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Manufacturing requirements in design: The RTM process in aeronautics

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ABSTRACT

A sub-unit of an aeronautical structure (fuselage, fin, wing, etc.) consists of a set of components fixed rigidly together. One of today's major industrial challenges is to produce these sub-units out of composite materials in order to increase the level of integration and reduce mass and cost. This article describes a procedure to assist in the industrialisation of aeronautical components produced from composite materials in a design for manufacturing (DFM) context. In a multi-expertise approach, the problem of optimising integration is combined with the feasibility of injection for the resin transfer molding (RTM) process. This approach then takes into account admissible manufacturing deviations, defined from a classification of the structure parts. The limits set for admissible deviations guarantee the mechanical behaviour of the assembled component and the requirements of the assembly as a whole. Finally, an industrialisation solutions space is defined. A constraint satisfaction problem solver is used to carry out this research with a spar from a horizontal plane in an aircraft used to illustrate the procedure.

1. Introduction

When taking industrialisation into account in the design cycle [1–3] two distinct and complementary aspects must be considered: technical feasibility and economic feasibility. The technical feasibility of the RTM process imposes specific shapes and dimensions. Moreover, the RTM process can cause strain as parts are removed from the moulds, caused by the architecture of the laminate and the great complexity of physical phenomena around the parameters governing the RTM process. These strains are characterised by manufacturing deviations from which the true geometry of the part can be defined in relation to its design geometry (CAD model). In order to integrate a part into a sub-unit, it is often necessary to distort it. This is due to the highly over-constrained architecture of sub-units for aeronautical structures. If a part undergoes strain when it is integrated into a sub-unit this gives rise to mechanical stresses which could mean that the functional requirement of the sub-unit is not respected and could affect the mechanical behaviour of the part itself. With a classification of the structure components it is possible to identify those components for which significant strains are acceptable. These must then be quantified in order to define the induced stresses in the component and the stresses added to the sub-unit during the assembly phase. The aim of our study is to integrate these stresses generated in the part and the sub-unit by the assembly operation into the choices in the flow-process grid. The problems involved in integrating industrialisation into the design cycle are already taken into consideration in the expert rules provided by many aircraft manufacturers. These rules are the result of work by experts within the company. They have a limited area of validity and restrict the area available for design investigation. In this study our aim is to develop knowledge models in order to be more effective in finding the level of integration of the parts into a sub-unit, thus reducing mass and controlling costs.

2. Classification of composite structural components

A classification of the structural components identifies two types of component: type_1 and type_2. Each manufactured part is in contact with other parts in a sub-unit, which are called the adjacent parts. The adjacent parts will exert efforts via the contact surfaces, generating mechanical assembly stresses which are then distributed throughout the manufactured part and the sub-unit. These stresses can compensate for manufacturing deviations to a greater or lesser extent, in correlation with the strain caused by the shaping process. For type_1 components, mechanical assembly stresses have a great influence on the manufacturing deviations. Thus a fairly large defect can be specified in the general shape of the part in its free state. Stresses are characterised by geometric specifications associated with a stress condition [4], and the unit is shown on the definition of the part. However, mechanical assembly stresses should not exceed a certain maximum limit, determined by two criteria:

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- One criterion intrinsic to the manufactured part: mechanical behaviour.
- One criterion intrinsic to the sub-unit: stress condition beyond which the sub-unit will be too distorted, thus jeopardising respect for certain functional requirements.

For type_2 components, assembly stresses have very little influence on strain generated by the process. As a result, manufacturing deviations cannot be compensated by contacts from adjacent parts. This results in a specification for a much more serious default in the general shape of the part in its free state than for the type_1 components. When the expert rules are applied to type_2 components, these components have symmetry from a geometrical point of view and also from the point of view of laminate architecture. This type of design limits the risk of strain but does not allow for the optimisation of mass and function integration. The use of specifications for each stress condition often proves to be unhelpful. In the design phase this distinction between groups of components will influence the laminate definition.

3. Laminate design and rtm process

For parts with large dimensions, matter needs to be put in the places where stresses will occur hence the laminate is organised by zone. This is indispensable in order to reduce component mass. Each zone is a stack of fibers, with the juxtaposition of the zones ensuring variations in thickness. Each zone is defined by its shape, the number of fibers it contains and the orientation of each fiber in relation to a common frame of reference. Designing by zone in this way is linked with expert rules. In one of his papers, Gay describes an example of design by zone [5]. This organisation defines the optimised architecture for the laminate. To limit strain due to shaping, the unidirectional fibers are positioned using ply symmetry. Ply symmetry is the symmetrical arrangement of the stacks according to a design where the laminate is divided into two halves. In the RTM process, the stiffening pieces used are generally woven. This woven stiffener has a number of unidirectional continuous fibers or associated and oriented materials. In aeronautics, cost and delays in certifying composite material constituents can limit the types of stiffener that can be used. During the laminate design phase, an optimised architecture is defined for the laminate, this optimization is constrained by structural calculations; in the case of composite materials we use the laminate theory, however, using certified woven stiffeners may be the source of deviations between the optimised laminate architecture and the manufactured laminate architecture, and Fig. 1 illustrates this using an example showing the differences. To simplify the diagram, this example does not follow the rules of technological minimum [5]. This difference between the architectures impacts on the thickness of the laminate, and hence on the mass of the component and may give rise to strains. Organisation of the stacking is defined in a second phase in order to reach a compromise between reduction in mass and symmetry of stacking. We plan to use asymmetrical stacking for type_1 components. This asymmetry produces strains that are acceptable for type_1 components although not for type_2 components. Moreover, strains associated with using the RTM process are not caused solely by the architecture of the laminate. The different heat expansions of the constituent parts and the thermal cycles of polymerisation can also produce strain as parts are removed from the mould [6].

4. Different geometries for a type_1 component

During the industrialisation phase for a type_1 component, the aim is to estimate acceptable limits for manufacturing deviations in the RTM process according to the maximal limit of mechanical assembly stresses. As well as specifying the acceptable limits for manufacturing deviations, industrial practices and ISO standards for geometric specifications also lay down a stress condition that derives either from the criterion defined for manufactured parts or the criterion for the sub-unit, as defined in the paragraph above, “Classification of structural composite components”. To quantify the strains associated with the shaping process we will first define several component states. These definitions will be based on behaviours of the product in the design cycle. Each state is associated with specific stress conditions (Fig. 2). Free state [4]: the manufactured component is subjected only to the action of gravity and to the residual stresses of the shaping process. The sub-unit state corresponds to the mechanical stresses of assembly: the manufactured part is integrated into the sub-unit to which it belongs. Lastly, we define an Airplane state where the aircraft is in normal operational conditions. The Primary stresses state corresponds to the inspection stage, where manufacturing deviations in the part must respect the two criteria: assembly requirements and mechanical behaviour.

5. Industrialisation model and solutions space

The level of functional integration of an aeronautical sub-unit is determined by the ratio of the number of components assem-

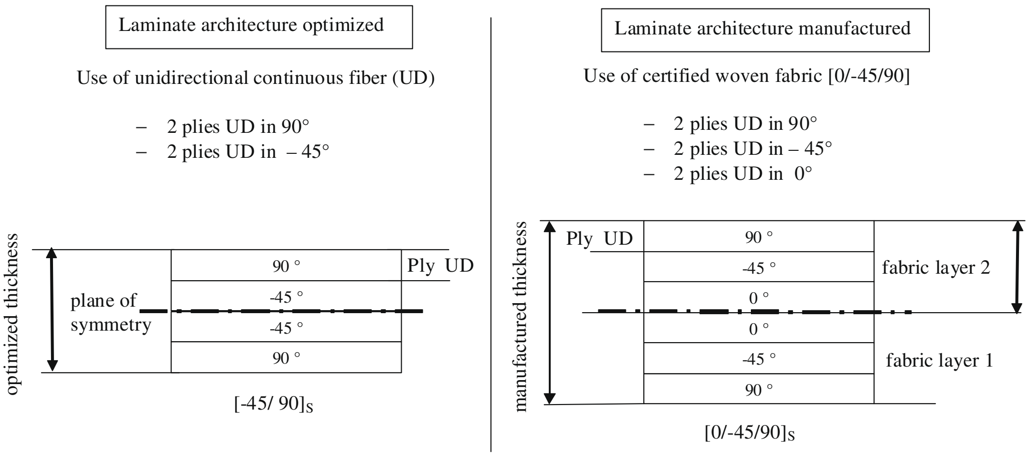

Fig. 1. Optimized and manufactured laminate architectures.