STRESS, FATIGUE ANALYSIS AND WEIGHT OPTIMIZATION OF WING-BOX WITH SPLICE JOINT OF A TRANSPORT AIRCRAFT

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Abstract - ***Wings are the structures of an aircraft which produces lift. Wings are attached to fuselage through wing-box structure. Wing-box usually includes parts like spars, ribs, wing-skin, stringers and rivets. Splice joints are used as it is strong, reliable and have inherent fail-safe features. The wing-box considered for the current work is made of Aluminium 7075-T651. The present project work deals with the stress, fatigue analysis and weight optimization of a wing-box with splice joint of a transport aircraft to determine the life for crack initiation and to increase the efficiency of the aircraft. Modeling is done using CATIA V5, stress analysis using MSC Nastran/ Patran. Life estimation of the component is carried out and finally the component is weight optimized.***

Key Words: Wing-box, ribs, spars, CATIA V5, MSC Nastran/ Patran.

1. INTRODUCTION

The word 'AERODYNAMICS' comes from two Greek words, aerios and dynamics. Aerios refers to the air and dynamics which means force. AERODYNAMICS is the study of forces and resulting motion of objects through the air. Many forces like lift, drag, weight and thrust act on the aircraft.

An aircraft is made up of different parts but few are very important like Fuselage, Wings, Empennage, Flight controls surfaces and Landing gear. Wing-box is an attachment in the wing and fuselage region. The fixed end of the wing-box experiences stresses, Life estimation of the wing-box for 1091 blocks is carried out and finally weight optimization is done.

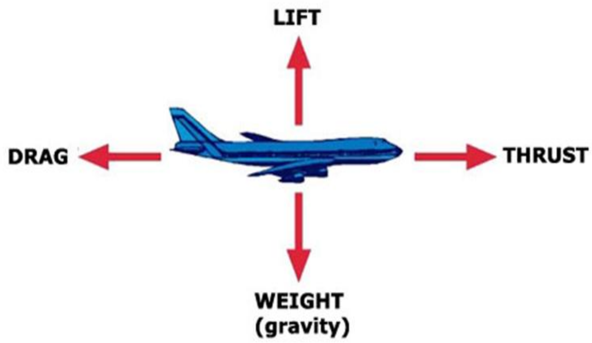

Fig -1: Major forces acting on an aircraft

1.1 Definition and use of wing-box

Wing-box is an important structural component in the aircraft which provides the support and rigidity to the wings. Wing-box is attached to the region where there is an attachment between the wings and the fuselage where both tensile and compressive forces act.

Wing-box is an attachment in the wing[3] and fuselage region. It provides necessary strength to the wings so that the component can withstand high stresses during takeoff and landing.

2. STRESS ANALYSIS OF WING-BOX

The WING-BOX is analyzed using linear static analysis. For the analysis MSC PATRAN is the pre-processor and post-processor and MSC NASTRAN[1] is the solver.

Wing-box is made of Aluminium 7075-T651. This is used in aircraft structures due to its high strength structural applications, and corrosion resistance.

2.1 Geometric Modeling

The first step in the analysis of wing-box is geometry creation. Wing-box is imported from CATIA V5 CAD tool by converting the file into parasolid model file. Fig-2 shows the geometry of the wing-box.

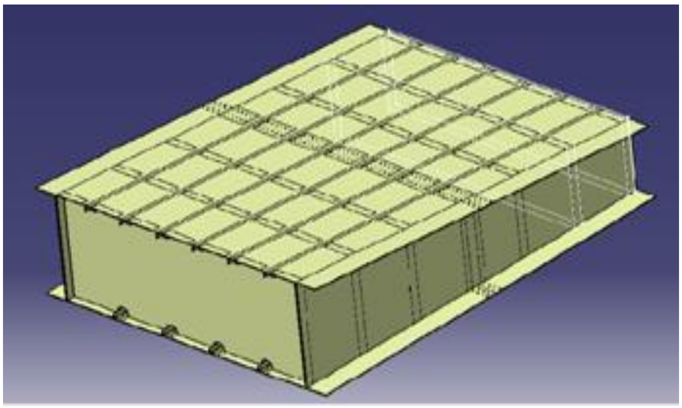

Fig -2: Model of the wing-box

2.1 Meshing

The second step in the analysis of wing-box is to create Finite Element (FE) model. Geometric model is meshed using triangular and quadratic elements. Fig-3 shows the finite element model of the entire wing box.

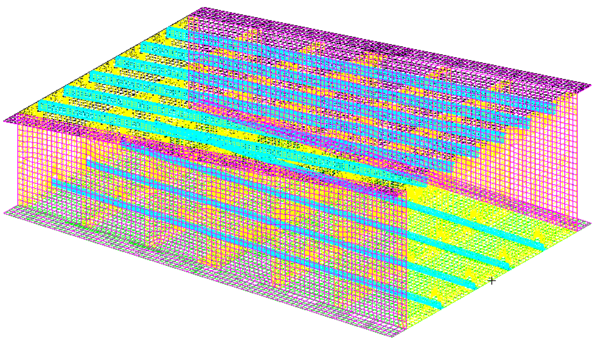

Fig -3: Finite element model of wing-box

2.3 Assigning Material Properties

Aluminium is used in aircraft structures due to its high strength structural applications, and corrosion resistance. The wing-box is made up of aluminium 7075-T651.

- Young's Modulus, E=71700N/mm^2
- Poison's Ratio, μ = 0.33
- Ultimate Tensile Strength, σ_u =572N/mm^2
- Yield Stress, σ_y= 503N/mm^2

2.4 Application of Loads and Boundary Conditions

Wings are the important structures in an aircraft which carries 80% of the total load of the aircraft. Fixed end of the wing-box is constrained in all the six DOF and load is applied at the free end.

Actual force acting= 3g
= 262662.75N

Load acting on wings = 80% of the total load
= 210130.2N

Length of each wing = 7150mm

Fig-4 shows the representation of load acting on the wing.

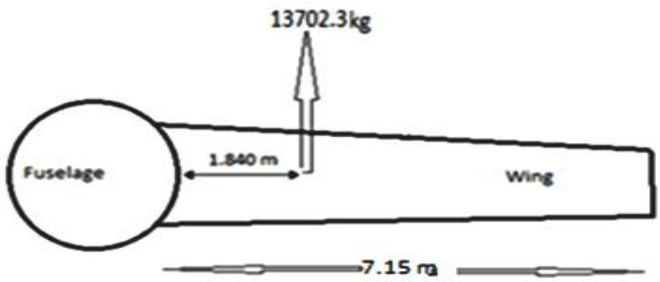

Fig -4: Load acting on wing-box

2.3 Stress Analysis Result Plots

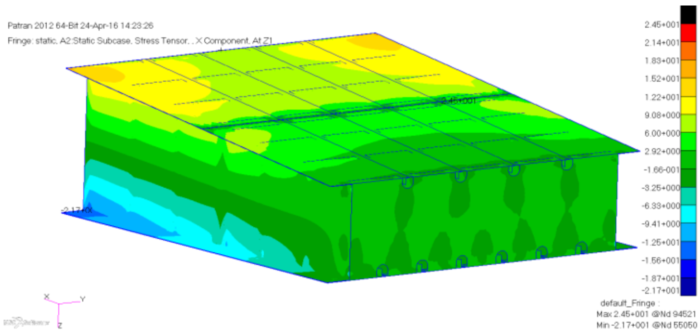

Fig -5: Maximum principle stress on wing-box

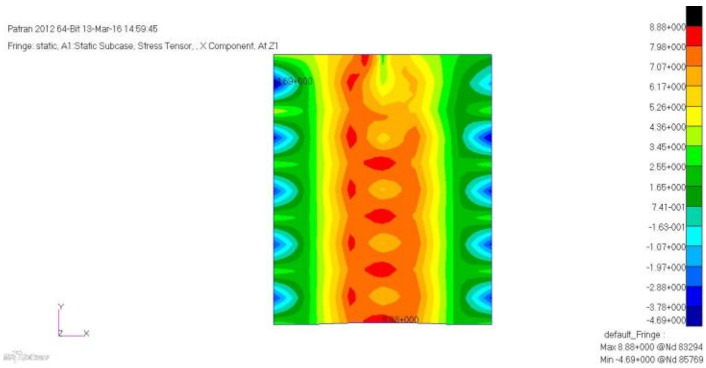

Fig -6: Stress contour on splice joint

3. FATIGUE ANALYSIS OF WING-BOX

Fatigue analysis is carried out to determine the life of the wing-box structure when subjected to repetitive load. Life of the structure is found out as a sum of crack initiation and crack growth life[2]. The transport aircraft considered for the current work is designed for **1091** blocks. Life estimation to meet 1091 blocks is carried out. Table-1 shows the load magnitude ranges.

Table -1: Load Magnitude Ranges

Range of 'g'	Actual number of cycles 'N_i'
0.5g to 0.75g	40000
0.75g to 1.00g	55000
1g to 1.25g	38000
1.25g to 1.5g	25000
1.75g	500
2g	300
2.5g	250
-0.5g to 1.5g	100

3.1 Calculation of Fatigue Damage

By using Palmgren-Miner hypothesis, which is the simplest technique for predicting the fatigue performance. It states that "Fatigue damage occurred at a given stress level is proportional to the number of cycles applied which is divided by the total number of cycles to failure"[2].

$$D = \sum_{i=1}^{k} \left(\frac{n_i}{N_i}\right)$$

The range of g, actual number of cycles (n_i), number of cycles to failure (N_f) is shown in Table-2. Here number of cycles to failure (N_f) is ∞[5], which means that, in aircraft industry ∞ refers to, for 1091 blocks the component does not fail. Hence the life estimation[4] of the component is satisfied.

Table -2: The range of "g", n_i and N_f

Range of 'g'	Actual number of cycles (n_i)	Number of cycles to failure (N_f)
0.5g to 0.75g	40000	∞
0.75g to 1.00g	55000	∞
1g to 1.25g	38000	∞
1.25g to 1.5g	25000	∞
1.75g	500	∞
2g	300	∞
2.5g	250	∞
-0.5g to 1.5g	100	∞

Damage accumulated from Miner's rule is 0, which is less than 1. Therefore for 1091 blocks crack does not initiate. Hence the requirement of the aircraft is met for fatigue analysis.

4. WEIGHT OPTIMIZATION OF WING-BOX

In aircraft industry weight saving plays a major role. Reducing the weight of the aircraft to a small percent affects to a larger extent. It reduces fuel consumption, increases range, cost[6].

4.1 Weight Optimization of Ribs

Ribs give aerodynamic shape to the wings, Weight optimization [6] is carried out by maintaining the stress constant. The initial stress acting on ribs is 127.53N/mm^2. Fig-7 shows the stress value obtained on ribs structure before creating the cut-outs, and Fig-8 shows the stress value obtained after creating cut-outs.

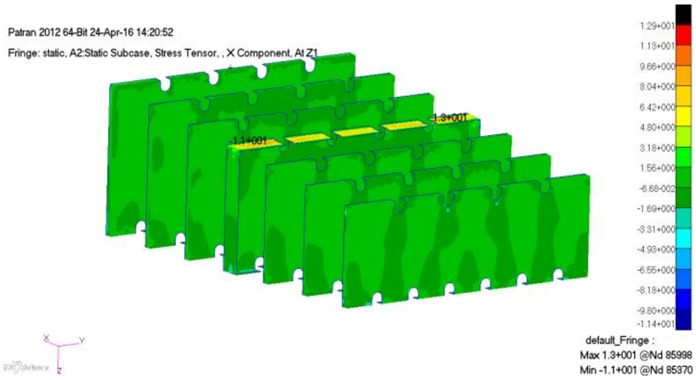

Fig -7: Ribs without cutouts

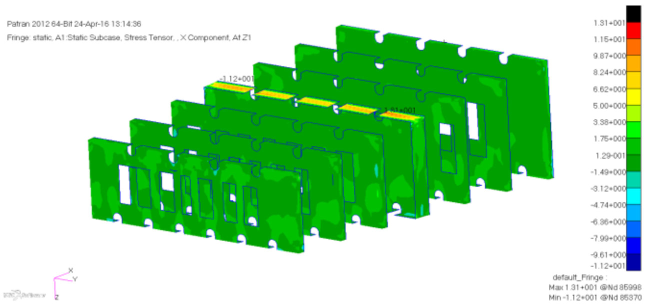
Fig -8: Ribs after cutouts

4.2 Weight Optimization of Spars

Spars are the important structural member[6] of the wing. The initial stress acting on spar is 192.28N/mm². Fig-9 shows the analysis carried out without cutout. Fig-10 shows the analysis with cutout.

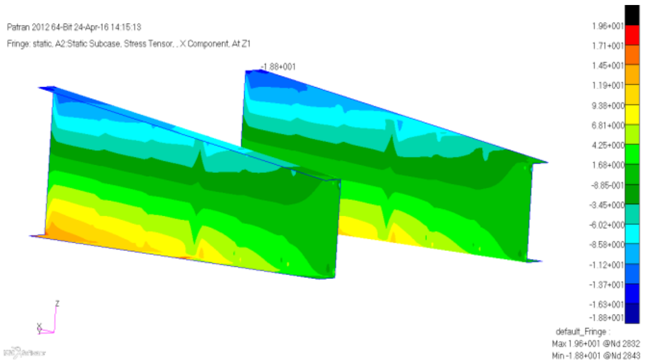
Fig -9: Spars without cutout

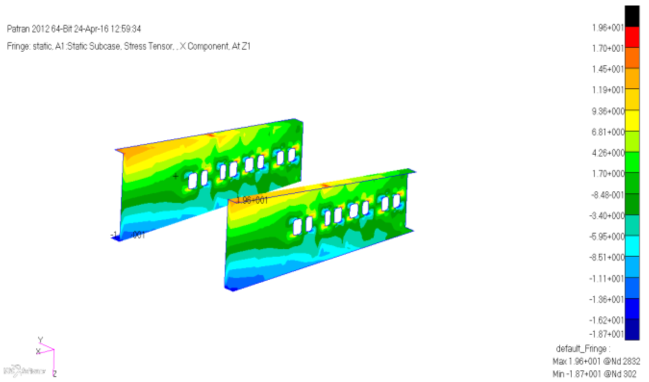
Fig -10: Spars with cutout

The initial mass of the wing-box structure before creating the cutout is 891.93N. After weight optimization, mass of the aircraft is 821.88N. Therefore weight reduction of 7.85% is observed.

Table-3 shows the stress with and without cutout for wing-box, ribs and spars.

Table -3: Stress with and without cutout

Components	Stress without cutout (N/mm²)	Stress with cutout (N/mm²)	Stress with increased cutout (N/mm²)
Wing-box	240.35	244.27	270.76
Ribs	127.53	128.51	142.25
Spars	192.28	192.28	203.07

5. CONCLUSIONS

- The maximum stress for Aluminium 7075-T651 is 240.35N/mm2, which has met the strength criteria for static analysis.
- Total damage in fatigue analysis is "0" and hence by Miner's rule crack does not occur for 1091 blocks.
- In the case of weight optimization there is reduction in weight by 7.85% and hence it plays a major role in the total weight of the aircraft.

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