# NOVEL APPROACHES IN DETAIL DESIGN OF COMPOSITE STRUCTURES: CASE STUDIES

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**Abstract**

*The detail design plays a vital role in the development of composite structures by exploiting the ability of composites for integral construction through cocuring technology. Detail design takes into account the requirements from stress, tooling, manufacturing and assembly to conceive the component. This paper addresses two case studies, wherein, the detail design of components in the wing of a transport aircraft was carried out using integral construction. The design was compared with the existing design on a prototype aircraft. The ingenuity of configuration led to several benefits associated with cocuring. In the first case, the wing tip structure was designed with fewer parts co-cured with reduced weight and part count thereby amounting to lesser tooling and manufacturing effort. In the other case, the flap track rib was designed by integrating two I-section ribs into one composite rib which led to increased stiffness and smooth diffusion of flap track loads into wing structure.*

***Key words**: CAD, Layout, Solid modeling, Composites, Co-curing*

## Introduction

Advanced composites are becoming the materials of choice for aircraft designers in general and carbon-epoxy composites in particular because of the numerous advantages like higher specific strength and stiffness, mouldability etc. Fighter aircrafts traditionally have used a large amount of composites compared to passenger aircrafts. With the higher demand on the performance of structures, passenger aircrafts are now being designed with a large composite content. Composite materials are best employed when smaller components are integrated into a single large component using co-curing technology. The principal advantages of this technology are the elimination of stress concentration due to fastener holes, reduced fuel leakage when used in a fuel tank, reduced assembly time and associated costs [1].

Design of composite airframe should meet all the functional requirements throughout the targeted life of aircraft. It is more often than not the structural failures occur because of improper detailing at regions of stress concentrations even though overall stress levels are within the limits. Owing to the anisotropy, brittleness and limited through-the-thickness strength, the carbon-epoxy composites require that these limitations are rigorously addressed. The performance in respect of desired life of airframe could be easily missed by a factor of 100 or more when the structure is improperly designed [2]. Detail design addresses these concerns by the smooth diffusion of loads into the structure. Composites present an excellent opportunity for integral construction which can further be exploited for smooth diffusion of loads through bonded joints thus eliminating the stress concentrations caused by fastener holes. However, cocured joints should be properly designed to avoid peel stresses. In addition, cocured construction will require a complex tooling. In order to arrive at an optimum cocured component in the early stages of the design, the detail designer has to liaise with stress, tooling and manufacturing departments. Subsequently, a simple and producible design is churned out by detail design which harmonizes conflicting requirements from various groups.

NAL has played a key role within the country for the development of cocured composite structures using both prepreg materials and infusion technology. In recent years, alternative processes like liquid composite moulding are being widely researched and NAL has developed a patented process called VERITy (Vacuum Enhanced Resin

Infusion Technology) for the development of cocured composite wing for a transport aircraft [3]. The composite wing was designed to replace a metallic wing under the weight reduction program. This paper addresses case studies, wherein, the detail design of two components in the wing were carried out using cocuring of carbon-epoxy composite components to get reduced part count and weight.

## Approach to Detail Design

The main objectives in detail design of composite structure are simplified construction, minimum number of parts and fasteners, ease of tooling and manufacturing, and lighter in weight. The design is carried out by maintaining interchangeability requirements (ICY), geometry of the structure and system requirements within the constraints of space. Initially, the preliminary layout is prepared using 2D software, in which, detailed configurations and connections are examined through various options. The component modeling [4, 5] is done in 3D software in order to ensure the interference among the components, space analysis and installation of fasteners. Finally, the production standard drawings are prepared where the layup detail, process detail, tolerances, inspection, and other related details are shown. This methodical procedure enables to facilitate the preparation of manufacturing drawing, solid modeling, tooling drawings, and assembly drawings.

## Case Studies

### Case 1 : Wing Tip Structure

The wing tip has functional requirements like installation of tip light, potentiometer and its linkage with aileron for its positional measurements. The design around this region has several constraints viz, [3]

- Accessibility requirements for mounting the instruments and limited space towards trailing edge
- Complexity at the junction of front and rear spar to connect skins through doublers
- Introduction of parts due to the closing angles and sequencing of parts for assembly
- Proper protection of wing tip from lightning strike

Wing tip was designed with a combination of metallic and GFRP parts for prototype aircrafts and the construction is shown in Fig.1.The GFRP skin was fastened to stiffeners and this removable assembly in turn was mounted on metallic spars. GFRP aft skin was mounted to the rear spar and aft rib as a fixed assembly along with the trailing edge metal piece. GFRP removable aft cover was attached with the aft skin. The wing tip light was fixed at the web of metallic C-rib at the juncture of nose box which was covered by transparent acrylic cover.

Design of these components was done with doublers and clips to avoid complex machining of components and assembly. The following were observed which led to increased part count, fasteners and weight in the existing design from Fig.1.

- Provision of two doublers over IS rib which is a machined C section to receive removable skin assembly
- Provision of two doublers on front spar to receive nose skin portion to avoid large stock size for the spar
- Provision of shear clips to connect the spars with IS ribs
- Riveting of trailing edge piece to aft skin
- Riveting of stiffeners to removable skin

It was proposed to make all parts out of CFRP by addressing the above limitations using cocuring and modifying certain components. Modified design was carried out as enumerated below.

Entire rib from front spar to trailing edge was made as a single piece which gave additional stiffness to the local structure to receive the aileron outer hinge. IS rib is combination of I and C section in-between spars and aft of rear spar respectively. The I section and co-cured gussets of IS rib were provided to avoid doublers and shear clips respectively. Transformation of I to C section at aft region of the IS rib was to facilitate the aileron installation. The modified design is shown in Fig.2 and Fig.3. Geometry and features of the cocured components are shown in Fig.4a, 4b and 4c. Appropriate layup sequences were designed so as to minimize discontinuity between layers during this changeover [1]. Details of the lay up for IS rib are shown in Fig.5. Furthermore, both the J section spars of wing were terminated at the IS rib and sparlets (front and rear) were designed with I section to eliminate the doublers to receive skins. Solid trailing edge was cocured with aft skin thereby eliminating heavy metal piece. Stiffeners in removable skin were reduced from two to one and relocated stiffener was cocured to the skin.

The modified design of wing tip led to a 50% reduction in part count, weight reduction over 31%, and reduced fasteners by 32%. The reduction in part count and number of fasteners facilitates lower manufacturing efforts, lesser assembly time and associated cost benefits. The comparison in terms of CAD weight, part count and number of fasteners of a modified design with existing design of a prototype aircraft is given in the Table-1.

**Table-1 : Comparison of Modified and Existing Design Configurations**

| | Existing | Modified |
|---|---|---|
| Weight (CAD) | 3.173 kg | 2.204 kg |
| No. of Parts | 21 | 11 |
| No. of Fasteners | 190 | 130 |

### Case 2 : Flap Track Rib

The aircraft under consideration was designed by the project office with single slotted Fowler flap mounted on two rollers moving in two guide tracks and two links. The rollers are mounted on flaps and guide tracks are mounted on the wing with links connecting the track and flaps. This arrangement made the flaps to move in a coordinated fashion to achieve the required rotation as well as translation. The challenge was to design with sufficient stiffness of local structure thereby avoiding excessive deformations to achieve required motion. The junction between inboard and outboard flaps required two back-to-back flap tracks with a spacing of 30mm mounted on aft ribs. This case study provides the details of converting two metallic aft ribs into one composite aft rib and its benefits. The design around this region has several constraints viz, [3]

- Maintaining of ICY for flap tracks
- Installation of the fasteners on closely spaced tracks on aft rib
- Insertion of the parts while assembly in the limited available space.

In the existing design, the tracks were mounted on two independent I-section metallic aft ribs. The rib 1 and rib 2 were in turn connected to rear spar web and gusset of rear spar respectively. Due to the limitation of machining and stock size, ribs were made unconnectedly. The assembly of ribs with tracks mounted is shown in Fig. 6. Tracks were redesigned from a curved to a linear grooved track for the functional requirements.

In the revised configuration, the single integral rib was designed by combining these two aft ribs as a box section. The assembly of rib with tracks is shown if Fig.7. Since both tracks were mounted on this rib, the shear transfer at the rear spar junction was addressed by proper design of layup and maintaining the continuity between web and flanges. Rib had an access at one end to remove the dissolvable core while fabrication. Additional requirement of a curved gusset to receive flap shroud was included in the aft rib as shown in Fig.8. The lay up details of aft rib are shown in Fig.9. The advantages by integrating the ribs are increased stiffness, reduced part count and reduced fasteners thereby reducing the assembly time along with cost reduction. A substantial weight benefits not achieved due to the revision in track design. The comparison in terms of CAD weight, part count and number of fasteners is made in the Table-2.

**Table-2 : Comparison of Existing and Modified Configurations**

| | Existing | Modified |
|---|---|---|
| Weight (CAD) | 1.734 kg | 1.724 kg* |
| No. of Parts | 2 | 1 |
| No. of Fasteners | 213 | 75 |
| * after revision in flap track design | | |

## Conclusion

Composites present an excellent opportunity for integral construction which can further be exploited for smooth diffusion of loads. Detail design plays vital role by harmonizing conflicting requirements and yet arrive at a part that is structurally superior and simple to produce. This paper addressed case studies, wherein, the detail design of two components in the wing was carried out using cocuring of carbon-epoxy composite components viz. design of wing tip and aft rib for installation of flap tracks. A comparison was made with an equivalent design on a prototype aircraft.

Design of wing tip had constraints like accessibility, limited space, assembly issues due to multiple members and provision of lightning protection. The challenge was to work out the layup for the IS rib when the configuration changed from I to C section. Modified design was 31%

reduced weight which was attributed to the combined effect of material change from glass-epoxy and aluminum alloy to carbon-epoxy. Further, integral construction led to reduced part count by 50% and fastener count by 32%.

Design of aft rib had constraints apart from being a loaded member. Design was done by integrating two aft ribs on which two back-to-back flap tracks were mounted. The layup details for the aft rib were worked out. Aft rib was designed with higher stiffness compared to the metallic design and both the designs weighed the same. However, integral construction led to reduced part count by 50% and fastener count by 65%.

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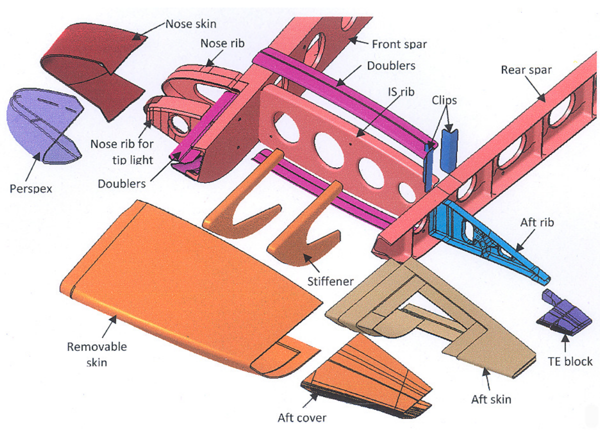


*Fig.1 Exploded View of Existing Wing Tip Structure*

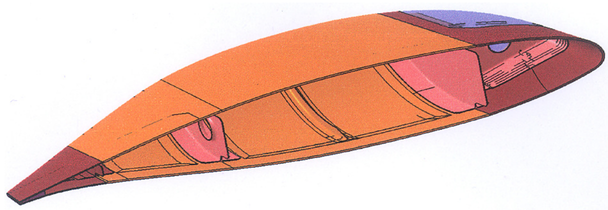

*Fig.3 Assembly of Wing Tip (IS Rib not shown)*

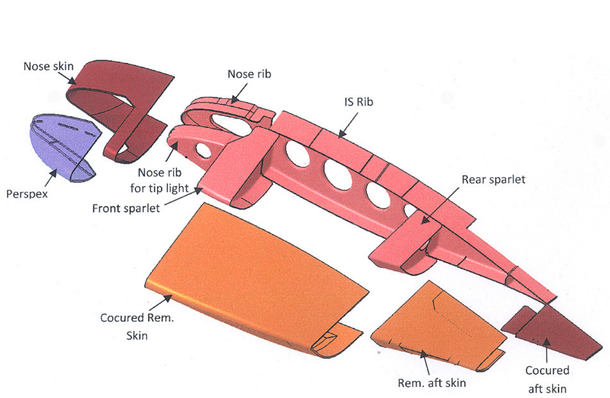


*Fig.2 Exploded View of Wing Tip Structure*

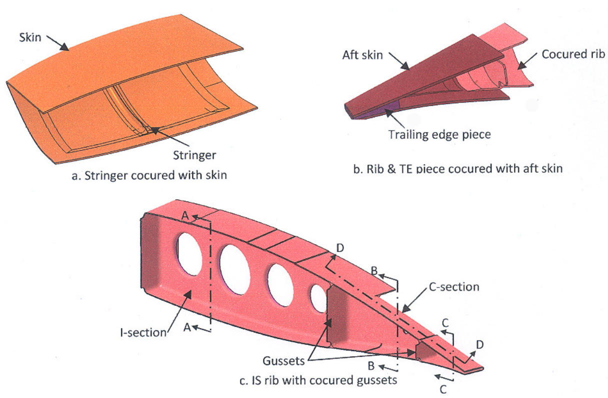


*Fig.4 Co-cured Components*

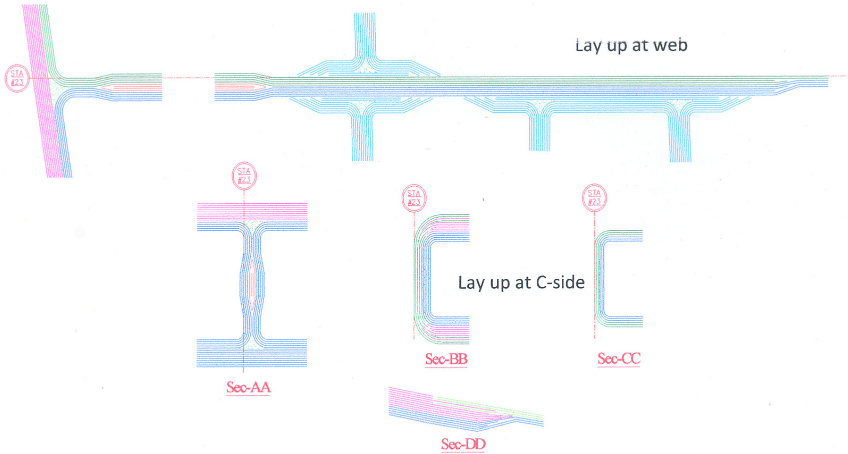


*Fig.5 Lay-up Detail of the IS Rib (Sections from Fig.4)*

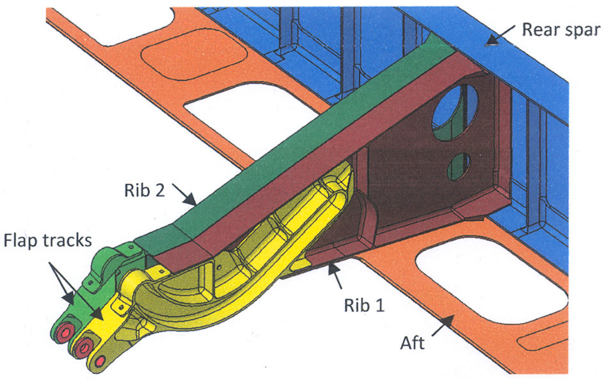


*Fig.6 Existing Flap Track Ribs in Assembly*

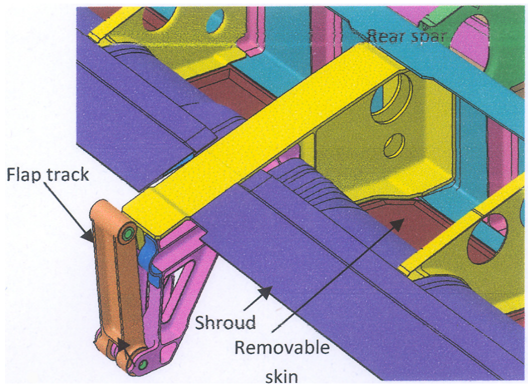


*Fig.7 Modified Flap Track Rib in Assembly*

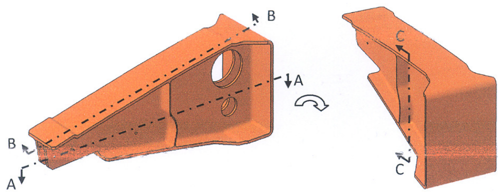


*Fig.8 Geometry and Features of the Aft Rib*

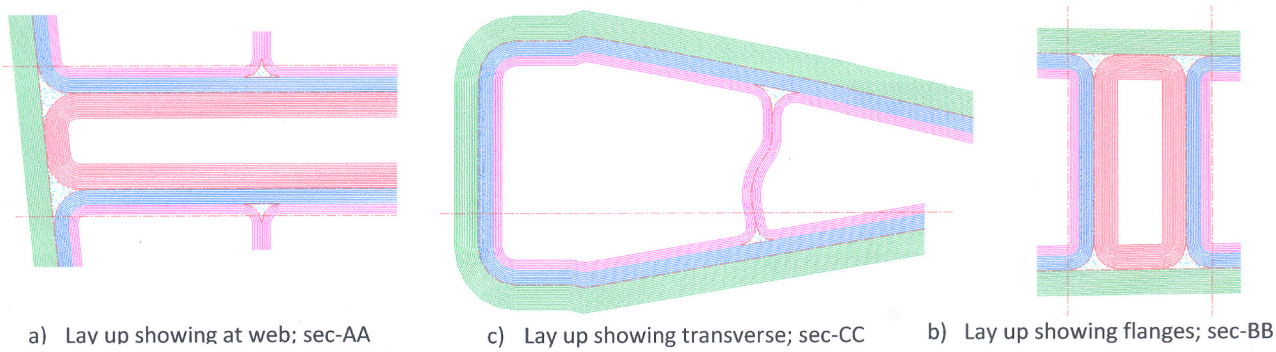


*Fig.9 Lay-up Detail of the Aft Rib*