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Complex composite technology investigation: simulations and experimental results

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Complex composite technology investigation: simulations and experimental results

Massimo Viscardi[1], Maurizio Arena[1], Pasquale Napolitano[1], Paola Iaccarino[2] and Pietro Cerreta[3]

[1] Department of Industrial Engineering, Aerospace Division, University of Naples "Federico II", Via Claudio 21, 80125 Naples, Italy
[2] LAER S.p.A., Research and Development Division, Via Caracciano 57/63 82011 Airola (BN) – Italy
[3] Protom Group S.p.A., Aerospace Division, Via Vicinale S.M. del Pianto – CPN, Ed. 6 80143 – Naples, Italy

Email: massimo.viscardi@unina.it, maurizio.arena@unina.it

Abstract. The paper deals with discussion of research activities within ITEMB (InTEgrated Full Composite Main landing gear Bay Concept) framework, an EU Clean Sky 2 program coordinated by Airbus. The driving motivation for the investigation on such a technology was found in the opportunity to design a main landing gear bay in a full composite configuration: rational approaches have been implemented in an efficient testing stage providing the necessary database for the static qualification of the conceived design. Advanced and innovative solutions for a "more integrated" system were duly analysed and experimentally validated thus proving the overall device compliance with industrial standards and applicable airworthiness requirements.

1. Framework description

Until today advanced composites are establishing always more markedly in the industrial sector: the improvement of manufacturing and integration technologies have certainly contributed to enlarge the use of these materials with particular emphasis on aerospace applications. Zweben underlined as awareness of the benefits of composites grows so will the understanding of their theoretical and practical implications, [1]. Composites have demonstrated a durability at least as good as their metal counterparts [15] suggesting that maintenance costs could actually be lower, [4-5]. The fiber composite approach could in fact provide significant improvements in specific strength and stiffness over conventional metal alloys, [6]. Particularly in the aviation sector, composite laminates have found a great use in fixed wing and rotary wing aircraft. Actually, fuselages, wing structures, aerodynamic appendages, tanks, internal and external panels, propellers, rotor blades and many other details are being made of composite material. Just as example: carbon fibers are used in engines and tail rudders; Carbon/Kevlar in fuselages and in the fittings of the wings, winglets; Kevlar in the motor gondolas and in the vertical stabilizer. Applications of composite materials were reviewed by Harris *et al.* for large commercial transport aircraft, general aviation aircraft, rotorcraft, military fighter aircraft, and military transport aircraft, [7]. Ongoing studies on emerging technologies are then further expanding the fields of application [17], [18]. NASA uses a technology readiness level (TRL) scale from 1 to 9 to indicate the level of maturity of a technology. TRL values of 1–3 indicate research levels, with TRL 1 being fundamental research. TRL values from 4 to 6 indicate technology development levels. TRL values from 7 to 9 indicate advanced development levels, with TRL 9 signifying mature technology that is ready for actual aerospace vehicles. As a developer of advanced technology, NASA usually targets its technology development programs to advance the technology to TRL 6 and then transitions the technology to the aerospace industry. The description of TRL 6 is as follows: system/subsystem validation model or prototype demonstrated in relevant environment (ground or space). A study of composite aircraft structures programs performed by Vosteen and Hadcock identifying some lessons learned and best practices relative to materials, processes, and manufacturing, [8]. Significant improvements in the properties and manufacturing of polymer matrix composite materials have occurred [9]. Automated manufacturing has been facilitated by the development of high-speed fiber placement and stitching machinery, which were adapted from those used in the textile industry. The development of advanced processing methods, such as powder-coated fiber tows, also contributed to the automated features of the processing of the material systems, [10]. Current research programs are addressing the development of design and manufacturing methodologies for A/C complex composite components applying infusion technologies in order to achieve improved primary structures in terms of weight and cost, and to enable immediate decisions for next future aircraft designs. The ITEMB program had the objective of releasing a prototype suitable to represent the main landing gear (MLG) bay for the new Airbus A3XX category. The synergic collaboration among the partners comprising: Protom Group, University of Naples “Federico II” and LAER Group has led to the development of a new manufacturing procedure, [11-14]. This paper deals with the description of specific aspects of the innovative monolithic composite structure developed within ITEMB scenario. More in detail, fundamental aspects of the paper will focus on the design phase up to laboratory testing of the innovative prototype: the critical analysis of the numerical results will be compared with the static T-pull tests.

2. Design and main processes description

As already mentioned, the primary objective of the ITEMB project is the development of a MLG bay for the new class of Airbus A3XX aircraft. The design philosophy [13], [14] was oriented towards the realization of an architecture as more “integrated” as possible: the reduction of the junctions, of the rivets and the optimization of the structural weight were therefore the main targets to be achieved. The Fig. 1 represents, by way of example, an advanced stage of the assembly design in question: the MLG bay consists of two monolithic composite components obtained by one-shot curing process: the horizontal roof and the vertical rear pressure bulkhead.

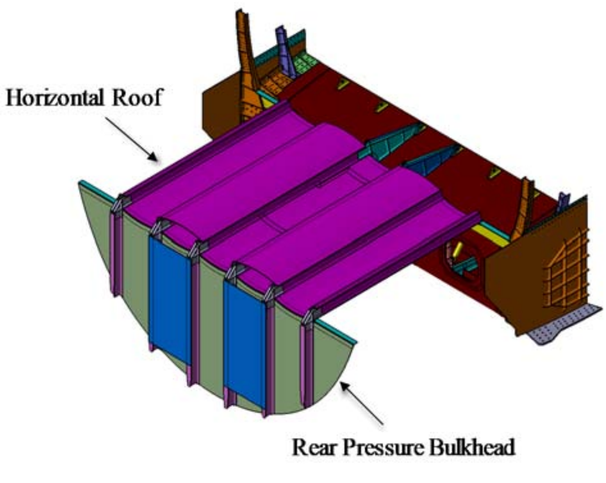


Figure 1. Design detail of fuselage bay.

Both parts are monolith CFRP structures made by one-shot autoclave curing process of a wet assembly comprising a shaped upper and lower skin, six I beam spars, each of them resulting from a wet subassembly of left/right C-shaped spar and upper/lower formed noodle (see Fig. 2). Few metal fittings with a very small amount of fasteners are enough to join both of them to the main structural frame. The structural design has been conceptualized giving to the two monoliths a so-called "waved" shape with connecting nodal lines: it strongly contributes to the resistance and stability. As better outlined in the following paragraphs, these nodal lines have required a dedicated design attention as they are realized by the hot forming of a filler and potentially represent the weakest structural element. Fig. 3(a) shows CFRP one-shot cured box and detail of node between spar flange and skin. This detail shows that a very good quality of radii areas can be obtained. Also, good quality of nodes was verified everywhere. The T-sample was extracted from the box for the subsequent static qualification tests, Fig. 3(b) and 3(c). Quality check tests have demonstrated a sound attenuation less than 6 dB everywhere indicating a very low porosity: moreover, A-scans does not show any delamination or voids (Fig. 4). The T-pull test had the purpose to verify the maximum allowable loads for the specific sub-element and also to highlight the failure mode and location.

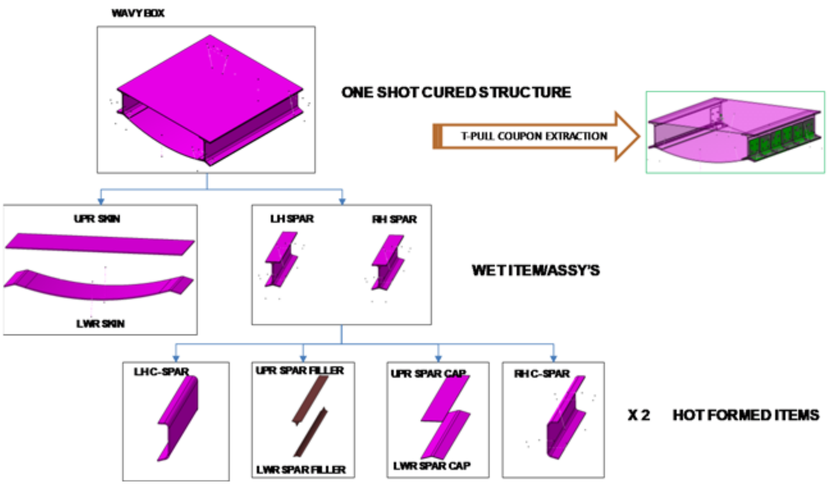
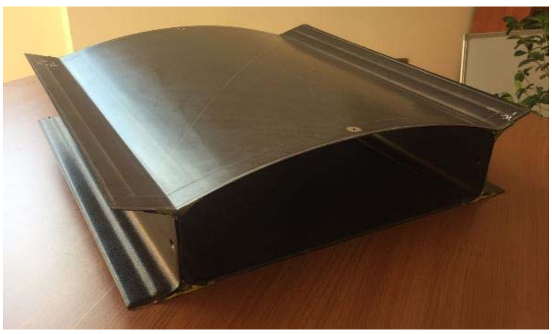
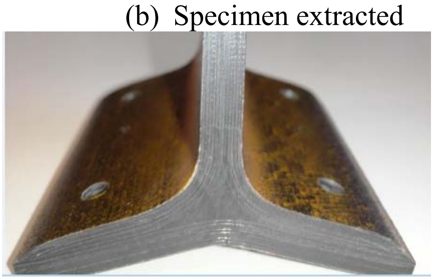


Figure 2. Manufacturing key-steps.



(a) Box assembly

(b) Specimen extracted



(c) Detail of filler

Figure 3. Real composite assembly: from whole box to T-pull sample.

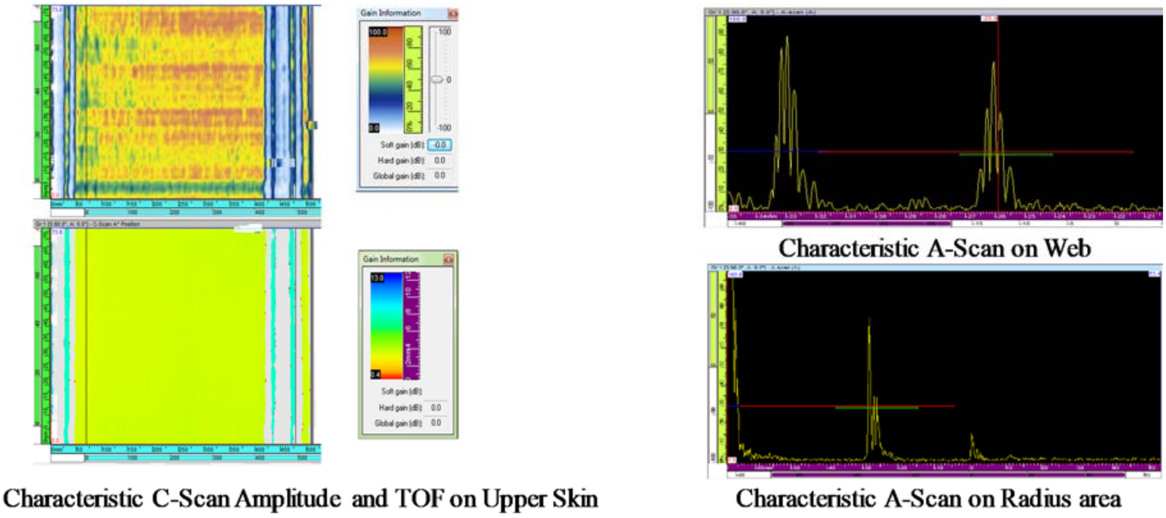


Figure 4. NDT quality check.

3. Numerical model and stress analysis

The design activity has been supported by the development of FE models to investigate the expected stress state during the static test, in particular by focusing on the most critical element: the central node, i.e. the filler. An overview of meshed parts, including also the metallic fixture, is outlined in Fig 5. The metal part is connected to the specimen through 1D elements (*rbe2-beam* couple elements to simulate the bolts) while the 2D elements representing the laminate are connected to the 3D filled through glue contact. According to the real case, the bottom side of the fixture was constrained to simulate the jaw effect on the specimen: the fixed condition (DOFs from 1 to 6 constrained) is used. No sliding between fixture and jaw has been considered. The total applied load is variable from 1 kN to 25 kN thus applied to the top part of fixture. Such resultant force is basically the interfacing load (free-body) between the specific component and the whole structure during the operative condition (up to 5KN and than extending the load range until the expected failure load). Table 1 and 2 summarize the main FE properties: numerical entities and material data have been imported according MSC Nastran® references, [15].

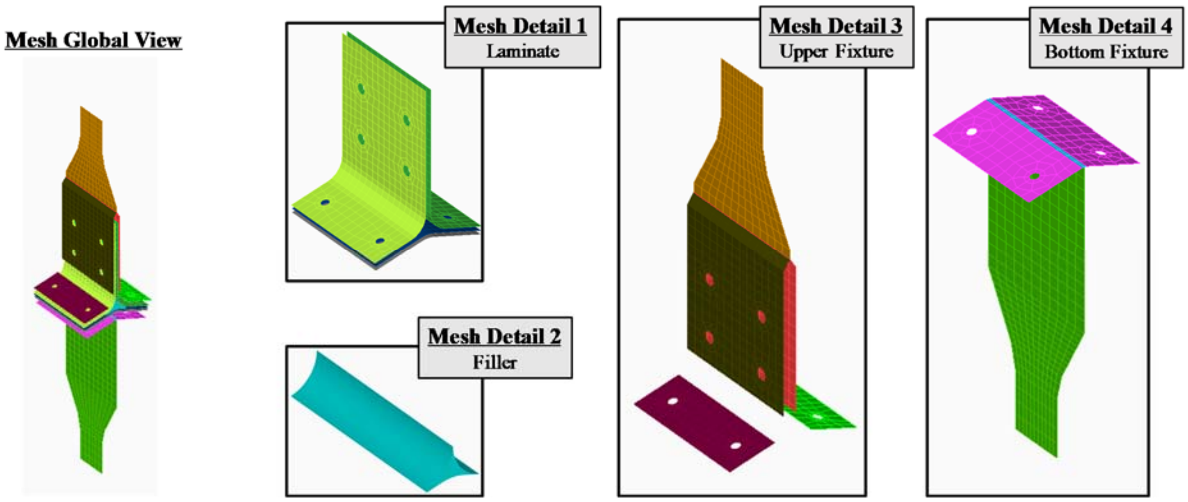


Figure 5. FE model overview.

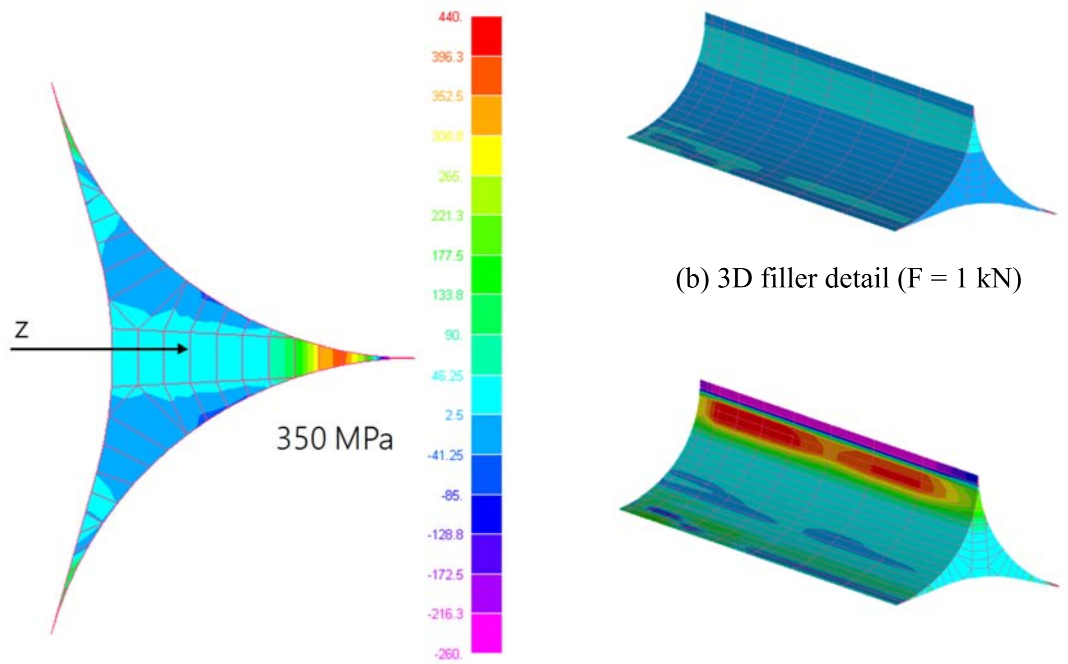
Table 1. FE model entities.

Part	Element type, [15]	Number of elements
Fixture	Plate Elements (CQUAD4)	1417
Filler	Solid Elements (CHEXA)	480
Laminate	Laminate Elements (CQUAD4)	1616

Table 2. Materials properties.

Part	Material	Young Modulus	Poisson Ratio
Fixture	Aluminum	E = 64000 MPa	0.34
Filler / Laminate	Carbon Fiber Pre-Preg (-45°, 0°, 90°, 45) basic lay-up	E_1 = 154000 MPa E_2 = 8500 MPa	0.35

Assuming an applied load of 25 kN (threshold experimental value), an average failure stress of 350 MPa (peak), i.e. about 2000 με, has been predicted close to the filler area as represented in Figure 6. Stresses contour is symmetric respect the center line of the filler indicating thus a good mesh quality.



(a) Section stress detail

(b) 3D filler detail (F = 1 kN)

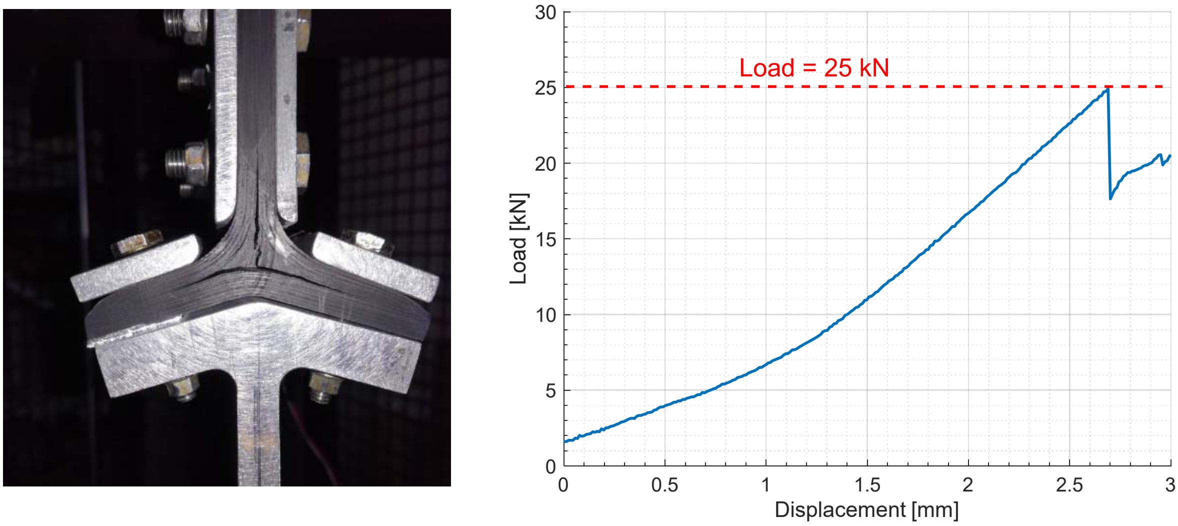
(c) 3D filler detail (F = 25 kN)

Figure 6. FE stress results: focus on internal node.

4. Experimental strain validation

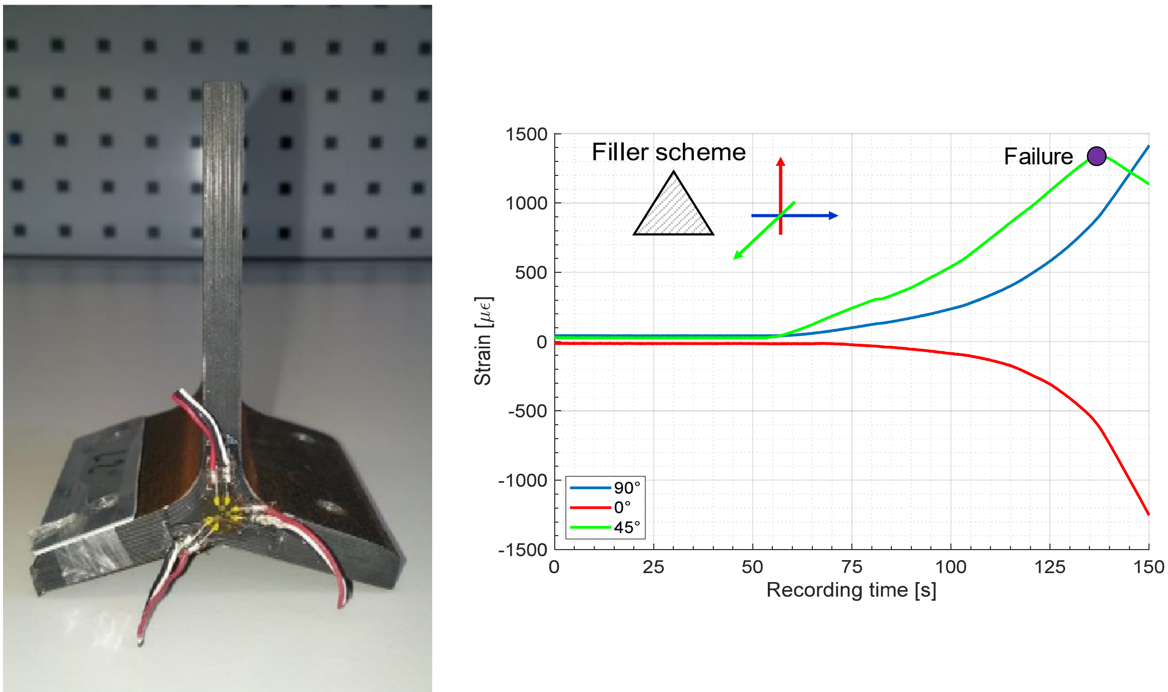
A test campaign has been scheduled in order to validate the specimen strength. Static loads were assigned based on the most critical design conditions. An Instron-8801 servo-hydraulic testing system has been used for the execution of tests. The loading head speed for the pull-off tests has been 0.10

mm/min for all specimens. This speed has been set lower than the planned one—equal to 0.5 mm/min—to better identify the filler crack initiation according to the pretest data results. In any case, all data were largely above the required value (5 kN). The manifestation of a crack occurred at around 25 kN, Fig. 7. A multi-axial strain gauge (rosette) was installed at the central node, because as expected representing the weakest point of the structure, Fig. 8(a). The strain deformation instead reached levels of approximately 1300 με, Fig. 8(b). A comparison between the numerical and experimental deformation is shown in the Figure 9. A good level of correlation was preliminarily achieved.



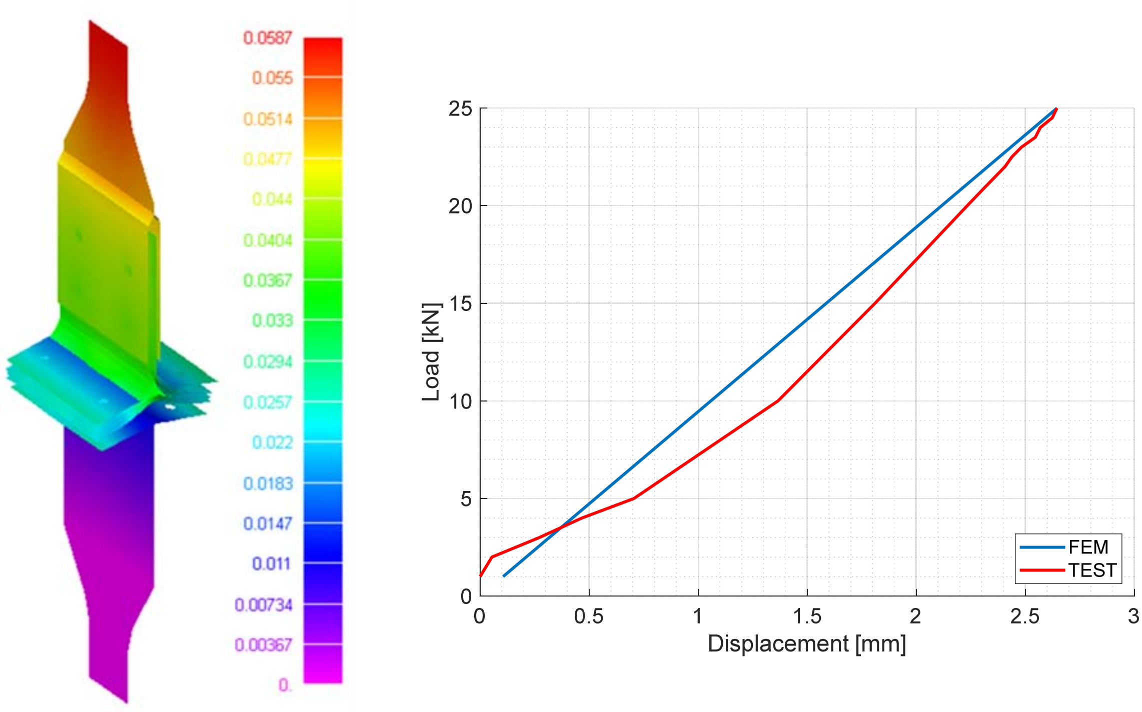
(a) Crack propagation (b) Load-displacement trend

Figure 7. Static test results.



(a) Strain gauge position (b) Time-strain trend

Figure 8. Strain acquisition.



(a) FE displacements (b) Load-displacement trend

Figure 9. Displacements correlation.

5. Discussion and conclusions

In the framework of ITEMB-Clean Sky 2 project, authors investigated a high TRL solution for an innovative composite concept for commercial aviation application. The design and technological demonstration of a novel MLG bay architecture were addressed: research activities were carried out to substantiate the feasibility of a "more integrated" concept in compliance with the low weight and manufacturing simplification requirements of next Airbus A3XX class. The paper presents the studies and tests limited to a portion of the final prototype: a specific characterization activity was planned in order to assess the robustness of the node representing the potential critical element of the monolithic conceptual design. Experimental outcomes showed that failure of most critical area occurred at about five times greater than the desired threshold. In addition, the reliability of preliminary numerical models has been considered satisfactory denoting a conservative result too: the experimental strain deformation is in fact less than about 35%. In this perspective, future studies will be aimed at a better numerical characterization of the crack propagation phenomenon.

Acknowledgments

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