

Part Redesign: From Fastened Assembly to Co-Cured Concept

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ABSTRACT

During the course of an aircraft program, cost and weight savings are two major areas demanding constant improvements. An Integrated Product Development Team (IPDT) was set to the task of proposing potential improvements to an aircraft under development. From a list of potential parts, the IPDT selected one which was considered as the most suitable to leverage a co-curing process.

In the aircraft manufacturing industry, any major modification to a part design should follow the program's means of compliance to certification. Furthermore, to demonstrate the new design's safety, sizing methodology and all supplementary testing must fit in the certification strategy.

The IPDT approach was used to ensure the maturity of both process and part. Indeed, a mature turnkey solution can be implemented quickly on the shop floor. This IPDT approach is detailed in another SAE 2013 technical paper entitled: "A Novel Approach for Technology Development: A Success Story" [3].

This paper demonstrates how the part substantiation process was performed by the IPDT putting emphasis on the pre-sizing strategy. The part redesign and associated FEM modifications along with the simplifying hypotheses required to perform a quick pre-sizing will be presented. The co-curing test list complementary to the program's existing building block approach will also be explained. Finally, it will be shown how the leveraging of the co-curing process on an actual production part could be beneficial. Ultimately it should answer the program's needs while laying the groundwork for future improvements.

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INTRODUCTION

Initially focused on R&D activities, the IPDT was developing an enhanced co-curing process. This novel process allowed to co-cure relatively complex open-shape reinforcements on flat or curved panels, ensuring compaction of laminate by means of sliding, rigid molds.

In general, using a co-curing process is enabling the capability to move away from "black metal" part designs. In those conventional designs individual composite parts are conventionally assembled together with fasteners. It is clear that in this situation the full benefit of the composite materials is not taken advantage of. On the opposite, co-curing allows for a more integrated design that can be weight optimized. Hence, this process mainly offers the opportunity to reduce part count and to remove assembly operations. As a consequence, the need for tooling to manufacture individual parts is removed. This drives non-recurring costs down. Furthermore, co-curing eliminated the need for mechanical

fastening and shimming which leads to reduced assembly time thereby lowering recurring costs.

For its first technology demonstrator, the IPDT selected a stiffened flat panel to apply the novel co-curing process. The chosen part, taken from an aircraft under development, was considered the most suitable for a redesign taking benefit of the co-curing process capabilities. It consisted in a fastened assembly of metallic beams on top of a composite flat panel.

This article aims at presenting the steps taken for part reengineering in the context of a cost and mass reduction exercise. First, the part redesign to suit the co-curing process following the program design guidelines will be presented. Then, a detailed description of the stress analysis using program methodologies and finite element model (FEM) for margin of safety (MoS) calculations will be given. Lastly, will be explained the concept feasibility demonstration strategy through testing performed by Materials and Processes (M&P) and Stress disciplines. Moreover, the testing synergies between both disciplines will be outlined.

PART REDESIGN OVERVIEW

The original composite panel consisted of a fabric layup skin assembled with four machined aluminum I-section beams. The beams are joined by perpendicular sheet metal intercostals fastened to their web.

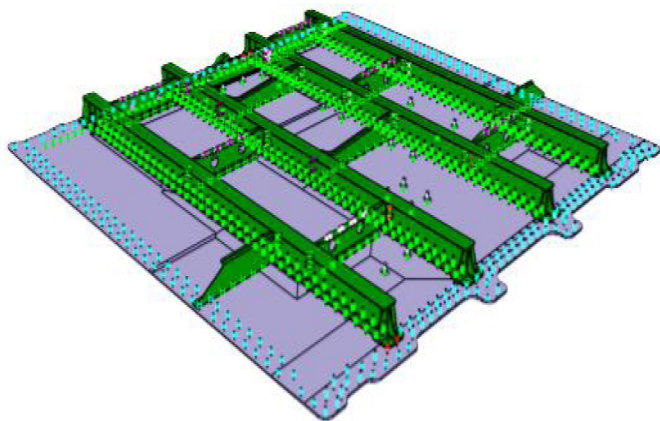


Figure 1. Representation of the original fastened design (metallic parts displayed in green, composite parts displayed in light grey)

The redesign for co-curing naturally led first to change the metallic beams for composite beams. Those beams would be directly co-cured on the panel.

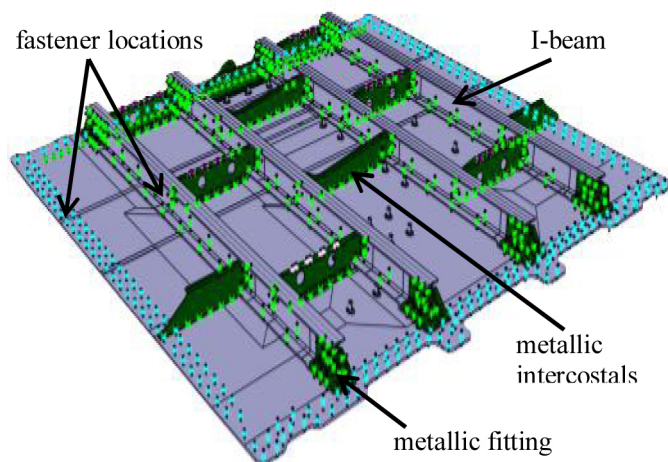


Figure 2. Representation of the cocured design (metallic parts displayed in green, composite parts displayed in light grey)

To reduce the laminate design and manufacturing complexity, the manufacturing process demands to keep surface variations to a minimum. In the case of a full fabric laminate the composite panel surface had multiple overlaps. To be more specific those overlaps are a consequence of panel dimensions surpassing the width of pre-preg rolls. Some difficulty in co-curing came from the panel surface which is "chiseled" for mass reduction purposes yielding an

assembly of zones with different thicknesses. Zone transitions contain multiple steps created because of ply additions and drops.

Since our co-curing process involves rigid molds on both panel top and bottom surfaces, those overlaps and thickness variations translated into a very complex mold surface. Indeed, surface variations across the panel had to be taken into account to ensure a uniform level of laminate compaction. Consequently, to reduce surface variation and remove overlaps a unidirectional (UD) ply laminate panel concept emerged. It consists of a UD laminate encapsulated with exterior fabric plies. Fabric plies minimize inlet and exit holes defects during drilling operations. They also greatly enhance the panel's impact tolerance.

Another modification arose to ensure tensile connection of the beams to the surrounding structure. Machined metallic fittings have been added and fastened through beam webs and skin flanges to panel skin. Those metallic fittings play a major role in load transfer and also provide support to prevent rotational instability (lateral buckling) of the beams. In this aspect we also take advantage on the current design which includes metallic intercostals supporting cable routing. Those intercostals support composite beams thereby increasing the margins of safety for both local and lateral buckling modes.

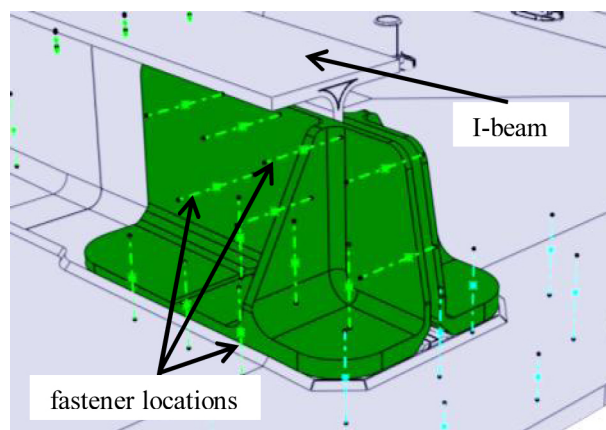


Figure 3. Metallic "bathtub" fittings (green) supporting beam extremities

Lastly, to reduce the burden of co-cured part certification, fasteners are installed through the panel's skin and beam's skin-flange. Instead of traditional assembly requiring a fastener pitch of 5 times the fastener diameter (5D), our design displays a 25D fastener pitch. Those fasteners counter the peeling effects that could occur at the co-cured junction thereby preventing disbonds and serving as crack arrest mechanisms. This approach has been validated by inter-rivet buckling analysis.

COCURING PROCESS EQUIVALENCE DEMONSTRATION

The strategy behind the process equivalence demonstration is to perform a partial process qualification. In

other words, only deviation to established process specifications will be addressed through tests. Material is already qualified and doesn't require additional testing effort.

Process equivalence takes place after the process has passed preliminary validation stages. It ultimately ensures part quality and process robustness. This means the process should be frozen to begin the qualification exercise. Preliminary validation includes confirming adherence to material cure cycle by monitoring part temperature using thermocouples. It also includes checking the quality of sensitive features (such as radii and end of parts) by evaluating polished cross-section of the manufactured part at various locations.

To provide proof of manufacturing process adherence to process requirements, M&P specialists must identify potential deviations from the program manufacturing guidelines and set up a test list to address each one. Mainly, the envisioned tests will be performed on panel and beam coupons to assess the laminate's physical properties. The test plan covers the following elements:

- fiber volume and void content measured,
- measure of degree of cure,
- glass transition temperature.

Lastly, mechanical testing will be performed on another set of coupons to assess the laminate's mechanical properties. These tests provide M&P process equivalence validation and will also serve stress in confirming the material allowables employed for sizing. This synergy aspect of testing will be covered in next sections.

OVERALL STRESS STRATEGY

Approaching the part redesign, the adopted Stress strategy includes three subsequent steps. First, stress specialists have to perform pre-sizing and validate the preliminary viability of preliminary design. At this point a preliminary stress report is produced. Second, stress has to devise a test plan to ensure all concept-level design choices are covered either by hand calculations or test results. Third, MoS are updated using allowables derived from mechanical tests. Modifications to the design are made if necessary. The final stress report is then produced, validating the final design. This is a conventional strategy followed in the aircraft manufacturing industry.

COCURED CONCEPT DEMONSTRATION: PRE-SIZING PHASE

Pre-Sizing Approach

The purpose of pre-sizing is to adjust the design variables through the initial concept design phase. As such, it is a quick stress sizing based on some simplifying assumptions such as load case selection for example. It ultimately aims at

evaluating if a concept is viable from a mechanical stand point. It is important to note that this pre-sizing is not enough to answer to all certification requirements. Indeed, following pre-sizing, a more thorough stress analysis of the adjusted design without simplifying assumptions is necessary.

In order to perform pre-sizing, stress aimed at comparing the baseline concept to the new co-cured concept on two different aspects. First, the new design had to exhibit similar failure modes and margins of safety for each mode at least equal to the baseline design. Second, the new design had to be at least weight neutral compared to the original assembled design. Taking this into account, the pre-sizing steps were as follows:

- Baseline FEM update
- Critical load cases identification
- Margins of safety calculations on beams and panel

Baseline Finite Element FEM Update

In order to quickly start assisting design it was decided to take advantage of the existing FEM local model. This detailed model, obtained from the aircraft program, represents the panel as well as its surrounding structure. Minor modifications were applied to migrate from the assembled to the co-cured concept. More specifically, the beam material was changed to composite; metallic fittings were added; fastening pattern was corrected and panel laminate definition was updated.

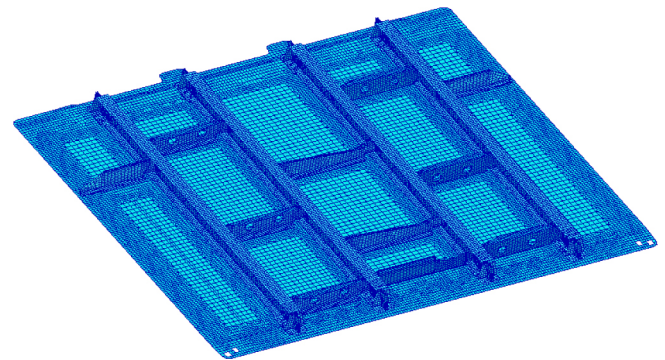


Figure 4. FEM representation of co-cured design

Critical Load Cases Identification

In the case of an aircraft program there are hundreds of load cases to produce representative mechanical and thermal behaviors of a structure. All those load case definitions are needed for certification purposes. Incidentally, the generated results are cumbersome to use and contain much more information than what is actually necessary to perform a pre-sizing. It was decided to select only the few load cases primarily influencing sizing to reduce computational and post-processing time. This simplification enabled stress to