental data is measured by PZT (damage detection based on a guided wave).

Over the last years, with the increasing pressure to meet unprecedented levels of eco-efficiency, the aircraft industry aims for super light structures and towards this aim, composites are replacing conventional Aluminium. The same trend is followed by civil, automotive, wind energy, naval and offshore industries, in which combining different composites can increase the strength-to-weight ratio. However, the joining design is not following this transition. Currently, composites are being assembled using fasteners. This represents a considerable weight penalty for composites since holes cut through the load carrying fibres and destroy the load path. Therefore, adhesive bonding is the most promising joining technology in terms of weight and performance. The main reasons for this lack of acceptance are the limited knowledge of their key manufacturing parameters, **non-destructive inspection techniques** (NDT), **structural health monitoring** (SHM) methodology and reliable diagnosis and prognosis of their structural integrity.

We chose to study the bonded area of the composite because it is more prone to failure than the substrate. While commonly used means in the SHM field, such as guided waves and optical fibres, can certainly detect structural failures, these methods are not directly employed to predict RUL. Merely detecting whether a structure is faulty is not enough for many applications. To be precise, we need to know when a structure will fail and how long the remaining life will last. This will make SHM and NDT more meaningful. When it comes to the life prediction problem, it is inevitable to refer to the use DL model. This project differs from popular data-driven based on DL methods, and the differences are explained below. First of all, as a typical data-driven method, what data (type) is used to drive the model? The project combines simulation and experiment, using a large amount of simulation data to train the DL model, mixed data to verify the model, and experimental data to test. This avoids the overfitting problem caused by a single data source.

How is the data obtained? This topic is unavoidable in any use of DL models. Much research currently receives crack-growing data of the bonded area through FEM. This method ignores the classical theory of fracture mechanics. It neglects the calculation of some critical parameters (for example, the maximum traction force and fracture energy in the traction separation law). Therefore, to study the problem of fracture, the theory of fracture mechanics must be reconsidered. Thus, the project will combine the crack growth model based on fracture mechanics with the FEM to obtain a large amount of simulation data. Then, the data will be filtered through the digital twin self-learning model, and valid data will be stored.

Reliability analysis of prediction results. After processing the experimental and simulation data through the DT hybrid model, it is necessary to call the data in the database for life prediction. A key question is whether the predicted results are reliable. The biggest problem with conventional DL models is that they can only output the point as a prediction result. In actual engineering, we would like to obtain a prediction interval to know how long the life of the material can last, which is more realistic. Therefore, a single DL model cannot do this job. Currently, the solution is to superimpose statistical networks based on a single DL model, such as Bayesian dynamic networks, Monte Carlo (MC) sampling methods, etc. These methods have achieved remarkable results in their respective research fields, but how to apply these methods? BDN needs to change the hyperparameters in the network to obtain uncertainty. The MC method can only sample the results and cannot truly realize the uncertainty of the DL network. Therefore, the project aims to use a technique of combining Dropout and MC to predict the results so that the interval of the anticipated results can be obtained without changing the original network structure. We believe this will be a very effective method, which avoids overfitting and outputs prediction intervals without changing the hyperparameters.

This project represents an innovative multidisciplinary research approach that considers the fracture mechanical properties of materials and the failure characteristics in actual measurements. By combining classical mechanics theory, guided wave damage detection technology, and cutting-edge DL and DT technology, the goal is to improve the application of SHM in bonded composite materials. The hope is that this field will attract the attention of more scientists, who can work together to promote composite structures that better serve human needs.