POLITECNICO DI MILANO

PhD in INGEGNERIA AEROSPAZIALE / AEROSPACE ENGINEERING - 39th cycle

PNRR 117 Research Field: DEVELOPMENT OF CONSTITUTIVE LAWS AND INNOVATIVE NUMERICAL APPROACHES FOR THE PREDICTION OF THE DAMAGE TOLERANCE OF STRUCTURAL ELEMENTS IN COMPOSITE MATERIALS UNDER FATIGUE LOADING

Monthly net income of PhDscholarship (max 36 months)
€ 1400.0 In case of a change of the welfare rates during the three-year period, the amount could be modified.

Context of the research activity	
Motivation and objectives of the research in this field	The superior stiffness-to-weight and strength-to-weight ratios of composite laminates and the possibility of manufacturing large monolithic elements with complex shapes led to conceive specific design approaches for such materials. In particular, some critical aspects involved in the usage of composites must be addressed, such as the tendency to the development of internal defects that can evolve as delaminations under the action of cyclic loading, going undetected by ordinary inspection techniques. The typical conservative approach prescribes that the risk of propagation of such damage phenomena in composites should be completely avoided. However, in the last three decades, numerical techniques have been developed, based on Cohesive Zone Models implemented in finite element procedures, which can predict the nucleation of delaminations and to evaluate the residual static strength of structural details in the presence of damages. These methods potentially represent a fundamental step towards the digitalization of the design processes of composite aeronautical structures, but a fundamental limitation is represented by the difficulty of predicting the propagation thresholds and the growth rate of defects under the action of fatigue loading. Actually, methods with the potential of being adopted for such predictions in realistic damage scenarios have been recently proposed. Such innovative methods are based on simplifying assumptions that proved to lead to appreciable

	predictions in the case of simple coupons, although their reliability in real-world applications is substantially unknown, as well as the possible adjustments and calibration strategies to take into account complex geometries, competitive damage propagations, as well as combined load conditions with variable amplitudes and environmental conditions. The research program proposed is aimed at achieving substantial progress relevant to the development of constitutive laws for the development of delaminations under fatigue loading as well as to the definition of modelling and analysis strategies suited for the application in industrial design processes. To reach such an ambitious goal, the candidate will be integrated into a research group and he will be able to exploit the knowledge acquired in the field of composite non-linear structural analyses in previous research activities, in particular in the areas of modelling and experimental characterization of delamination phenomena.
Methods and techniques that will be developed and used to carry out the research	Considering the objectives of the activity, the program will include an initial phase, aimed at the identification of the most promising constitutive formulations for the accumulation of interlaminar fatigue damage. A first test campaign will be conceived for the acquisition of the data required for the calibration of constitutive laws, selecting materials that have been already well characterized statically. This campaign will include a limited number of cases with realistic lamination sequences, more complex than the ones of characterization coupons, but still based on simple geometries and damage scenarios. Such laminates will be tested both in static and fatigue conditions. In the second phase of the activities, the results of previous research programs will constitute the basis for the development of effective constitutive laws to be implemented in commercial finite element codes. The cooperation with the industry involved in the project will be exploited to develop numerical tools and calibration protocols developed to be adopted in the aircraft design process. Model calibration will be performed by using the data acquired in a set of experiments included in the first of the activity, while a second set of tests on simple

	coupons will be used for the validation of the approach, focusing on the propagation of delamination in loading cycles. The static tests performed on more complex lamination sequences will be used for an evaluation of the most effective modelling approaches, by comparing techniques based on conventional cohesive elements and non-conventional techniques based on cohesive zone models smeared in solid elements. Moreover, the role played by residual thermal stress on propagation thresholds and damage growth will be investigated by applying implicit and explicit analysis procedures in multi-step analyses. The results obtained in the first two phases of the activity will make possible the selection of constitutive laws, modelling techniques and analysis approaches with the potential of being used in the design of real-world composite structures. In the final phases, validation tests on coupons representative of structural elements or details will be designed, produced and tested to provide an experimental basis for the assessment, validation and improvement of the methods developed in the program.
Educational objectives	The activity will provide the possibility of achieving high-level competencies in the design of modern composite structures. The experimental activities will represent a fundamental experience for the knowledge of state-of-the-art characterization standards and methods, including diagnostic methods for the identification of internal delaminations. The accomplishment of non-linear numerical analyses with different approaches and analysis methods will guarantee a solid background in finite element procedures for structural problems. The specific aspects related to the programming of the material law subroutine for composite damage will enhance the numerical skills of the researcher. Such activities and competencies in the experimental field will give a detailed comprehension of damage modes of composite materials, which is a fundamental step in the path required to become an expert designer of composite structures. The interaction with the academic research group and the industrial environment is an important added value of the program, giving the possibility of

	observing and understanding the dynamic of research activities in engineering, and in particular in the aeronautical, field.
Job opportunities	The competencies acquired by the researcher will be highly valuable for the methodologies that will be applied in the structural design of future aerospace vehicles. The digitalization of design and analysis processes and the inherent multi-disciplinary approach adopted in the research will help find job opportunities in top-level national and international industries, where the demand for engineers capable of understanding and managing complex design processes will certainly increase. Moreover, the specific competencies in composite structures will have potential applications in many fields not exclusively related to the aerospace world. The knowledge of fatigue phenomena and the general skills acquired in non-linear finite element analyses could be applied for the design of lightweight structures non necessarily made of composites, in automotive and marine industrial fields. Accordingly, employment in national and international research centres and consultancy companies could be included in the job opportunities at the end of the research program.
Composition of the research group	1 Full Professors 1 Associated Professors 1 Assistant Professors 4 PhD Students
Name of the research directors	Prof. Alessandro Airoldi

Contacts
Dipartimento di Scienze e Tecnologie Aerospaziali - Politecnico di Milano - via La Masa 34, 20156 Milano - Italy - tel. +390223998323 - fax +390223998334 - email: alessandro.airoldi@polimi.it - web site: www.aero.polimi.it

Additional support - Financial aid per PhD student per year (gross amount)	
Housing - Foreign Students	--
Housing - Out-of-town residents (more than 80Km out of Milano)	--

Scholarship Increase for a period abroad	
Amount monthly	700.0 €
By number of months	6

National Operational Program for Research and Innovation	
Company where the candidate will attend the stage (name and brief description)	Leonardo S.p.A.
By number of months at the company	6
Institution or company where the candidate will spend the period abroad (name and brief description)	Università di Patrasso (GR)
By number of months abroad	6

Additional information: educational activity, teaching assistantship, computer availability, desk availability, any other information
The PhD candidate will receive a desk, possibly through a hot-desking procedure, and a personal computer, if needed. Apart from the compulsory ones, the PhD candidate will have the opportunity to follow additional courses and receive economic support to attend summer schools and participate in conferences. There will be the possibility of paid teaching assistantship.