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# Design and fabrication of a helicopter unitized structure using resin transfer moulding

S. Laurenzi [a,*], A. Casini [b], D. Pocci [c]

[a] Department of Astronautic, Electrical and Energy Engineering, Sapienza University of Rome, Italy
[b] Aerospace Composites Center, AgustaWestland, Anagni, Italy
[c] Centro Sviluppo Materiali S.p.A., Rome, Italy

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ABSTRACT

We present the numerical and experimental studies for the design of a novel unitized configuration for the manufacture of a three-dimensional aerodynamic beanie using resin transfer moulding (RTM). The beanie is a component with complex closed-shell geometry, which is traditionally manufactured using autoclave processes that require several bonding steps during production. In our work we use a multidisciplinary approach to fabricate the component not through a succession of steps but rather integrating design and manufacturing into the realization of a pre-industrial RTM prototype, with significant reduction of the production time. The new RTM-based design has several advantages in terms of reduced manufacturing cost and enhanced mechanical properties. A bird impact analysis was performed to investigate the structural behaviour of the unitized solution. The peak contact pressure during the bird strike is reduced, as well as the maximum vertical displacement. At the same time, the total weight of the structure is reduced by approximately 26% and the production time of 47% with respect to prepreg manufacturing processes. Mechanical tests performed on the manufactured RTM-based prototype also show that the interlaminar shear strength is improved by 70% with respect to the prepreg-based ones.


## 1. Introduction

In the growing development of new preforming techniques and manufacturing processes the use of polymeric composite materials is spreading to components of complex shapes, including unitized fasten-less structures. The concept of unitized structures is an appealing design approach, as it implies a strong reduction of the number of assembling parts, of manufacturing cycle time and fabrication costs, while being associated with weight-saving and performance benefits [1–4]. For example, this approach is driving the development of novel design methods for the next generation of air vehicles [5,6]. Several patents deal with stiffened integrated panels, such as the aircraft vertical tail where pre-formed sleeves are co-cured with two skins [7], or the engine nacelle structures obtained from co-curing of skins, septa and truss score [8]. Recent scientific works focus on orthogonally-tailored skin-stringer design and stiffened panels [6,9]. The above mentioned cases show that, in general, the geometrical complexity of unitized structures is limited to small curvatures with rigid inserted ribs, and examples of unitized closed-shell composite structures are still uncommon. The main factors that prevent the realization of complex-shaped integrated structures are the manufacturing requirements, rarely the maintenance, or the subsystem integration necessities. Liquid composite manufacturing processes, in particular resin transfer moulding (RTM), are recognized as suitable approaches to overcome the technological limitations of structures with complex geometry [5,10–14]. Main challenges in the RTM manufacturing process are the design of the preform and of the mould, because both structural and manufacturing requirements need to be satisfied at the same time. The optimization of the injection scheme of the mould is another challenge, especially in the manufacture of components with complex closed-shell geometry.

This paper presents the numerical and experimental studies performed to re-design a helicopter closed-shell component with a unitized configuration using resin transfer moulding (RTM) technique. The component under investigation is the three-dimensional aerodynamic surface beanie that is used for protecting the rotor blades of the helicopter during flight. The beanie is a complex closed-shell element with double curvature, which is currently made by assembling different sub-components with secondary bonding (Fig. 1). The sub-components are originally manufactured separately using pre-impregnated materials, in a production cycle

* Corresponding author. Tel.: +39 06 49919756; fax: +39 06 49919757.
*E-mail address:* susanna.laurenzi@uniroma1.it (S. Laurenzi).

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that involves a large number of steps. The purpose of adopting the RTM process is to provide the component in a one shot injection, integrating the structure as much as possible with consequent reduction of labour. In the first part of the work we present the RTM fabrication concept and the bird strike analysis performed to illustrate the suitability of the novel unitized configuration. Then, we show the process simulations used to determine an optimal strategy for the injection scheme. The identification of the injection scheme allowed to design the RTM matched mould used to manufacture the component. The quality and the reproducibility of the fabricated parts were analyzed.

## 2. Unitized structure concept

The identification of a novel unitized configuration for the beanie component requires determining those elements that can be integrated in a unique preform while matching design requirements and manufacturing aspects as well. Main design requirements are maintaining the interfaces with the other helicopter components, preserving the aerodynamic characteristics, and ensuring resistance to the external loads. This means that the external geometry and the volume of the beanie component in the new unitized concept must be the same as those currently present in the helicopter. Fig. 1 shows a schematic of the beanie component and its elements. The beanie presents an aerodynamic surface with a rather complex double curvature, which is realized, in the original configuration, by overlapping adjacent sectors. The aerodynamic surface is structurally preserved using ribs, which also have the function of bonding the surfaces of two adjacent sectors (Fig. 2a). Every ribs and sectors are manufactured separately with an independent and repeated production process using autoclave technique. The aerodynamic surface is then jointed to the rest of the helicopter by the conical support that has a metal flange bonded at one extremity (Fig. 1). The conical support is also realized separately by prepreg technique.

A major saving in terms of time of production cycle can be achieved with a technological solution that adopts a three-dimensional preform including ribs and sectors. This configuration can be realized using a sacrificial mandrel that replaces the ribs, and where the aerodynamic surface is obtained directly by fibre deposition. In this manner, secondary bonding, sector and rib fabrication are eliminated from the manufacturing process.

Based on the above considerations, the proposed unitized configuration is formed by a mandrel made of close-cell foam on which the Kevlar reinforcements are layered (Fig. 2b). In this study, we identified the lamination sequence for a hand lay-up stratification. For future industrial applications the use of an automated preforming technique, such as knitting or braiding, can render

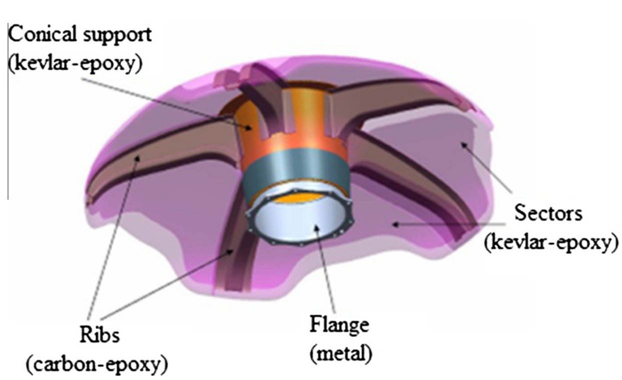


**Fig. 1.** View of the beanie fabricated in prepreg-based technique with indication of sub-components: sectors, ribs, conical support, flange. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

the realization of the preform more repeatable and cost-time efficient. The conical support and the metal flange can be also integrated in the preform as an extension of the aerodynamic surface preform. In this way, the metal flange is replaced by a composite one, therefore adding a great weight-saving feature to the configuration.

In the materials selection phase, Rohacell 51 was chosen as foam for the mandrel, whereas Kevlar 49, typically used in aeronautic applications, was considered for the skin and the other elements. In particular, we adopted the 5H Satin woven with area weight of $170 \pm 10\ g/m^2$. This fabric style was selected because of its good drapability that avoids the formation of wrinkles during the deposition on curved surfaces. For the resin, the aerospace mono-component epoxy RTM 6 by Hexcel was selected.

## 3. Structural analysis

The finite element analysis was performed to investigate the structural behaviour of the RTM configuration. The beanie is a main rotor aerodynamic cover that withstands impact events to protect the main rotor and the blades. Therefore, resistance to bird strikes is a basic structural requirement. The bird strike analysis is a non-linear dynamic analysis that can be solved using three different approaches: Lagrangian, Arbitrary Lagrangian Eulerian (ALE) or Smoothed Particle Hydrodynamics (SPH). The method used in this work was the Lagrangian one, which is typically used in the aeronautical field [15]. In this case, the numerical mesh moves and distorts with the physical material, allowing accurate and efficient tracking of material interfaces and the incorporation of complex material models. The bird strike event is schematized as the impact of a soft body on a rigid target, because the yield strength of the bird is much lower than that of the surface aeronautical target. For this reason, the volatile is considered as a fluid that produces loading profiles similar to those of real birds [15]. The code used for the simulations was LS-DYNA v. 970. The initial and boundary conditions were provided by AgustaWestland based on project requirements and following aeronautical standards: initial velocity 88 m/s, bird mass 0.9 kg, and impact energy 3.48 kJ. Two different impact scenarios were considered (Fig. 3): the impact at incidence angle of 0° and the impact at incidence angle of 30° as indicated by the industrial technical requirements.

### 3.1. Model

The finite element model for the beanie in RTM configuration was obtained by modifying the geometry of the original model. The aerodynamic surface was discretized using two-dimensional shell elements characterized by the constitutive law "MAT_ENAHANCED_COMPOSITE_DAMAGE "that allows to assign multiple layers. Particular attention was paid to the mesh construction in order to avoid abrupt transitions in the dimensions of the elements, with a possible discontinuity of the resulting stress field. Further, the number of elements was increased in the impact zone to ensure a more stable contact between the impacting body and the beanie, and a regular mesh pattern in correspondence of the transition between the positive and negative curvature. The foam was discretized using tetrahedral solid elements. The discretization was carried out in such a way that the nodes of the elements in contact (2D and 3D) coincide, assuming perfect bonding between foam and laminate. The beanie is connected to the helicopter body by fasteners positioned around the circular nut of the conical support. All nodes at bolt locations were restrained in all directions with the exception of the screw axis. The bird was modelled as a uniform cylinder and discretized with solid elements with 8 nodes. The hydrodynamic behaviour was obtained using the