Abstract

The development of the aerospace sector is inherently linked to technological progress. Research and development activities, methodological advances, and testing in this field drive innovations that find applications not only in aviation but also in other sectors, such as materials engineering, information technology, and energy systems. The objective of this doctoral dissertation, presented as a series of publications, is to develop and validate an integrated methodology for the design and assessment of aerospace structures using advanced material technologies, with particular emphasis on composite and additive manufacturing technologies. The need to address this topic stems from a significant research gap, namely the lack of coherent approaches encompassing the entire life cycle of aerospace structures, from material selection and design, through manufacturing and integration, to validation under actual operating conditions, including both ground and flight testing.

The methodology developed in this work is based on the integration of modern engineering tools (CAD/CAE/FEA/CFD), material characterization, structural optimization, and experimental validation of full-scale components. In the field of additive manufacturing, material characterization studies were conducted on selected alloys, including stainless steels and titanium alloys, while topology optimization methods implemented in a CAD environment (CATIA) were employed in structural design. An important aspect of the research was the use of two different additive manufacturing technologies developed by independent organizations, which enabled the cross-validation of design assumptions and the assessment of the influence of manufacturing processes on the final properties of the structures.

In the field of composite technologies, the research focused on the development and analysis of composite aircraft engine nacelle structures. The work included the development and refinement of selected manufacturing technologies, particularly Out-of-Autoclave (OoA) processes and high-temperature composite materials tailored to the specific structural and operational requirements of aircraft engine nacelles. Structural components were subsequently manufactured and integrated into airframe assemblies, enabling their compatibility and functionality to be assessed under representative operational conditions corresponding to Technology Readiness Level 6 (TRL 6).

The research process was iterative and encompassed successive stages implemented across a series of research projects, including material selection, design and optimization, component manufacturing, system integration, and experimental validation. Ground and flight tests constituted a key element of the work, allowing the actual structural behavior to be assessed, the proposed methodology to be verified, and

the effectiveness, advantages, and limitations of the developed technologies to be evaluated in comparison with conventional manufacturing approaches.

The results confirmed the feasibility of effectively integrating additive manufacturing and composite technologies into aerospace structures. The studies demonstrated the potential for significant weight reduction while maintaining the required mechanical performance, confirmed the effectiveness of topology optimization techniques, and highlighted the substantial influence of manufacturing processes on the final properties of aerospace components. In the case of composite materials, the research also demonstrated their suitability for high-temperature applications typical of engine nacelle structures, particularly firewall structures.

The practical significance of the research is substantial for the modern aerospace industry. The proposed methodology can reduce design time, part count, structural weight, overall costs, and technological risks while facilitating the implementation of innovative structural solutions. The results can be directly applied in future research and development projects, including European programmes, thereby supporting the progression of emerging technologies towards higher Technology Readiness Levels (TRLs) and the development of advanced aerospace structures.