Physics-driven machine learning for robust design and process simulation of advanced aerospace composites

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| Context of the research activity | Aerospace composite structures are nowadays realized by means of highly automated layup processes and then consolidated through autoclave. Albeit improved over the last two decades, the Automated Tape Laying (ATL) and the Automated Fibre Placement (AFP) technologies are affected by meso- to micro-scale defects, which ultimately result into mechanical deficiencies of the structural components. Available (deterministic i.e. science-based) computational models and failure criteria are unable to characterize the propagation of those unwanted manufactured-induced defects within the composite materials and their effect on the ultimate strength properties of the final components. As a result, most of the aeronautical composites are designed according to the "no-crack growth" principle, which inevitably leads to unjustified heavy structures.  
Recently, machine learning is rising as a as a theory-agnostic approach to tackle issues related to the understanding of the governing physical laws or to their limitations, including trade-off between fidelity, accuracy and computational speed, which is of fundamental importance in many applications in which a real-time response may be needed, e.g. digital twins and manufacturing processes. Nevertheless, machine learning algorithms may suffer the scarce availability of large... |
In this context, the present project proposes the use of theory-guided machine learning to bridge the divide between physics-based simulations and artificial intelligence and take advantage of their respective strengths. The resulting hybrid models will be able to simulate the manufacturing processes of aerospace components, from lay-up to consolidation, and will provide a tool to carry out robust design and multi-scale optimization of large components. Inevitably, the developed physics-based machine learning approach will also play a role in the improvement of process technologies towards waste reduction of composite structures.

This PhD research is part of PRE-ECO, an ERC-StG project for the exploratory study into a radical new approach to the problem of design, manufacturing and analysis of printed composite materials, see [www.pre-eco.eu](http://www.pre-eco.eu). The research will deal with the development of advanced simulation tools for the mechanical characterization and the process simulation of advanced aerospace composites. The tools will be based on the Carrera Unified Formulation (CUF), which provides a unique framework for the development of refined structural theories with scalable accuracy. In detail, the models developed will make use of component-wise kinematics for an accurate prediction of internal stress states, from fibre-matrix to laminate scales. The developed concurrent multiscale simulations will allow a precise, although computationally efficient, characterization of manufacturing and consolidation processes of composites and will provide a unique framework for failure analysis, also taking into account sensitivity against unwanted process-induced defects, such as voids, laps, overlaps, fibre kinking and waviness. Aspects related to the computational efficiency and multifield interactions will be handled through the application of Best Theory Diagrams and Node-Dependent Kinematics developed by the supervisors in recent years. In the second part of the research, we will combine these “science-based” multiscale methods with machine learning. The main objective is to create a new physics-based AI paradigm able to improve current machine learning approaches used for the analysis of composites. Preliminary studies, in fact, demonstrate that machine learning algorithms integrating physical laws, even with a reduced number of iterations, are able to capture correct trends beyond the boundaries of the training zone.
Secondments to University of Washington at the Composite Group ([www.composites.uw.edu](http://www.composites.uw.edu)) will be possible depending on the research interests and the performance of the PhD candidate.

### Skills and competencies for the development of the activity

Ideal candidate will have the following competences:

- Excellent academic background.
- Excellent mathematical skills and engineering attitude.
- Experience in computational engineering and machine learning is a plus.
- Appropriate competencies in English speaking and writing.
- Programming skills (e.g. Python, Fortran).