HIGHLY INTEGRATED COMPOSITE STRUCTURES: PROCESS AND TOOLING CHALLENGES.

F. J. Chamorro[a], F. Domínguez[a*]

[a] *Fundación para la investigación, desarrollo y aplicación de materiales compuestos (FIDAMC)*
** felix.dominguez@fidamc.es*

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Abstract

The increasing relevance of composite materials and its extensive application on aircraft structures has been the principal driver to the development of a wide range of manufacturing processes and tooling configurations mainly aimed to obtain highly complex integrated structures. The alternatives this report briefly describes are listed below:

1. Thermal expansion PTFE blocks to complement the autoclave pressure
2. Metallic modular tooling
3. Deformable tooling
4. Inflatable mandrels

1. Introduction

This work tries to outline the most promising tooling configurations developed over the past few years in Airbus Group Innovations-Spain (FIDAMC) facilities that are and could be satisfactorily applied in future composite integrated structures.

Composites highly integrated structures, as they are referred in this article, are those structures where elements of different nature or function, which are normally joint together by means of bolts, are co-bonded in a single structure [4]. This kind of integration projects usually face different challenges:

1. Limited accessibility to certain points of the structure, which conditions the definition of the tooling, the geometry of the part and could jeopardize the final outcome.

2. Autoclave pressure might not be applied to all the elements to be pressed. In this case, solid laminates should be compacted by additional pressing elements.

3. Costs. Although the integration of different composite elements could definitively reduce the costs of the parts, part of those costs turns back in terms of tooling costs, which in the case of the integrated structures could be extremely high. It is so not only in production sets, but also during the development phases of the part.

2. FIDAMC projects development

All these challenges were faced and satisfactorily solved during the development of all the projects that are going to be briefly described in this review.

2.1. ATICA (Advanced Technology for Integrated Composite curved pAnels) - Expansion blocks

Ambitious project lead by Airbus Group (AOSL) and Airbus Group Defense and Systems (Airbus Military at that time) and carried out in FIDAMC facilities. The main target of the project was to integrate in a double curvature reinforced panel representative of the S-19.1 of the A320, an access for maintainability purposes (see Figure 1). All materials used were epoxy pre-impregnated materials: fabrics for in the variable section hat stringers and all the frames, and tape for layup the skin and the rest of the hat stringers.

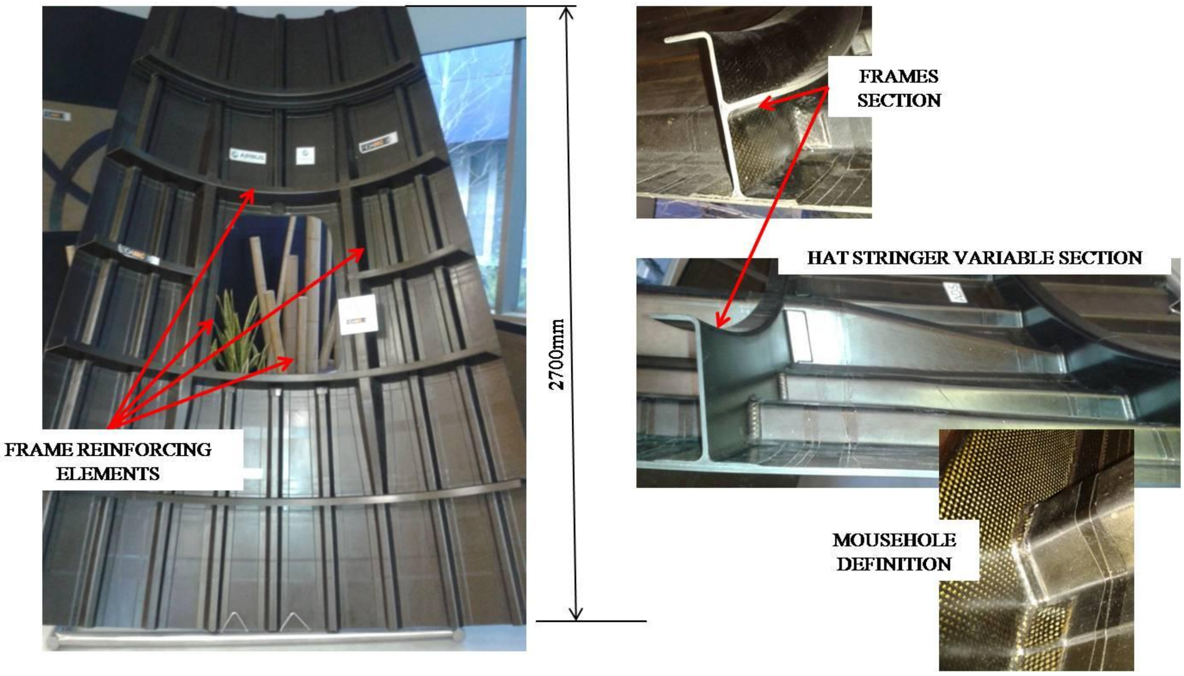

Figure 1: ATICA concept

The manufacture of covers with longitudinal reinforcing elements is a well known process that is widely used to manufacture all sort of parts. The main challenges come from the fact that also the frames and the reinforcing elements of the access hole are also co-cured with the cover. They all certainly complicate not only the geometry of all the elements involved and their interfaces but also the tooling (due to the limited accessibility) and the manufacturing process, since not all the parts to be compacted are accessible to the autoclave pressure. Therefore, an additional pressing element is required to ensure the structural integrity of the part. The thermal expansion induced in most materials by increasing their temperature provide the pressure require to complement the autoclave pressure. This is a concept already applied in other structures, such as the grid stiffened structures [5].

In the case of ATICA the elements that are not accessible to the autoclave pressure are the frames. The geometry of the frame is described in Figure 1. The upper, lower and intermediate cap are compacted by the combined effort of both autoclave pressure and the thermal expansion of the Teflon (PTFE) blocks. In the case of the web, which is not accessible to the autoclave pressure, only the Teflon blocks are the responsible of its compaction. The following figure reflects the sketch of the forces applied over the frame during the curing process.

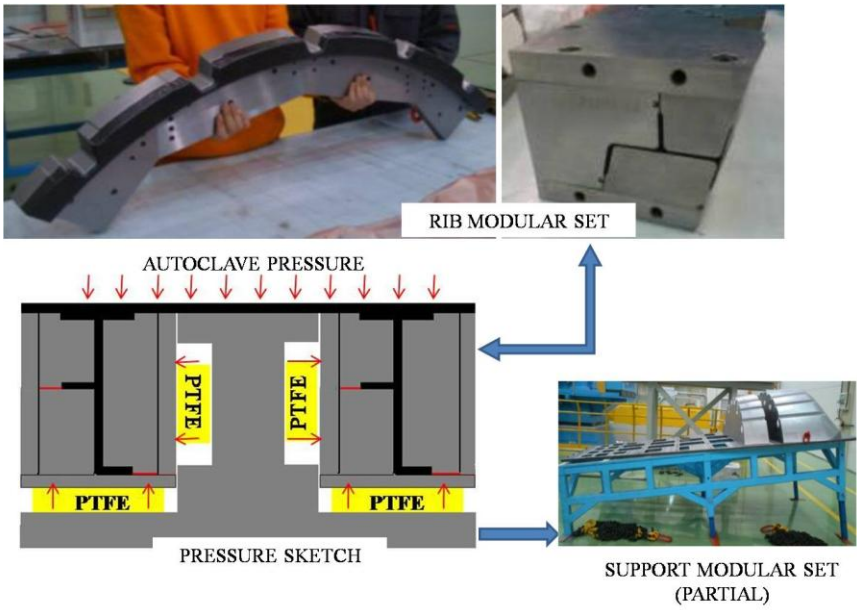

Figure 2: frame curing forces sketch and tooling details

The geometry of the hat-stringers that reinforce the access hole also poses certain difficulties to the manufacturing process. Since they do present a variable section, being the middle section of the part bigger than the rest (approximately section relation 1:4), a different tooling and/or process concept approach should be used. During the skin lay-up, when all the hat-stringers are placed on the male tool, instead of placing a lay-up mandrel inside the hat-stringers to create a continuous surface over which the fiber placement lay-up head applies compacting pressure it was decided to apply an specific lay-up approach where the FP head run over the hat stringer empty space and placed the fiber just by tension.

2.2. Rib to skin (RTS - Airbus Group) / HTP skin cover integration concept (Aernnova) - Metallic modular tooling

- *Rib to skin (RTS) - project lead by Airbus Group and financed within the frame of the ICARO cenit.*
- *HTP skin cover integration concept - project lead by Aernnova and also financed within the frame of the ICARO cenit.*

As a part of the recent efforts to reduce costs it has been developed new integration concepts for the horizontal tail plane (HTP) main box of the future single aisle aircraft; integration concepts that include all sorts of reinforcements. However, although it could be thought of this solution to be similar to the ATICA project already presented, the tooling concept and the manufacturing process are essentially different.

In both cases presented under this title, the composite parts are manufactured from a metallic modular concept where the autoclave provides the pressure and temperature the material requires to cure. No other element is involved to provide the curing pressure. In the case of the Rib to Skin project (see Figure 3), the particularity relies on the disposition of the tooling. The main design target is to keep at a minimum the number of elements to be moved around the workshop floor during the manufacturing process, although due to the particular geometry of the HTP and the level of integration of the specimen the number of metallic modules it is still too high.

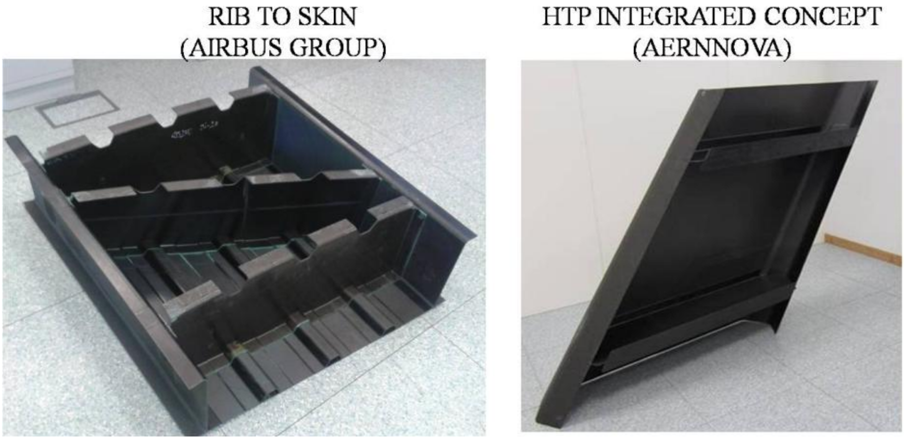

Figure 3: Rib to skin and HTP skin cover concept specimens

The tooling concept is reflected in the following figure. There is a set of modules bolted to the main support base that stays untouched throughout most part of the process. It is not even disassembled during the tool cleaning and conditioning prior to the manufacturing process. The rest of the modules are assembled to the ribs (which are resin transfer moulding -RTM, parts already cured) and they are inserted between the fixed modules. Adjustment between the cured parts and the tooling is critical, and it is also relevant the sealing system between the different elements to avoid drying the part during the process.

Figure 4: rib to skin tooling concept

Once the part is cured, the part is extracted from the tooling assembly. Searching for a point to hoist the part without damaging it during the de-moulding process resulted also quite challenging, and satisfactory resolved during the development of the project.

In the case of the Aernnova skin cover project, it presents a different concept solution in terms of composite design (see Figure 5). It does not present any longitudinal reinforcing element and the skin and both spars form part of the very same lay-up. All the elements are made of tape pre-impregnated epoxy material to be cure in one shot.

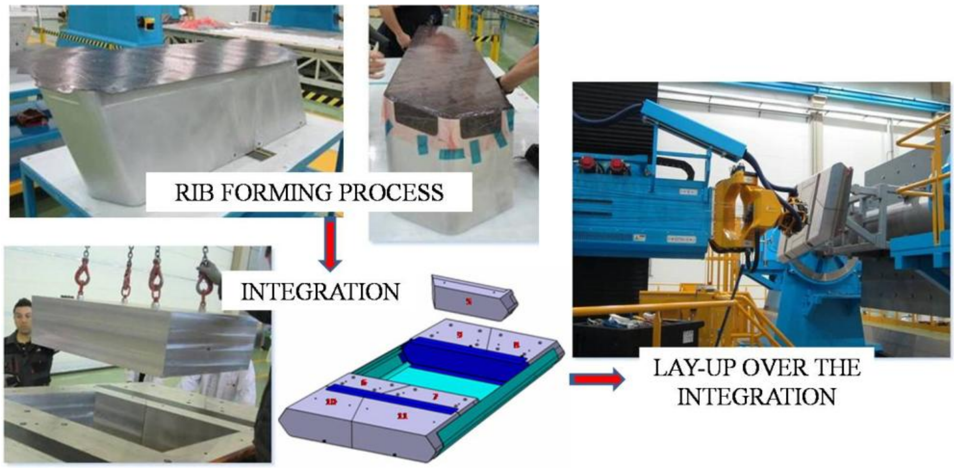

Figure 5: Aernnova project - HTP integration concept

From the manufacturing point of view, the main challenge is centered in the lay-up strategy, since the geometry of all the elements involved is particularly challenging. However, the modular tooling concept is similar to other processes already known, such as the A320 covers. The ribs are formed from 2 C-section preforms that are integrated together with the rest of the ribs and the space between them is also filled with modules. All together form the lay-up male tool over which is lay-up the skin and both spars. In this case, all the structure is vacuum bagged and cured in the autoclave. Therefore, all the elements are compacted by the autoclave pressure. No metallic thermal expansion or any other pressure agent are required to fully compact all the pre-impregnated epoxy elements.

2.3. Multispar HTP concept - Flexible tooling

- *Multispar HTP concept - project lead by ACITURRI (ARESA) and financed within the frame of the ICARO cenit (WP4.3.1)*

This project particularity is the study of the feasibility of the carbon fibre / airpad (Airtech commercial name for a rubber pad) combination to provide a robust tooling solution for areas of limited accessibility. An optimum combination of stiffness, to provide geometrically reliable and repetitive structures, and deformability, to ensure an easy extraction of the tool from the part once the specimen is cured. Therefore, first step of the process is defined the relation between CFRC/Airpad stacking and its deformability or stiffness. Then, it is necessary to adjust locally those properties over the tool to adapt it to the needs of the part.
As it was mentioned earlier, one of the main drawbacks of integration processes is the cost of the tooling. This is relevant not only when it comes to production sets, but also in the earlier stages of the development of any production part. Also, another important factor that increase the cost and the complexity of any process is the accessibility to certain areas, as it has been mentioned earlier.

Figure 6: ACITURRI HTP configuration and tooling examples

2.4. REMAIN - Inflatable mandrels

- *REMAIN - project lead by Airbus Group*

Another solution when trying to reduce the cost and complexity of the tooling used in very low accessible areas is the use of inflatable mandrels. An example of this alternative was carried out in the development of the REMAIN project, where it was necessary to integrate an RTM reinforcement doorframe to the skin it was bolted to (see Figure 7).

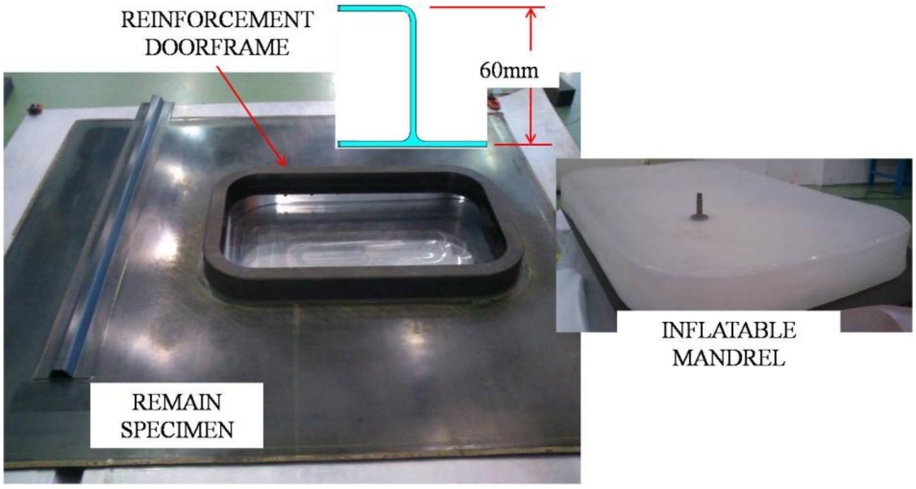

Figure 7: REMAIN description

The target was to lay-up the skin directly over the RTM reinforcement doorframe with the fiber placement machine. Once it was completed, it is necessary to cure the skin bonded to the frame. Although the pressure of the FP machine was supported by a single aluminum foil 3mm thick, during the curing process it was necessary to support and balance the autoclave pressure. Due to the particular geometry of the reinforcement doorframe, although a metallic modular concept would have done the work just fine, it would have cost a considerable amount of money. Then it was decided to replace the modular concept by a custom-made silicon inflatable mandrel (see Figure 7).

3. Conclusions

In order to select the most appropriate process and/or tooling when referring to highly integrated structures, several factors should be considered: costs, size, material availability, dimensional stability, durability are, among others, the main drivers of any choice. The tooling/process configurations listed in this paper, present a level of maturity that makes them eligible to be used in any process. However, each of the alternatives presents open issues to be improved:

- Modular tooling configuration: costs of such structures are very high. Also, time invested in handling all the elements during the manufacturing process is very high.
- Mandrel configuration: although cost of the mandrel manufacturing process could be high they could be easily paid off in production sets. However, the durability, in terms of dimensional stability (not very relevant though), and structural integrity, of these elements is yet at stake.
- Deformable tooling: the main issue was to ensure the dimensional precision of all the elements finally obtained.

In the particular case of mandrels and deformable tooling configurations, the maximum processing temperature is also a limiting factor.

In other situations, the technological improvement of the automatic lay-up processes or even the optimization of certain steps of the manufacturing process itself could lead to avoid using certain auxiliary tooling only required before the curing, such as the solution implemented in ATICA. However, it is important to notice that the requirements of any given process could be easily fulfilled with a combination of all the elements described in this paper: from the tooling to the process itself.

Therefore, future developments should be defined in the line of improving the main drawbacks detected: cheaper and simpler processing [1] materials [3] to create simplified modular assemblies; better processing and more resistant materials to obtain highly durable deformable tooling or inflatable mandrels [1]; increase the temperature requirements of the plastic materials used as an alternative of metals.

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