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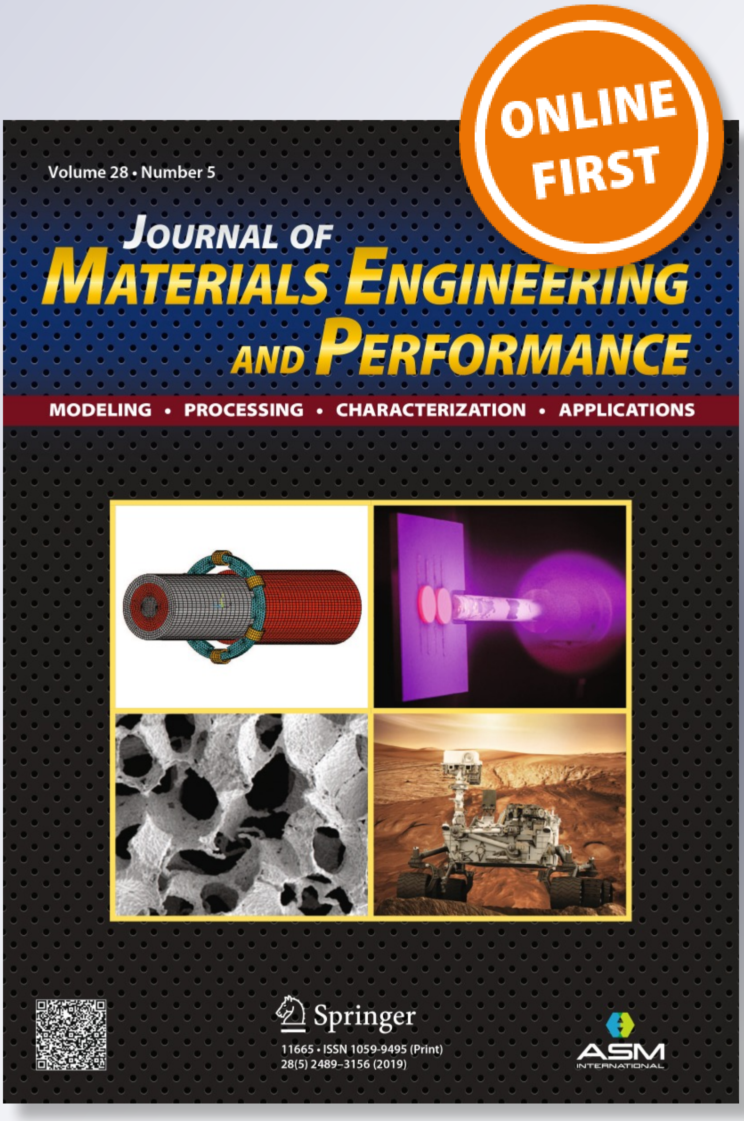

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Composite materials may reduce the final weight of the aircraft structural components, in addition to improve fatigue performance and corrosion resistance. In order to achieve the optimization of air transport systems, making them increasingly sustainable, the structural design must be surely reviewed, starting to follow the "composite thinking" philosophy. The present research provides some relevant outcomes concerning the design of a composite sample for the main landing gear bay of a large commercial airplane (EASA CS25 category), within ITEMB (integrated full composite main landing gear bay concept) project, a program of Clean Sky 2 EU research framework. The most ambitious goal is to develop a new generation of lower center fuselage (LCF) with an innovative integrated landing system in the fuselage, which is considered the next frontier in the development of landing systems for medium-haul aircraft, such as the Airbus A320 aircraft family. The development of a different architecture, with the landing gear integrated within the related fuselage bay, could lead to a simplification of the whole subassembly with potential advantage in terms of construction and assembly times. Final target of the project is the manufacturing of an innovative monolithic composite structure that will replace the actual configuration (a mixed structure of metal and composite subassemblies) reducing or actually removing all the cost of assembly and increasing the production rate. This paper presents the main results of the work, introducing the main processing steps and prototype results; in the last part of the work, also some experimental tests on significant element are introduced as the first assessment of the technology readiness level that has been achieved.

Keywords aircraft, composite, main landing gear bay, manufacturing, testing

1. Introduction

Research and technological innovation have been making significant improvements in the aeronautical structures in recent years. Composite materials with increasing performance have been developed to increase functionality while optimizing costs and weight penalties (Ref 1-3). Looking at the new generation of aircraft, Airbus Company issued a call for proposal within European Research Program Clean Sky 2, aimed to a new design of main landing gear bay (Fig. 1) compliant with new landing gear installation and using composite material. Technological innovation has brought the industrial production the need to research new materials that allow, with their properties, a huge improvement in all kinds of sectors. By choosing an appropriate combination of matrix and reinforcement material, a new material can be made that exactly meets the requirements of a particular application. Particularly, the aeronautical field has encouraged the research of composite materials that can offer, in contrast to a traditional material, more strength, less weight and less manufacturing costs, with an easier realization method. Furthermore, these materials have been demonstrated strong opportunities for performance enhancements (Ref 2-17). Within ITEMB project (Ref 15), carbon fiber composite materials have been used to design a midsize aircraft main landing gear bay bulkhead in the contest of the ITEMB program, performed by an Italian consortium coordinated by Protom Group and involving the LAER Srl and the Department of Industrial Engineering of the University of Naples, under the supervision of Airbus France. This paper discusses some of the outcomes in the implementation of advanced composites on general aviation aircraft. Such specific application has been selected that highlights the most crucial phases that the aeronautical industry went through while trying to extend the adoption of composite materials. The engineering application of laminates both in civilian and in military aircraft followed the typical stages that every novel "proof of concept" goes through during its implementation: design, manufacturing and experimental validation of the strategies. Final target of the project is the realization of an innovative monolithic composite structure that will replace the actual configuration (a mixed structure of metal and composite subassemblies) reducing or actually removing all the cost of assembly and increasing the production rate.

2. Structural Design, Materials and Manufacturing Process

2.1 Main Properties

Moving from a conventional buildup metal/composite structure to a highly integrated monolithic composite structure

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is the main ITEMB challenge in order to reduce weight of MLGB without increasing or reducing recurrent cost. Therefore, two composite monolithic structures obtained by one-shot curing process have been selected to be developed and verified by both design and manufacturing points of view: one for horizontal roof and the other for vertical rear pressure bulkhead.

Both items are monolith CFRP structures obtained by one-shot autoclave curing process of a wet assembly made of

- a shaped upper and lower skin
- six I beam longerons, each of them resulting from a wet subassembly of
- left/right C-shaped spar
- upper/lower formed noodle.

Few metal fittings with small quantity of fasteners will join both to obtain the structure object of the project.

One of the main peculiarities of the structural design is represented by the so-called waved shape with connecting nodal lines (see yellow spot in Fig. 2) that strongly contribute to the resistance and stability of the configuration.

As better described in the following paragraphs, these nodal lines will need to be verified as they are realized by the hot-forming of a filler and potentially represent the weakest element of the entire design.

Both the laminate and the filler (as better discussed in the following paragraphs) are made of carbon fiber pre-preg, whose name is IMA/M21E. Main properties of the materials are described below:

- Young Modulus, E [MPa] of 154,000 (laminate) and 8500 (filler);
- Poisson Ratio, ν [-] of 0.35.

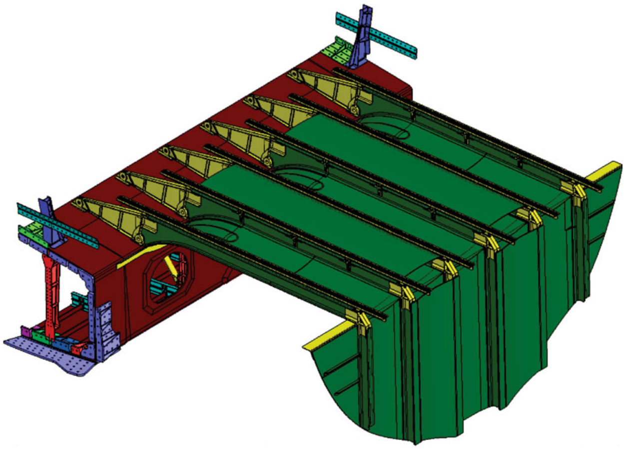


Fig. 1 Overall view of the design configuration

2.2 Process Approach

ITEMB innovation is mainly consisting in pursuing a process and design aiming to demonstrate that one-piece design approach with standard materials and achievable in a short time for real manufacturing, which would be feasible for avoiding the cost of assembling many parts.

To achieve this result, an integrated work between manufacturing and engineering has been done: In this case, engineering has had the task to (possibly) demonstrate viably a promising manufacturing approach.

A "bag against bag" technology has been adopted, and the capability to get a good product for a landing gear bay has been achieved, supported by manufacturing trials followed by inspections and corrective actions and manufacturing flow definition.

One-shot curing process is based on the following principles:

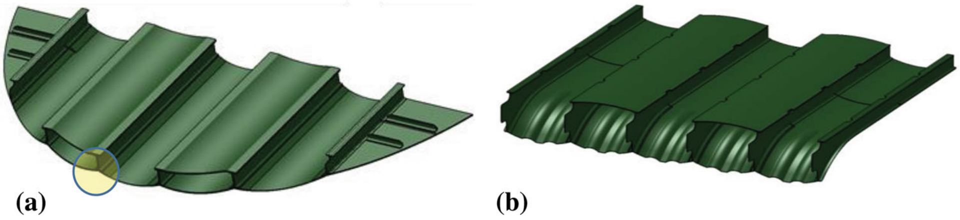
a. Upper and lower skins cocured with longitudinal I-shaped spars
b. Tool configuration based on

- closed shell, outer rigid molds, to obtain good finishing on outer surfaces
- rigid plugs to position spars and to hold auxiliary materials of inner bag

c. Vacuum bag scheme (Fig. 3) to obtain even pressure on all part surfaces including radii (Fig. 4)

One-shot curing process has been performed by the following steps:

I. Spar wet assys obtained by assembling hot-formed LH/RH C-spars, fillers and caps.
II. Reverse bag preparation on each plug using (starting from plug surface) tubular bags, surface breather, release film held tight by temporary vacuum application.
III. Spars position supported by rigid plug, on lower skin indexing plug end pins on tool suitable supports
IV. Monolithic wet assy obtained assembling skins and wet spar assys
V. Vacuum bagging closure sealing inner (reverse) bag each other and with UPR and LWR tools
VI. Monolithic wet assy is autoclave cured in a closed shell formed by upper and lower rigid molds precisely indexed.



(a) (b)

Fig. 2 Two monolithic (one-shot cured) large components (Color figure online)

The main expected process's positive aspects were:

- One-shot curing of a large complex structure with significant reduction in fasteners for assembly
- Parallel execution of different phases with flow time reduction
- Use of disposable nylon bags: no expensive reusable inflatable mandrels
- Bag even pressure on complete surface including radii: to avoid uneven pressure with rigid mandrel
- Easy debagging due to clearance between plugs and cured part.

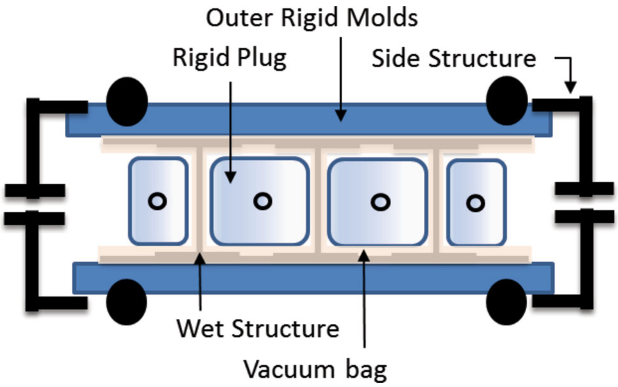


Fig. 3 Vacuum bag scheme

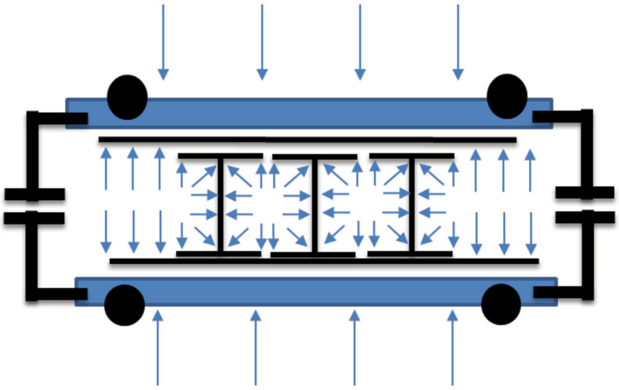


Fig. 4 Autoclave pressure distribution for one-shot curing process

Expected process issues were:

- Bagging learning curve is necessary
- Not tight tolerance on spar Web positioning (solved with sacrificial material)
- Specific NDI equipment required (Ref 3).

2.3 First Prototype

In order to cover all main technical issues concerning "One-Shot" curing process applied on MLGB horizontal roof and rear pressure bulkhead, a small wavy box has been fabricated to assess vacuum bag configuration and tooling design guidelines. Figure 5 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.

3. Experimental Characterization

3.1 Test Article and Test Setup Definition

In order to assess the robustness of the solution, especially in terms of structural resistance of the node (Ref 6-9) that represents the potential critical element of the monolithic conceptual design (Fig. 6), a specific test campaign has been planned. This test (T-pull test) (Ref 8-11) has been designed on the basis of specific computational activity mainly referred to the free body of this specific element, to precisely simulate the load introduction during the operative condition of the entire structure.

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. In order to achieve a vertical load on the coupon, avoiding any misalignment, the test article has been attached to a dedicated "Fixture," an aluminum (isotropic) item made up by three parts: load plate fittings, steel strap and load T-section fitting, as shown in Fig. 7.

The mechanical characterization of the representative coupon is defined by the use of fiber Bragg grating (FBG) sensors. As shown in Fig. 8, seven hot point locations have been identified and monitored under the application of a quasi-static loading condition.

Sensors are bonded on the outer surface, and in order to detect multi-point structural response by minimally affecting

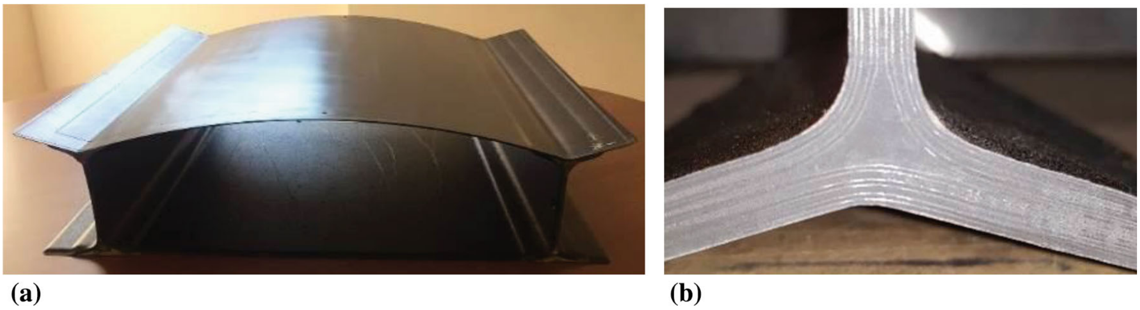
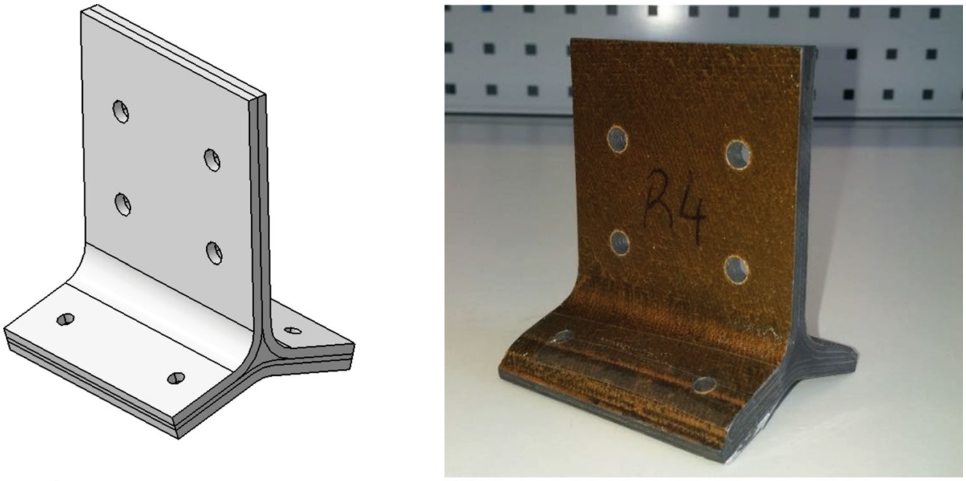
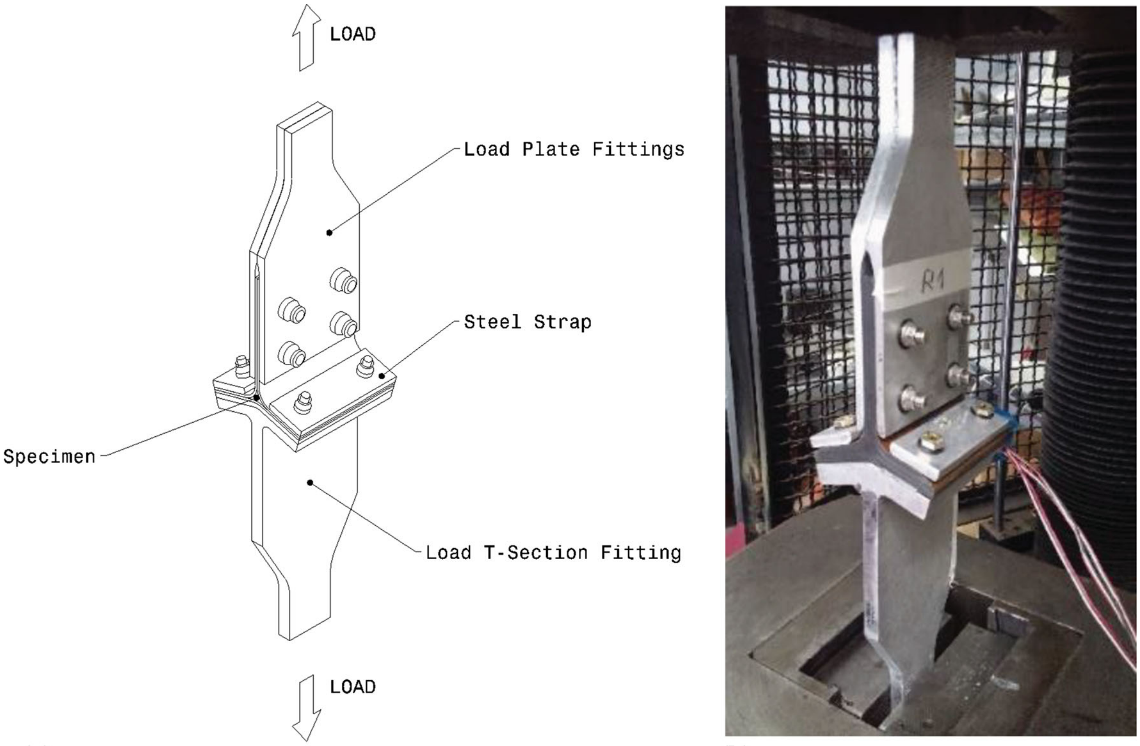

(a) **(b)**

Fig. 5 A waved one-shot cured box (a) and detail on node (b)



(a) (b)

Fig. 6 Sample representation



(a) (b)

Fig. 7 Static test design

the cable complexity over the test article, a sensor system is made by two multiplexed arrays of FBG.

The efficiency of different noninvasive techniques was also experimentally validated on the ITEMB coupon: DIC is an innovative non-contact optical technique for measuring strain and displacement, crack tip and propagation; it works by comparing digital photographs of a component or test piece at different stages of deformation. By tracking blocks of pixels, the system can measure surface displacement and build up full-field 2D and 3D deformation vector fields and strain maps. Such technique has been implemented in order to detect the tensional state in larger areas than as locally measured by wire-based sensors (Fig. 9, 10, 11).

Another innovative method used to forecast the shape and the location of the breakdown showed in the filler of the ITEMB coupons was the acquisition of images from a thermal camera. A thermographic camera is a device that forms an image using infrared radiation, similar to a common camera that forms an image using visible light, and thermal measurements can be potentially useful to understand the crack triggering inside the sample.

Investigation activities were completed by the use of high-speed camera to alternately identify the crack ignition area and progressive failure specifics.

3.2 Experimental Procedure and Results

An Instron-8801 servo-hydraulic fatigue 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.) This speed has assured a static loading procedure.

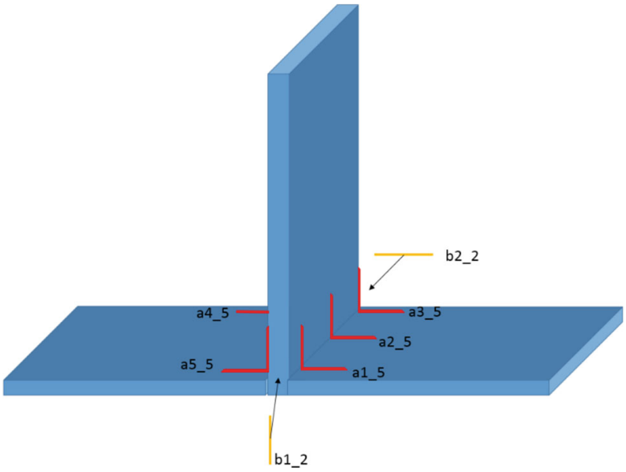


Fig. 8 Simplified sketch for the sensor system layout

All tests have been performed at RTA conditions (room temperature/ambient humidity 21 ÷ 25 °C, 45 ÷ 55% R.H.).

Before each test:

- each coupon has been named, marked and controlled (coupons dimensional check);
- required environmental testing conditions have been verified;
- all instrumentations have been reset;
- specimen is installed into test machine and pretest photographs have been taken.
- coupons vertical flange and opposite test fixture flange have been taken aligned (together with applied load), so some shimming (minimum thickness = 0.25 mm) has been required on bottom flange side to recover angular irregularities.

As evident from the above diagrams and table, most of the coupons presented first crack of the filler between 32 and 36 KN. Only two of them were below 25 KN. In any case, all data were largely above the required value (5 KN).

The FBG sensors showed the following results: FBG2-1, installed on the vertical side of the filler, highlights a compression, while the FGB2-2, installed on the horizontal side, highlights a traction. Excluded installation and measurement errors, FBG1-5/3/2/1 (installed on the edges of the coupon alongside the depth of it), show similar values of deformation, while FBG1-4 (installed in the center of the coupon) shows a lower value, suggestive of a slight nonlinear load alongside the laminate of the coupon.

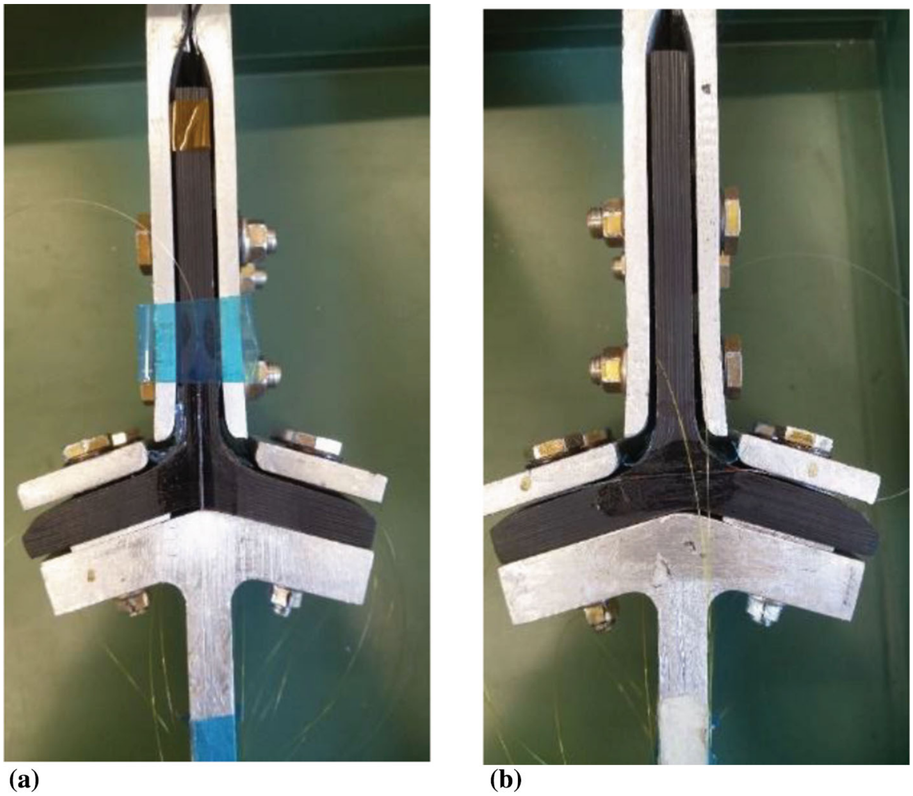
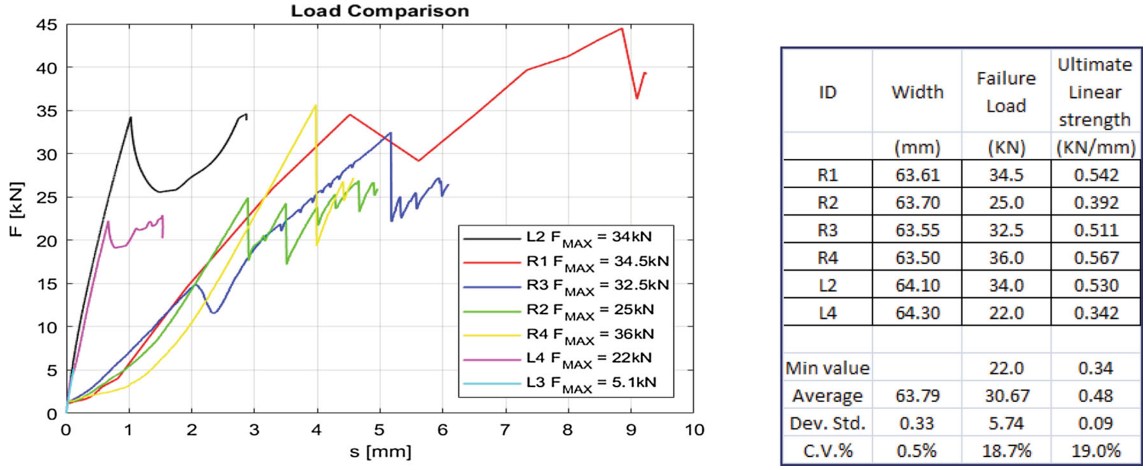

(a) (b)

Fig. 9 FBG sensors details



ID	Width	Failure Load	Ultimate Linear strength
	(mm)	(KN)	(KN/mm)
R1	63.61	34.5	0.542
R2	63.70	25.0	0.392
R3	63.55	32.5	0.511
R4	63.50	36.0	0.567
L2	64.10	34.0	0.530
L4	64.30	22.0	0.342
Min value		22.0	0.34
Average	63.79	30.67	0.48
Dev. Std.	0.33	5.74	0.09
C.V.%	0.5%	18.7%	19.0%

Fig. 10 Force/displacement diagrams and table

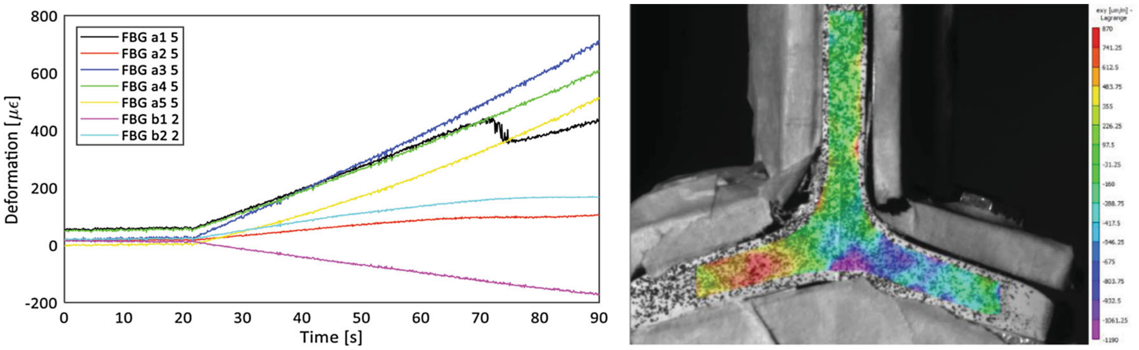


Fig. 11 FBG (left) and DIC (right) strains measurement

A very good correlation was appreciated by the comparison of FBG (Ref 2, 4, 8) and DIC (Ref 7, 13, 14) data with respect to the strain distribution.

The thermal camera measurements were useful to understand the crack triggering inside the sample, as shown in Fig. 12. The frame sequence highlights a compression of the filler, and then a sudden and symmetrical failure of it, that expands on each side of the coupon. The increase in the load over the failure brings other traction on the laminate.

This general behavior has been also confirmed by the high-speed camera pictures.

4. Final Demonstrator Production

Critical manufacturing steps of ITEMB one-shot curing process have been verified by the above-discussed small demo units and additional trials. Overall process feasibility has been largely demonstrated (Fig. 13).

Anyway, as ITEMB horizontal roof is of complex geometry, a final demonstrator has been realized representing the front segment of horizontal roof including two longerons, inner skin and pressure plate with dimensions of 1mt length and 1mt width. This area has been selected as it contains some specific geometrical complexities of the component (anyway already tested on smaller trials), like:

- curved longerons
- curved filler
- double curvature wavy skin
- more complex vacuum bag configuration

ITEMB HR lower fillers are curved in the transition zone between roof and center wing box. Curving a straight filler obtained by pultrusion process would generate wrinkles during bending. Therefore, a dedicated process has been envisaged, having demonstrated the feasibility of the curved filler by multiple-layer lamination. In the left picture of Fig. 14, curved CFRP filler is assembled in wet KFRP spar assy, where no wrinkles occur. In the right picture of Fig. 14, curved longeron is shown. Curved C-spar has been obtained by hot drape forming using a tensioning vacuum bag as shown in Fig. 15, where no wrinkles along radius area occur.

Figure 16 shows the representative final ITEMB demo.

5. Conclusions

The present work has been developed within the ITEMB framework, an European research project, under the supervision of Airbus. ITEMB intends to contribute to the optimization of air transport systems in accordance with the general objective of reducing CO_2 emissions and fuel

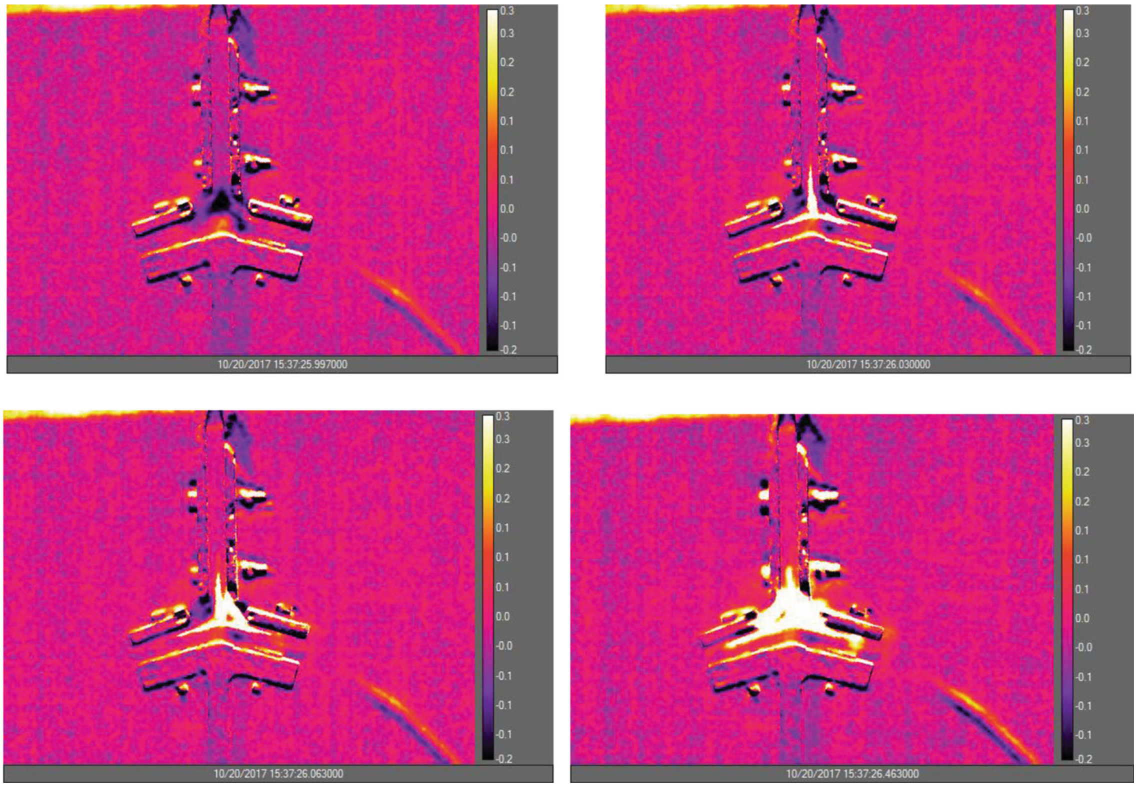


Fig. 12 Thermal camera sequences

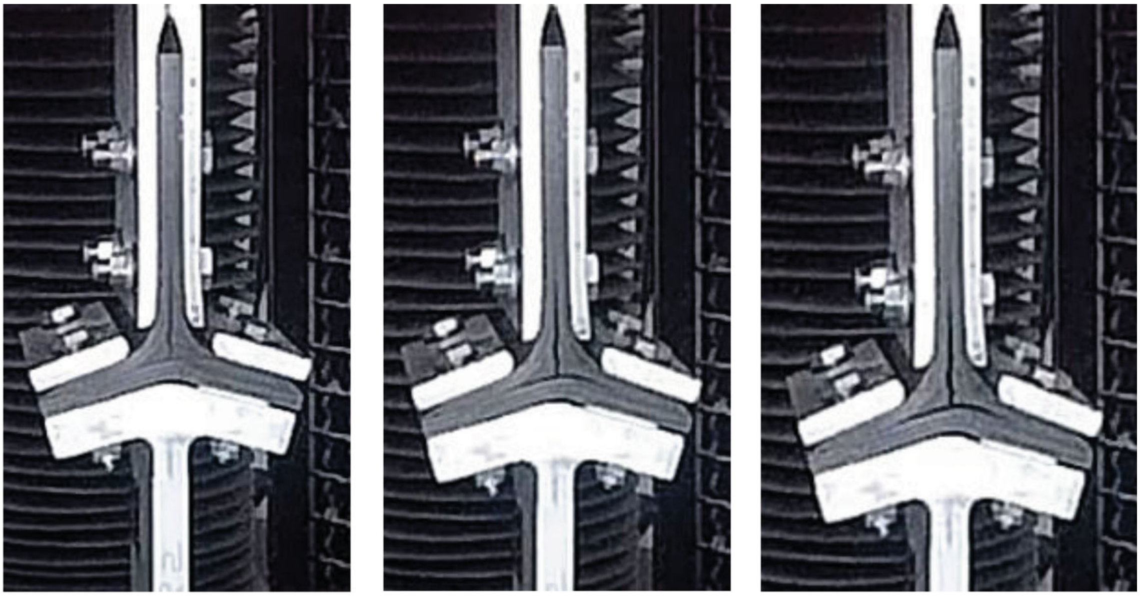


Fig. 13 Camera picture at test conclusion

consumption. Currently, in the typical configuration of medium-haul aircraft such as A320 series, the main landing gear bay is integrated under the wings and composed of metal parts; ITEMB intends to explore a different scenario, based on an integrated landing system in the fuselage of the aircraft and aims at conceiving a new structural configuration in which the MLG bay must be integrated. The approach is based on the implementation of composite materials. The manufacturing strategy followed the "bag against bag" approach which guarantees good compaction and quality of the final part.

Structural test on most critical elements has demonstrated the consistency of the design and the manufacturing process.

Representative demo of MLGB horizontal roof manufactured by one-shot curing process supports manufacturing feasibility, and consequently ITEMB study performed to verify that one-shot cured structure can provide a saving up to 80% of assembly recurrent cost.

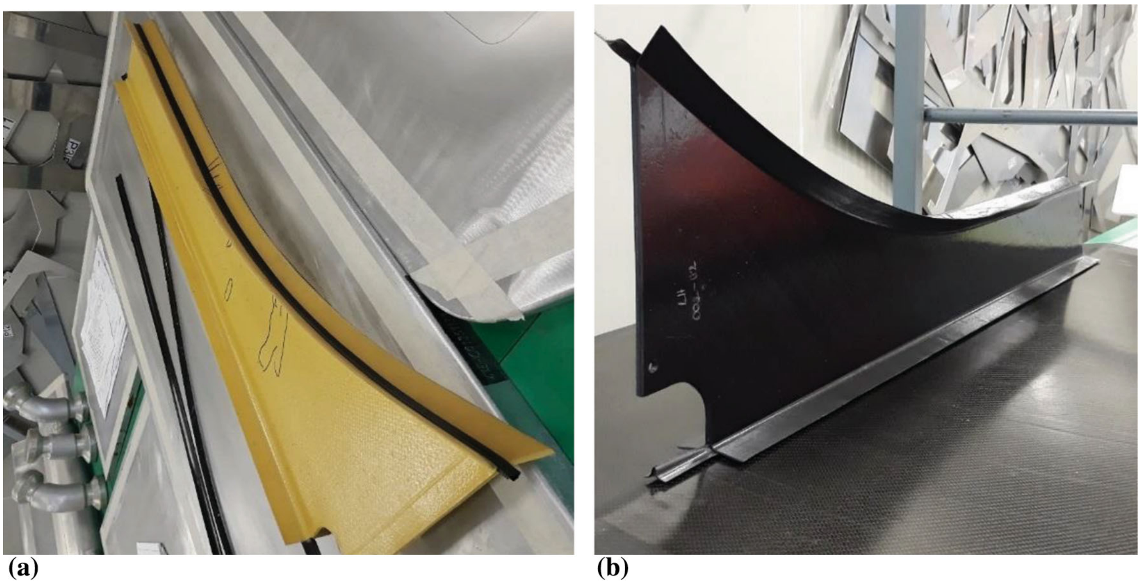


Fig. 14 Intermediate manufacturing trials curve filler (a) and curved spar (b)

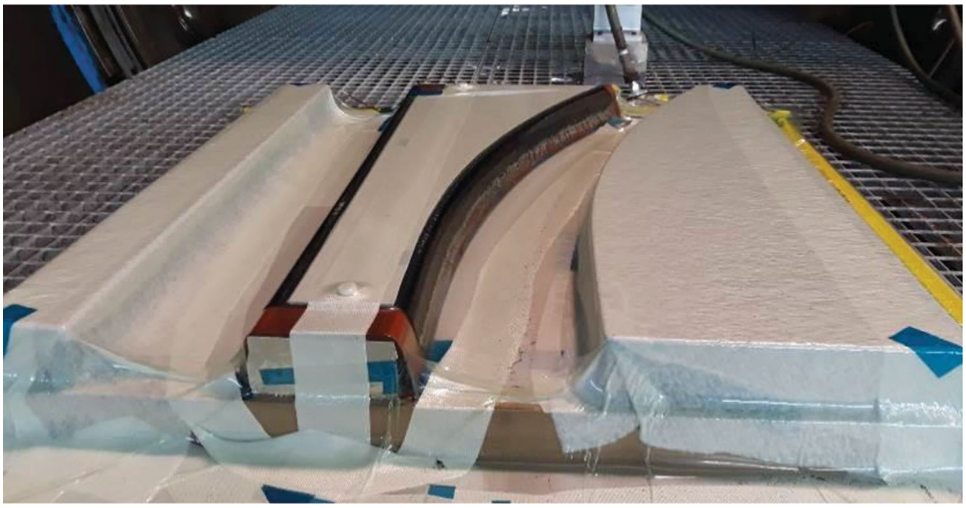


Fig. 15 Hot drape forming vacuum bag for wet C-spar

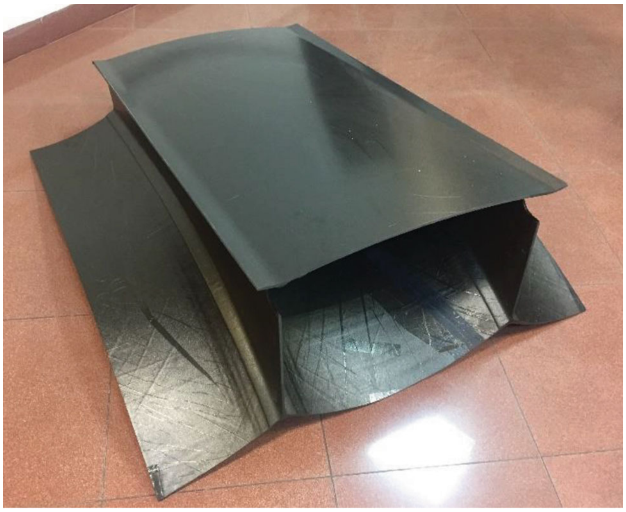


Fig. 16 Representative demonstrator of ITEMB HR by one-shot curing process

One-shot curing technology is promising and mature for further application and higher level of maturity up to flying components.

Acknowledgments

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