Stress Analysis of Splice Joint of the Aircraft Bottom Wing Skin by Finite Element Method

[1,] A.Rukesh Reddy, [2,] P. Ramesh, [,] B. Siddeswara rao
[1,] (Department of Mechanical Engineering, Sri Venkateswara college of engineering and technology,Chittoor-517002
[2,3,] (Department of Mechanical Engineering, Siddhartha college of engineering and technology, Puttur- 517583

ABSTRACT:
This paper investigates the maximum stress concentrated part of the splice joint of an aircraft bottom wing skin due to tensile loading. Wings are the aerofoils attached to each side of the fuselage to produce lift force. Joints are inevitable in any large structure like an aircraft wing. Splicing is normally used to retain a clean aerodynamic surface of the skin for most of the aircraft structure. This analysis considers the wing box with a bottom skin splice joint. The wing box comprises of two spar beams, three ribs, stiffeners covered with skin plate. In this paper the chord-wise splicing of wing skin is considered for a detailed analysis. The splicing is multi row riveted joint under the action of tensile in plane load due to wing bending. The stress analysis of the joint is carried out to compute the stresses at rivet holes due to By-pass load, bearing load and secondary bending. The splice is optimized to minimize the rivet hole local stress. A finite element analysis is carried out to evaluate the stresses. Analyses were performed by MSC PATRAN and NASTRAN software.

KEYWORDS: *stress analysis, splice joint, wing skin and rivet holes.*

1. INTRODUCTION

The ideal flight vehicle structure would be the single complete unit of the same material involving one manufacturing operation. Unfortunately this cannot be achieved in practical because the every portion of aircraft structure involves numerous numbers of parts and the unavailability of material for required span. So joints are inevitable in any large structure like an airframe. Splicing is normally used to retain a clean aerodynamic surface of the skin for all structural components. The wings are the most important lift-producing part of the aircraft. Wings vary in design depending upon the aircraft type and its purpose. The wing box has two crucial joints, the skin splice joint & spar splice joint. Top and bottom skins of inboard and outboard portions are joined together by means of skin splicing. Front and rear spars of inboard and outboard are joined together by means of spar splicing. The spars resist much of the bending moment in the wing and the skins resist the shear force.

In this paper the chord-wise splicing of wing skin will be considered for a detailed analysis. The splicing is a multi-row riveted joint under the action of tensile in plane load due to wing bending. The basic knowledge about the loads acting on aircraft is necessary to understand the wing bending.
The Loads acting on the aircraft structure are,

1. Weight
2. Lift
3. Drag
4. Thrust

Weight
Weight is a force that is always directed toward the center of the earth. The magnitude of the weight depends on the mass of all the airplane parts, plus the amount of fuel, plus any payload on board

Lift
To overcome the weight force, airplanes generate an opposing force called lift. Lift is generated by the motion of the airplane through the air and is an aerodynamic force. "Aero" stands for the air, and "dynamic" denotes motion. Lift is directed perpendicular to the flight direction.

Drag.

As the airplane moves through the air, there is another aerodynamic force present. The air resists the motion of the aircraft and the resistance force is called drag.

Thrust.

To overcome drag, airplanes use a propulsion system to generate a force called thrust.[2]

Wing and Wing Box: Wing is the important structural unit of an aircraft and it is going to bend during flying due to lift load acting in it. Hence bottom wing skin subjected to tensile load and top wing skin is under compression [4]. The largest forces on the wings occur when the plane is airborne. Since the wings must then support the whole weight of the aircraft the steady stresses are high, and with the wings bending upwards, so that the upper surfaces are in compression and the underside in tension. Due to this tension force the maximum tensile stress concentration will be found on the joints of bottom wing skin of the aircraft.This paper is focused on the middle part of the wing with riveted splice joint at the bottom skin, which is called wing box. The wing box comprises of two numbers of spar beams (C-section), three numbers of ribs (I-section), four numbers of L-shaped stiffeners at top of ribs and four numbers of rectangular shaped stiffeners at bottom of ribs. The top and bottom portions of the wing box are covered with the thin sheet which is called wing skin. The top skin is designed as the integrated part with wing box structure. The bottom skin is designed in two pieces and they have joined by the splice plate. Here the bottom flange of the middle rib is considered as the splice plate of the joint. The bottom skin and splice plate is joined by rivets.The wing box is completely unsymmetrical in its all axes. The dimensions of the wing box parts have been finalised by the aerodynamic calculations which involve the computational fluid dynamics procedure. the aerodynamic calculations provide the thicknesses of spar beams (3 mm), ribs (2 mm), skin (1.5 mm) and stiffeners (4 mm).

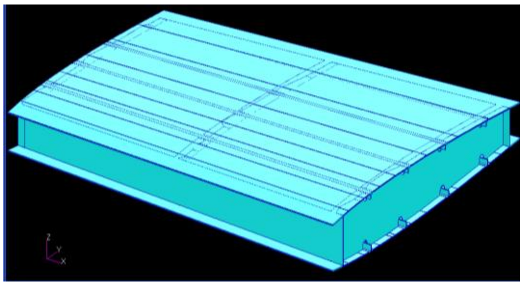


Figure 1(a): CAD model of Wing box (CATIA V5R19)

II. EXPERIMENTAL DETAILS

2.1 Stress Analysis Using Finite Element Analysis Software.

The IGES model was imported from the CATIA V5R19 into the Finite Element Analysis software MSC-PATRAN for geometry extraction. The components of wing box such as spar beams, ribs, stiffeners and skin are meshed separately. Quadratic and triangular elements have been used in this model, due to their lower stiffness properties. The beam elements were used for rivet connections. Near the stiffener cut-out region the fine mesh has been done and the coarse mesh has been done for the rest of the portions of wing box. The material properties, loads and boundary conditions were applied to the meshed wing box to ascertain the stress distribution at wing box.

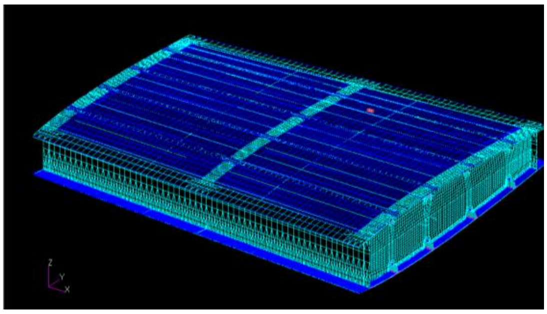


Figure 2(a) Meshed model of wing box

2.2 Finite Element Analysis Software's.

- PATRAN pre-processing and
  Post processing
- NASTRAN solver

2.3 Load Calculations.

All-up weight of the aircraft considered for the analysis is 2000 kg.
(4-seater aircraft)

- ➢ Weight of the aircraft = 2000 kg.
- ➢ Design load factor considered= 3g.
- Total load acting on the aircraft
  = 2000×3
  Total load = 6000kg
- ➢ Factor of safety considered =1.5
- The design load = 6000×1.5
  Design load = 9000kg

Lift load experienced by both fuselage and wing.

- Lift load on the wing = 80% of total load= 0.8×9000
- Lift load on the wing = 7200kg
- ➢ Load acting on each wing = 7200/2
  =3600 Kg

The total span of the wing and the wing box (portion shown in dark line) dimensions with resultant load are shown in figure 2(b)

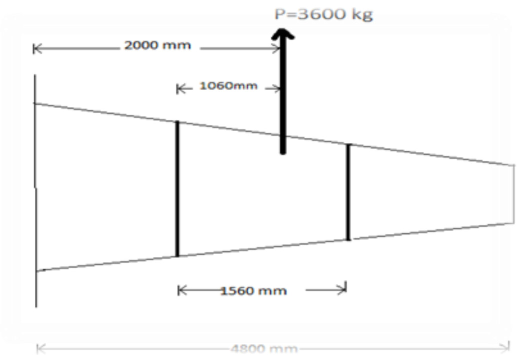


Figure 2(b) Wing box dimensions with load.

The resultant load is acting at a distance of 2000 mm (from aerodynamic calculations) from the root of the wing.

- The maximum B.M at the wing root = 3600 x 2000 =7.2 x 10^6 kg-mm
- The B.M at the root of the wing box = 3600 x 1060 = 3.392 x 10^6 kg-mm
- The load at tip of the wing box = 3.392 x 10^6/ 1560 = 2174 kg

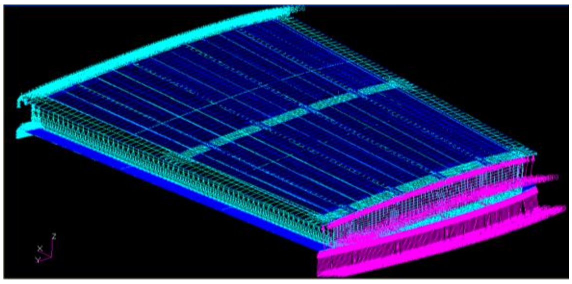
- ➢ This 2174 kg load is converted into uniformly distributed load (1.03 kg/mm as UDL) and applied at tip side of wing box in bending direction of wing.

2.4 Loads and Boundary Conditions.

Uniformly distributed load of 1.03 kg/mm was applied at tip side of the wing box and other end is fixed which is called the root side of the wing box. A two dimensional linear static stress analysis is carried out using finite element analysis software MSC PATRAN and MSC NASTRAN. Mesh independent stress magnitudes are obtained through iterative mesh refinement process. Aluminum 2024-T351 alloy properties are given to the Pre-processor material properties. Load corresponding to the maximum lift load on the wing is considered to be applied on the wing box

III. RESULTS AND DISCUSSION

The loads and boundary conditions applied to the wing box are shown in figure 3(a).



.

Figure 3(a) wing box loading conditions

The stress distribution for the given loads have been observed and that reveals the stress is distributed uniformly but maximum stresses are developed near the rivet joint portion of the bottom skin splice joint.
The maximum stress concentrated portion of the wing box i.e. splice joint of the bottom wing skin is shown in below figure 3(b)

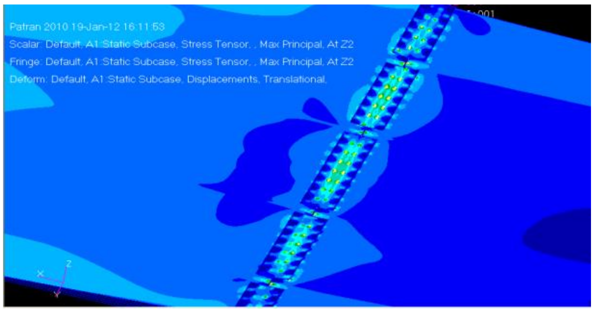
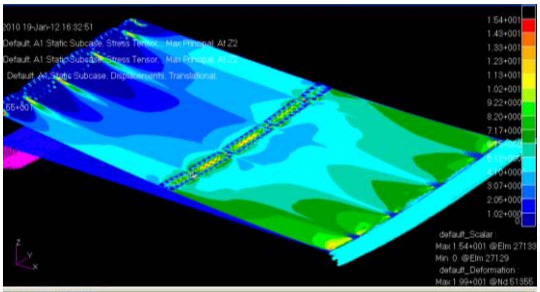


Figure 3(b) maximum stress concentration at bottom skin splice joint
Figure 3(b) shows the maximum stress near the small riveted circular holes by applying load 1.03 kg/mm, the maximum stress is σ_{max} =25.2kg/mm^2.the figure 3(c) and figure 3(d) shows the maximum stress in red colour.

Figure 3(c) maximum stress near splice joint rivet hole



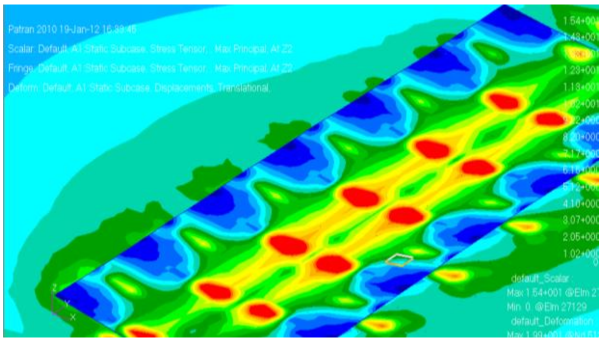


Figure 3(d) maximum stress at rivet holes of the splice plate

From the figure 3(a), 3(b) and 3(c) it was observed that maximum stress of the wing box is concentrated near the rivet hole locations of the splice joint of the bottom wing skin. And these will be fatigue critical locations in the aircraft bottom wing skin.

IV. CONCLUSIONS:

- The maximum stress concentrated part of the bottom wing skin splice joint has been identified for the stress analysis
- Finite element method approach is used for the stress analysis
- Loads and boundary conditions are accurately simulated to obtain the response of the wing box similar to the response of the parent structure at this location.
- Maximum stress of σ_{max} =25.2kg/mm^2 is obtained near one of the rivet hole location of the bottom wing skin splice joint.
- The highest tensile stress location will be the location of fatigue crack initiation spot in the wiring box. So using these results we can go for the fatigue life to crack initiation calculations.

REFERENCES

[1] Fawaz, S. A. and BörjeAndersson. "Accurate Stress Intensity Factor Solutions for UnsymmetricCornerCracks at a Hole". Proc. of the Fourth Joint NASA Conference on Aging Aircraft, vol 15 (2000),pp 135-139

[2] C.S. Kusko, J.N. Dupont, A.R. Marder, "Influence of stress ratio on fatigue crack propagation behavior of stainless steel welds". Welding Journal, vol 19,(2004), pp 122-130,

[3] N. Ranganathan, H. Aldroe, F. Lacroix, F. Chalon, R. Leroy, A. Tougui. "Fatigue crack initiation at a notch". International Journal of Fatigue, vol 33, (2011), pp 492–499.

[4] Newman, J.C. "A crack opening stress equation for fatigue crack growth". International Journal of Fracture, vol 24(2003), pp 131–135.

[5] Lance Proctor et al, local analysis of fastener holes using the linear gap technology using MSC/NASTRAN, Presented at MSC Aerospace Users' Conference, 2000, pp1-24.

[6] A.M.Brown, Simulating fretting contact in single lap splices, International Journal of Fatigue, 2009, pp 375-384.

[7] M.R. Urban, Analysis of the fatigue life of riveted sheet metal helicoptor airframe joints, International journal of fatigue, 2003, pp 1013-1026.

[8] Gresnigt AM, Steenhuis CM. Stiffness of lap joints with preloaded bolts, Proceedings of the NATO ARW, 2000.

[9] Brombolich LJ. Elastic–plastic analysis of stresses near fastener holes. AIAA 11th Aerospace Sciences Meeting, 1973. [AIAA no. 72-252].

[10] S.G.S. Raman, V.M. Radhakrishnan, "On cyclic stress-strain behaviour and low cycle fatigue life," Materials and Design, 2002, Vol.23, pp.249- 254.

[11] RamzyzanRamly et al, Design and Analysis for Development of a Wing Box Static Test Rig, International conference on science and social research, December 2010, pp 113-117.

[12] Huth H. Influence of fastener flexibility on the prediction of load transfer and fatigue life for multiple-row joints. In: Potter JM, editor. Fatigue in mechanically fastened composite and metallic joints, ASTM STP 927. 1986. p. 221–50.

[13] Szolwinski MP, Farris TN. Linking riveting process parameters to the fatigue performance of riveted aircraft structures. AIAA-99-1339, 1999.