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Design, Fabrication, Static Testing and Analysis of Composite Wing box using E-Glass Epoxy Composite

B. Siva Prasad[1]
Assistant Professor,
Department of Aeronautical Engineering,
Vignan's Institute of Technology & Aeronautical Engineering,
Hyderabad-508284, India

CH. Ravinder Reddy[2], P. Srikanth[3], B.Nikhil[4]
Department of Aeronautical Engineering,
Vignan's Institute of Technology & Aeronautical Engineering,
Hyderabad-508284, India

Abstract: **In general sense, wing can be assumed to be cantilevered to the fuselage. All airplane wings need longitudinal members to sustain the bending moments. These moments are caused due to lift force which acts upwards. Thus the lower cover is loaded primarily in tension and upper cover is loaded primarily in compression. As a result of the all lift forces evolved, there is a large moment created at the intersection of the wing and fuselage. Those moments cannot be sustained by wing and fuselage attachments. All these moments are withstand by Wingbox which connects with to the fuselage. The present investigation deals with the design, manufacture and structural testing of a composite wingbox made out of E-Glass epoxy. Finally the results are validated using FEM (Nastran) software package.**

Keywords: Fuselage, wing, lift, moment, composite, structural test, wingbox, E-Glass epoxy.

I. INTRODUCTION

The structural design of an airframe is determined by multidisciplinary criteria (stress, fatigue, buckling, control surface effectiveness, flutter and weight etc.). Several thousands of structural sizes of stringers, panels, ribs etc. have to be determined considering hundreds of thousands of requirements to find an optimum solution, i.e. a design fulfilling all requirements with a minimum weight or minimum cost respectively. The design process involves various groups of the airframe manufacturer and its suppliers, and requires the application of complex analysis procedures to show compliance with all design criteria. Traditionally the structural sizes of a wing box are determined by the stress group of the airframe manufacturer or its supplier. This is done by analysing the stress and buckling reserves for a few selected loads.

Modification of the structural sizes usually affects not only local stresses but also the internal load distribution. Therefore, this approach requires an iterative, complicated and time-consuming process. Since the design process is performed with a few dominating load cases only, there is a risk of not meeting the design criteria for the complete set of design driving load cases. Furthermore, fatigue requirements are only considered on an approximate basis [2], [3].This can result in re-work and additional cost when the full set of load-cases and fatigue criteria are considered later in the design process. Due to resources and time limitations, the manual iterative process is usually stopped after achieving a design which is feasible, from a strength viewpoint, and which is close enough to the target weight. This design is not necessarily a minimum weight design. A typical schematic of a wingbox is shown in Fig.1.

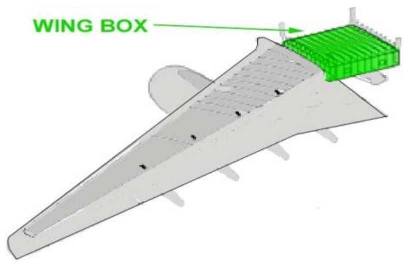

Fig.1. Wing Box

II. METHODOLOGY

As per the literature survey [1], the outer dimensions of the wingbox at root section should be as follows

Length	320 mm
Width	370 mm
Height	70mm

TABLE 1. Scaled Configuration of Wing Box

The load distribution[1] along the span of the wingbox is shown in Fig.2, Shear force and bending moment calculations for the selected wing are given in Fig.3 &4.

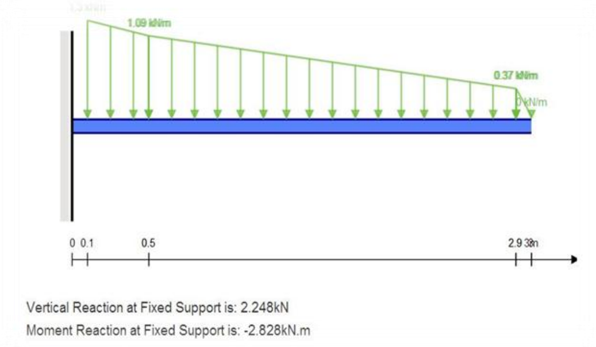

Fig. 2. Wing Loading

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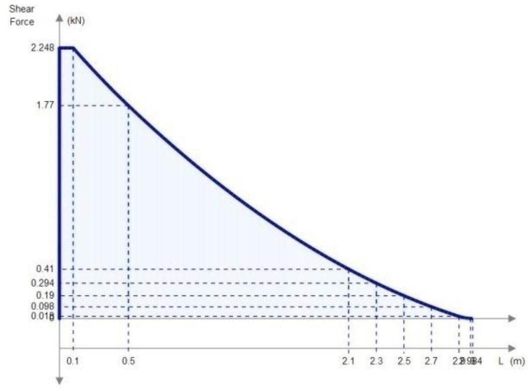

Fig.3. Shear force diagram

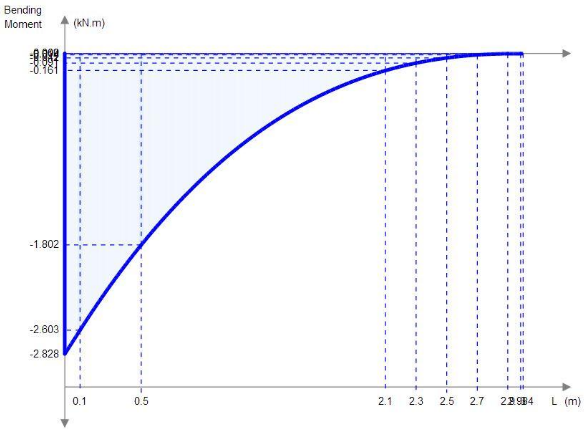

Fig.4. Bending Moment Diagram

By using deformation theories as follows, we can formulate an equation to find the thickness of wingbox C-section[5],[6,],[7], [8]

$$\frac{M}{I} = \frac{F}{Y}$$

M = Bending moment
F = Flexural strength

Considering the aerofoil section in the wing to be a box section for calculations convenience (Fig.5).

The moment of inertia at each station is calculated, which is the function of t (composite thickness). We will get equation in terms of t, composite thickness is obtained after solving the equation. Span-wise wing thickness is obtained.

The chord-wise thickness is obtained by CFD analysis. The aerofoil is divided into 5 zones chord-wise. With the varying pressure values in zones the thickness is obtained.

The estimated composite thickness for one ply from previous results is 0.5. Therefore to get 7.5 thickness 15 plies are used.

CALCULATIONS

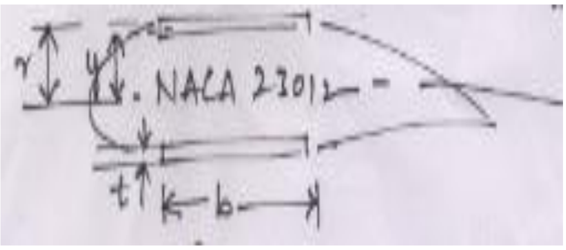

Fig.5. SHOWING WING BOX DIMENSIONS

Bending moment at station 0

$$r = \frac{maximumthickness}{2} = \frac{142}{2} = 71$$

$$I_{xx} = 2[\frac{bt^3}{12} + AY^2]$$

b is 55% of chord=653mm

t thickness of composite unknown

$$\frac{M}{I} = \frac{F}{Y} = Z$$

$$I_{xx} = 2[b \times \frac{t^3}{12} + \left[(b \times t)\left(y - \frac{t}{2}\right)^2\right]]$$

` Finally t = 5.68 at station ‘0’

Considering the factor of safety and ply drop-off, the minimum thickness of composite is increased to 7mm

t = 7mm

III. DESIGN OF MOULD

The Matched Die Molds (Fig.6) are initially designed in CAD software and manufactured. These moulds are used to make the required composite parts.

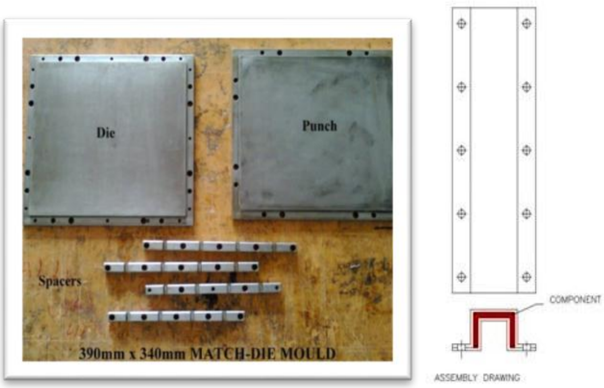

Fig.6. Matched Die Molds

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IV.SELECTION OF MATERIAL

A. E-Glass Fabric

The use of E-Glass Fabric as the reinforcement material in polymer matrix composites is extremely common. Optimal strength properties are gained when straight, continuous fibers are aligned parallel in a single direction. To promote strength in other directions, laminate structures can be constructed, with continuous fibers aligned in other directions. Such structures are used in storage tanks and the like.

Technical specifications:

1. Nomenclature : 13 mil E-GLASS FABRIC
2. Thickness, mm : 0.36
3. Width, inch : 40"
3. Weave : 4 Harness Satin

B. Resin and Hardener

Resin and hardener used in this project are Lapox L-12 (Resin) and K-6 (Hardener) respectively.

V.FABRICATION OF WING BOX

As the other layup techniques involve lot of workload, equipment and costly and time consuming we preferred to use the hand layup assisted Matched Die Molding technique as it exactly suits our requirements.

A. Fabrication of E-Glass Epoxy Laminates & C-Sections

Single layer of a laminated composite material is generally referred to as a ply or laminate. It usually contains a single layer of reinforcement, unidirectional or multidirectional. A single lamina is generally too thin to be directly used in any engineering application. Several laminae are bonded together to form a structure termed as laminate. Properties and orientation of the laminae in a laminate are chosen to meet the laminate design requirements. Properties of a laminate may be predicted by knowing the properties of its constituent laminae.

The various steps involved in the manufacture of composite laminate are

1. Marking the fabric as per the mold dimensions
2. Mixing of matrix (Resin and Hardener (1:10))
3. Application of resin mix on the fabric
4. Lay up on the mold
5. Closure of Mold

Finally it is allowed for 24 hours to cure the rectangular laminate / C-section. After the curing is over, the laminate and C-Sections are trimmed using diamond edge cutter at the edges to match the planned dimensions.

The specifications of the rectangular laminate and C-section are given in the following tables.

Rectangular laminate specifications

Length	370mm
Width	320
Thickness	5mm
Number of laminates	2

TABLE 2. RECTANGULAR LAMINATE SPECIFICATIONS

C-section specifications

Length	3700mm
Width	40mm(WEB)&70mm(flange)
Thickness	16mm

TABLE 3. C-SECTION LAMINATE SPECIFICATION

Fig.7. Top view of wing box

Fig.8. Front View of Wing Box

Dimensions of wing box.

Length	370mm
Width	320mm
Height	80mm
Number of rivets	28

TABLE 4. DIMENSIONS OF WING BOX

VI. TESTING AND ANALYSIS

The static analysis of wing box is carried out using NX9 software. Being a structure the main loads on the wing acts as the cantilever loads, the main purpose of the wing box is to with stand the cantilever loads acting on the wing as they are interconnected. So we can analyse the load effect on the wingbox [10].

The composite wing box structure was then tested and analysed under the designed loads.

A. Static Analysis in NX9

Earlier we have designed the wing box structure in the solid works software and later imported to NX9 for the analysis, now the simulation file is updated.

The meshed body and loading conditions are shown in Fig:9. The analytical results obtained i.e. the displacements for various applied loads are shown in Fig. 10, 11 & 12.

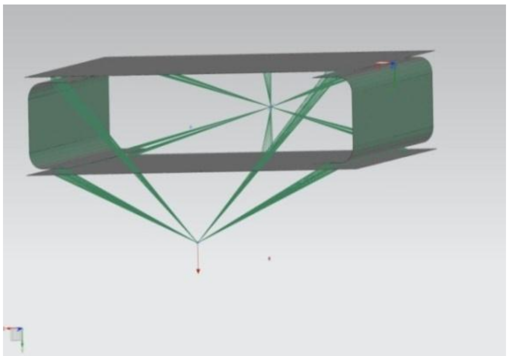

Fig.9. Boundary Conditions

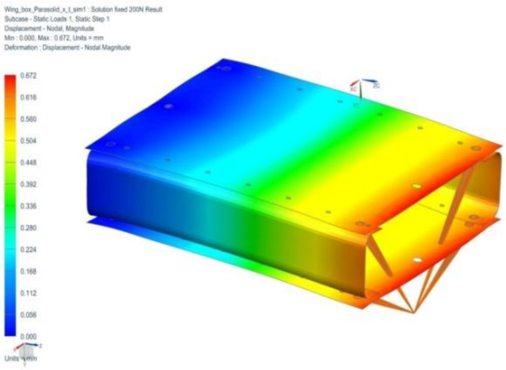

Fig.10. Displacement for 1500N

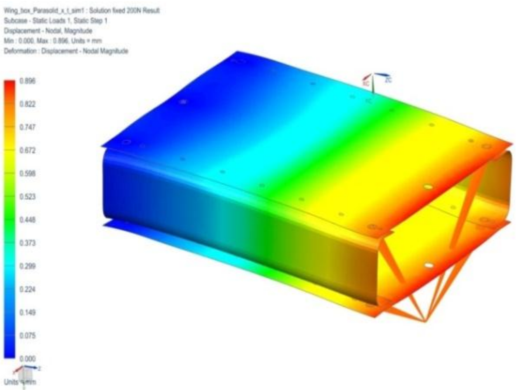

Fig.11. Displacement for 2000N

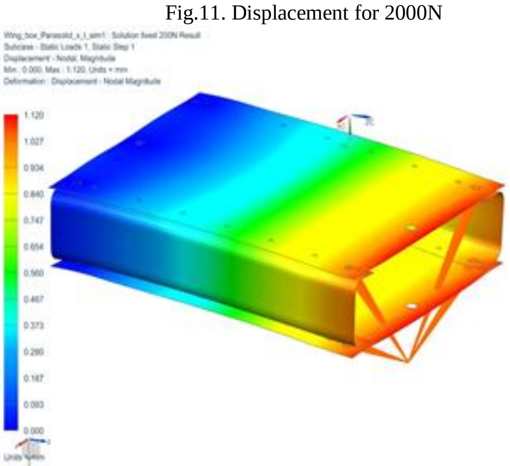

Fig.12. Displacement for 2500N

B. Experimental Testing

The experimental analysis is done now to correlate the computational results

1) Test Setup

3 holes are drilled to wing box at one end to fix it and other end 2 holes are drilled to apply loads. Then a loading setup as shown in Fig.13 is attached to the wingbox at its free end to apply loads.

Fig.13. Experiment Set Up

2) Deflection meter

The deflection of beam for particular load is obtained using the deflection meter attached at the free end of the section as shown in Fig.14.

Fig.14. Deflection Guage

The loading has carried out by gradually increasing the loads and the respective applied loads and its response to the applied load were noted down carefully. The various deflections resulted due to the application of various loads are shown in TABLE 5.

Load(N)	Experimental deflection(mm)
200	0.7
230	0.8
250	0.9
270	1
300	1.05
320	1.14
350	1.25
500	3.25
1000	7.1
1500	12.45
2000	18.95
2500	23.15

TABLE 5. Load and Deflection

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After the application of 2500N load at the free end we have observed De-Laminations at fixed end. We considered it as a failure and stopped loading it further. The De-lamination at the fixed end are shown in Fig.15.

Fig.15. Component After Final Testing

C. Comparison of Computational and Experimental Analysis

Load(N)	Computational deflection(mm)	Experimental deflection(mm)
200	0.0896	0.7
230	0.1031	0.8
250	0.112	0.9
270	0.121	1
300	0.134	1.05
320	0.143	1.14
350	0.157	1.25
500	0.224	3.25
1000	0.448	7.1
1500	0.672	12.45
2000	0.896	18.95
2500	1.12	23.15

TABLE 6. Comparison of computational and experimental analysis

VII. CONCLUSION

The following conclusions are derived

1. The values of deflection in the experiment is not too close as compared to analysis because of unpredictable behaviour of composites.
2. The experimentation is not as simple as fixing the boundary condition in software, so the constraints play a major role
3. The computational stiffness of structure is very high compared to experimental, this may lead to property validation of composite material
4. The present results generated are used to validate the property of material or it can also be used as a research topic for further projects

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