Research Article

Evaluation of Static and Buckling load carrying capability of the Wing box through FEM approach

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Abstract

The most important aspects in the aircraft design are safety and weight of the structure. Wing is one of the major components of the aircraft. Wing creates the lift required for flight. Spars, ribs and skins are the major structural elements of the wing. Spars are the structural members which run through the wing root at the fuselage to the wing tip. Spars carry the major wing bending loads. Ribs are the structural members which are oriented in the chord wise direction. Ribs carry the shear loads on the wing. Ribs also help the wing to maintain its aerodynamic shape under loaded condition. Current study includes a wing box configuration consisting of five ribs and two spars. The aerodynamic distributed load on the wing creates shear force, bending moment and torsional moment at wing stations. Static load carrying capability of the wing box is carried out through a linear static stress analysis. The top skin of the wing box will experience the axial compression during wing bending. The top skin panels between the ribs and stiffeners will be considered for the buckling analysis. These panels will be evaluated for their buckling critical loads through analytical approach.

Keywords: Wing-box, Design, Stress analysis, Spar, Rib, Design optimization, Compression, Buckling.

1. Introduction

Aircraft design is a complex and multi-disciplinary process that involves a large number of disciplines and expertise in aerodynamics, structures, propulsion, flight controls and systems amongst others. During the initial conceptual phase of an aircraft design process, a large number of alternative aircraft configurations are studied and analysed. Feasibility studies for different concepts and designs are carried out and the goal is to come up with a design concept that is able to best achieve the design objectives. One of the crucial studies in any aircraft design process is the conceptual design study of an aircraft wing. The aircraft wing is one of the most critical components of an aircraft not only from an aerodynamics point of view but also from a structural point of view. The aircraft wing is designed in such a way that it is able to provide the requisite lift while minimizing the drag. Drag is critical from the aerodynamics point of view because it directly affects the performance of the aircraft like fuel efficiency and range. Not only does the wing provide the necessary lift during flight, the aircraft wing is also designed structurally to carry the entire weight of the aircraft. The aircraft wing has more than one role. It not only carries the fuel required for the flight but is also used to provide

storage bays where, the aircraft landing gears can be mounted and stowed during take-offs. This means that the aircraft wing has to be sufficiently strong from the structural perspective to carry the weight of these engines, fuel inside the wing box and internal components. Along with its high strength the wing is required to have light weight.

1.1 Wing Box

Wings develop the major portion of the lift of a heavier-than-air aircraft. Wing structures carry some of the heavier loads found in the aircraft structure. The particular design of a wing depends on many factors, such as the size, weight, speed, rate of climb, and use of the aircraft. The wing must be constructed so that it holds its aerodynamics shape under the extreme stresses of combat manoeuvres or wing loading. In its simplest form, the wing is a framework made up of spars and ribs and covered with metal sheet. The construction of an aircraft wing is shown in figure 1.1.1

Spars are the main structural members of the wing. They extend from the fuselage to the tip of the wing. All the load carried by the wing is taken up by the spars. The spars are designed to have great bending strength. Ribs give the wing section its shape, and they transmit the air load from the wing covering to the spars. Ribs extend from the leading edge to the trailing edge of the wing. The wing is a complex structure and its analysis will be tedious, so

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this complex structure needs to be simplified to a structure which can be analyzed easily. Therefore the wing is considered as a box like structure for the ease of analysis.
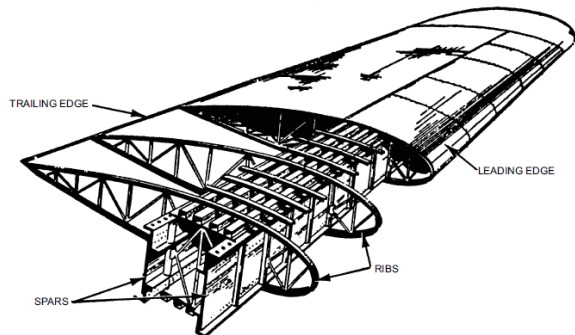

Fig 1.1.1 Two Spar wing construction

1.2 Buckling

There are two major categories leading to the sudden failure of a mechanical component: material failure and structural instability, which is often called buckling. For material failures you need to consider the yield stress for ductile materials and the ultimate stress for brittle materials. Buckling refers to the loss of stability of a component and is usually independent of material strength. The load at which buckling occurs depends on the stiffness of a component, not upon the strength of its materials. When a structure whose order of magnitude of length is larger than either of its other dimensions, is subjected to axial compressive stress, due to its size its axial displacement is going to be very small compared to its lateral deflection this phenomenon is called *Buckling*. Buckling is a tendency of slender compression members to bow out, which causes bending. When the combined bending and compressive stress exceeds the buckling capacity failure occurs. Buckling effects all compression members, such as columns, truss bars, bracing, etc. Buckling bends a column progressively. Increasing offset e increases bending, which in turn increases e further which finally causes buckling failure. Euler formula, developed by the 18th century Swiss Mathematician Euler defines critical buckling load as:

$$P_{Crit} = \frac{\pi^2 EI}{L^2} = P_E \qquad (1.2.1)$$

Pcr = critical buckling load
E = Elastic modulus
I = Moment of inertia
L = Length (un-braced)

2. Problem description

When the aircraft is in flight, lift forces act upward against the wings, tending to bend them upward. The wings are prevented from folding over the fuselage by the resisting strength of the wing structure. The bending action creates a tension stress on the bottom of the wings and a compression stress on the top of the wings.
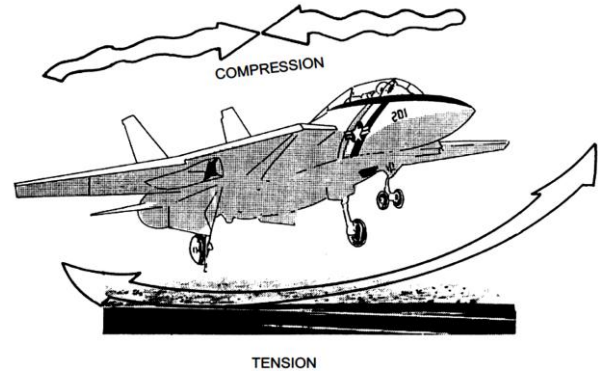

Fig: 2.1 Bending action occurring during flight

As the top skin of the wing is subjected to compression stress it may experience buckling at certain load value, and may lead to failure. Hence in this paper we are going to carry out buckling analysis of the wing to evaluate whether the wing is capable of withstanding the buckling load.

3. Proposed work

3.1 Modelling

In this paper we have modelled the wing box of a medium transport aircraft using CATIA V5 CAD software. The wing box model consists of five ribs and two spars, along with top and bottom skin. The model is as shown in figure below
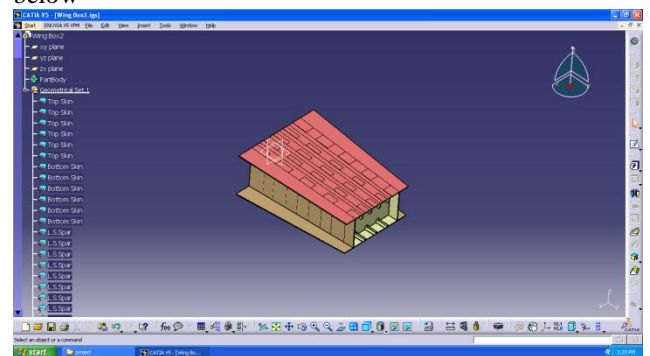

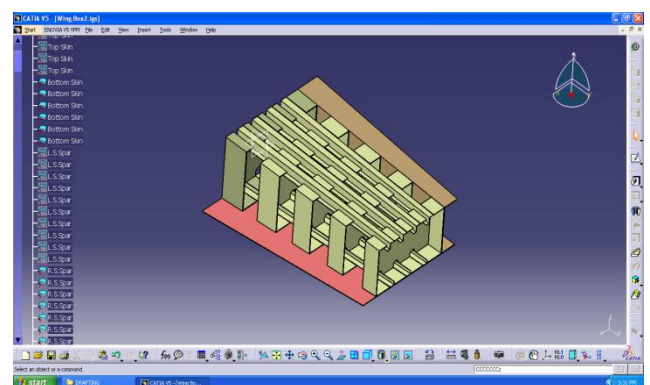**Fig: 3.1.1** CAD model of Wing box

Fig: 3.1.2 CAD model of Wing Box showing five ribs

3.2 FEA Analysis

The CATIA model is extracted using MSC PATRAN software, it is a pre-processor and a post-processor. This model is then meshed in Patran using suitable elements and the necessary boundary conditions and loads are applied.

Boundary Condition: one end (larger) is constrained and at the other end a distributed load is applied on the fifth rib.

Load Calculation for the wing box:

Weight of the aircraft considered = 2500 Kg
Design load factor = 3'g'
Factor of safety considered in design of aircraft   = 1.5
Therefore Total design load on the aircraft = 7500 kg
Total lift load on the aircraft is distributed as 80 % and 20 % on wing and fuselage respectively.
Total load acting on the wings = 6000 kg
The load acting on each wing = 3000 kg
The resultant load is acting at a distance 1200 mm from the wing root
The bending moment about a section at the root= 3.6×10^6 kg – mm
The load required at the tip of the wing box to simulate the same bending moment at the root of the wing is $3.6 \times 10^6/1026 = 3509$ kg
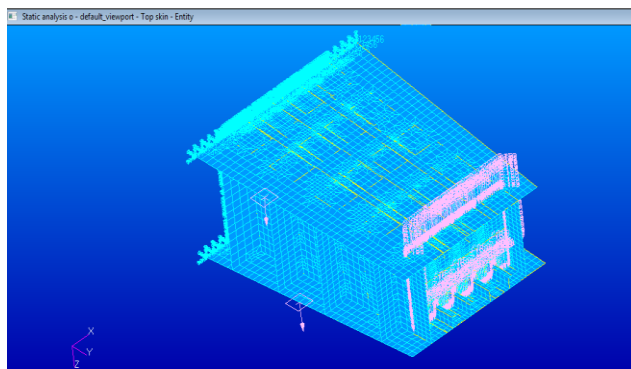This **3509 kg** of load is converted into uniformly distributed load (UDL) and applied at the tip of the wing box.

Fig: 3.2.1 Wing box with one end constrained and other end loaded

After applying the above mentioned BC's and load the Static analysis of the wing box is carried out using MSC NASTRAN, it is a solver and the stress contour is obtained. For the same BC's and load the Buckling analysis is carried out and the buckling factor for various modes is obtained.
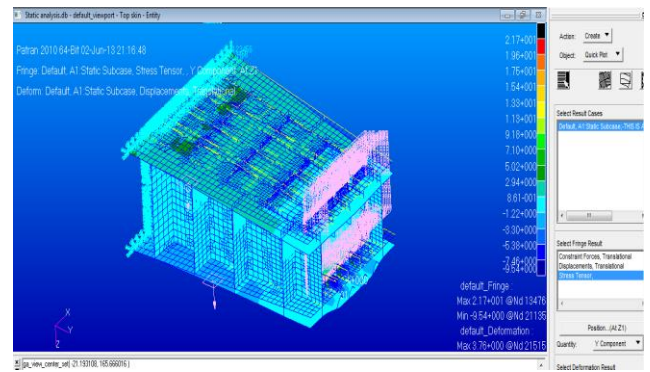
4 Results

4.1 Static Analysis Stress Contour

Fig: 4.1.1 Static analysis stress contour

Maximum Stress: 21.7 kg/mm^2

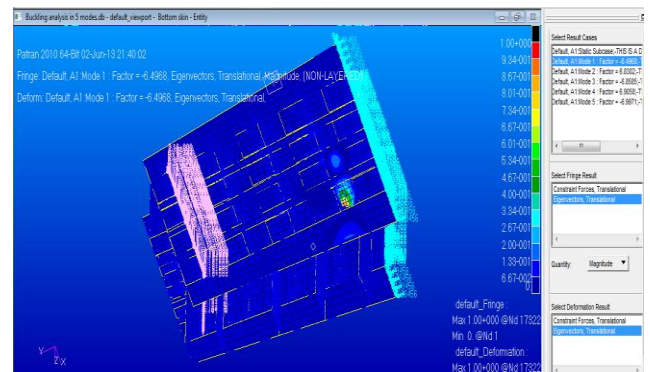*4.2 Buckling Analysis At Various Modes*

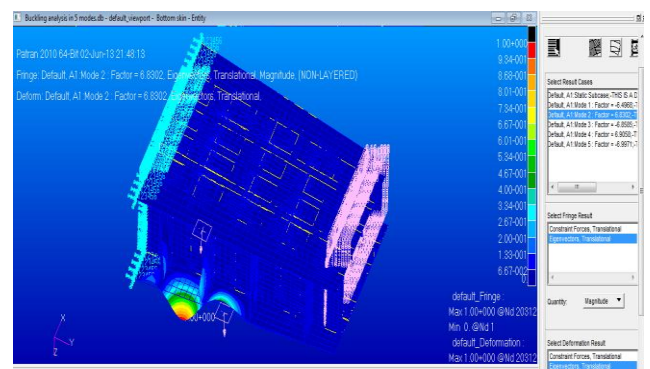**Fig: 4.2.1** Buckling analysis result at mode 1with buckling factor (-6.4968)

Fig: 4.2.2 Buckling analysis result at mode 2 with buckling factor (6.8302)

4.3 Local Buckling Analysis Of Top Skin Pannels

Local buckling analysis of each panel between two ribs is done by extracting the compressive stresses acting on each panel of top skin and converting it to compressive force. This compressive force is then applied on each of the respective panel and the buckling analysis is done and the buckling factor is obtained. Theoretically the critical stress

is calculated by using the below equation for elastic buckling strength of flat sheet in compression
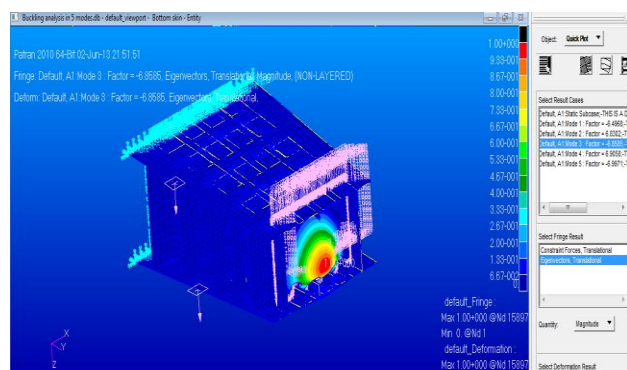

Fig: 4.2.3 Buckling analysis result at mode 3 with buckling factor (-6.8585)

$$\sigma_{Cr} = \frac{\pi^2 k_c E}{12\,(1-\vartheta^2)}\left(\frac{t}{b}\right)^2 \qquad (4.3.1)$$

Then the critical load is obtained by multiplying critical stress with cross sectional area. The buckling factor is obtained as the ratio of critical load and applied load.

$$BF = \frac{P_{cr}}{P_{app}} \qquad (4.3.2)$$
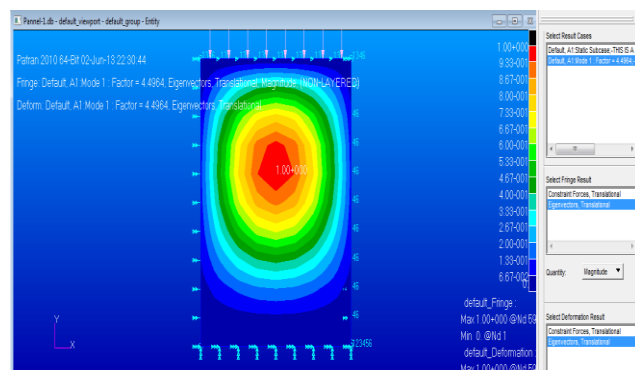
Buckling Factor result for each panel:

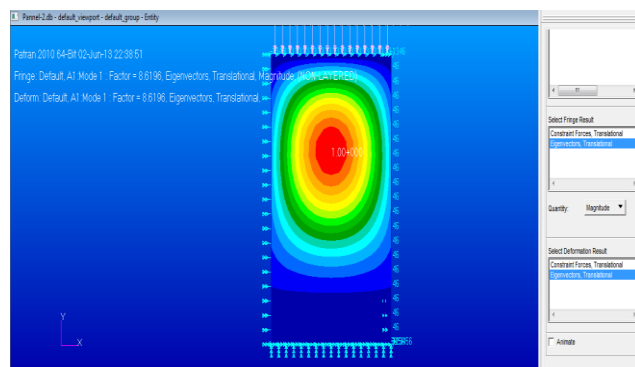**Fig: 4.3.1** Buckling analysis of panel 1

Fig: 4.3.2 Buckling analysis at panel 2

Buckling Factor values for first 5 panels:

Table 4.3.1 Verification of buckling factor values

S.No.	Panel no	Theoretical Buckling Factor	Patran Buckling Factor
1	1	4.677	4.4964
2	2	9.8	8.6196
3	3	8.9716	8.0992
4	4	8.3949	7.5785
5	5	4.0679	4.1468

5. Conclusion

From the static analysis we observe that the maximum stress is 21.7kg/mm^2 is less than the yield strength of aluminium which is 35kg/mm^2 hence it is safe. Then from the buckling analysis at various modes we obtained the buckling factor as 6.8302 in the top skin which is greater than 1 and hence it is concluded that buckling does not take place, as well the wing box being considered is capable of taking buckling load. The local buckling analysis values of buckling factor are in good co-relation with the theoretical values. Further the analysis can be made used for weight optimization of wing structure. Further torsion and combined loading effects can also be analysed for the wing structure.

Acknowledgment

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