

Analytical and Numerical Investigation of Critical Buckling Analysis of Composite Wing

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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 and compression loads on the wing. Ribs also help the wing to maintain its aerodynamic shape under loaded condition. Current study includes a composite wing configuration consisting of five ribs and two spars. The aerodynamic distributed load on the wing creates shear force, bending moment and torsion moment at wing stations. Static load carrying capability of the wing spar 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 spar and ribs 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, Compression, Buckling, composite.

I. 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 analyzed. 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.

A. 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 maneuvers 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

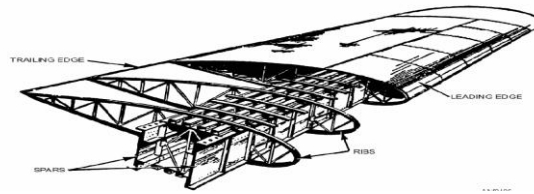


FIG. 1. Two Spar Wing Construction

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 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.

B. 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 affects 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:

$$P_{Cr} = \frac{\pi^2 EI}{L^2} = P_E$$

- P_{Cr} = critical buckling load
- E = Elastic modulus
- I = Moment of inertia
- L = Length (un-braced)

C. Material

The composite wing of Light Transport Aircraft is proposed to be fabricated by Vacuum Resin Infusion Technology (VERITY). The carbon epoxy composite material of HS carbon UD fabric G0827-B-1040-HP03-1F is used as reinforcement and RTM 120 and hardener of HY2554 are used for the resin system. The reinforcement is having 97% carbon fibers in the warp direction and 3% glass fibers in the Left. The glass hold carbon fibers together in warp direction. Design allowable under hot wet conditions for laminates at room temperature and hot wet properties of the coupons made by VERITY process have been evaluated as per requirements of FAR. The room temperature and hot wet properties of the coupons made by VERITY process have been evaluated as per requirements. The following are the base line data for unidirectional carbon fiber composites manufactures by VERITY process.

II. 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.

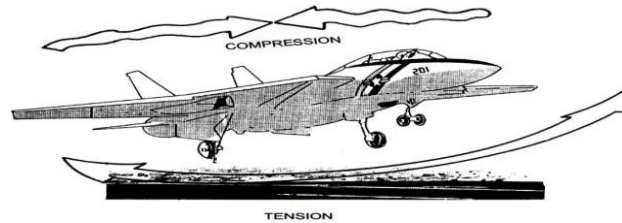


Fig 2 .Bending action of aircraft

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.

III. Proposed Work

A. Modeling

In this paper we have modeled 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

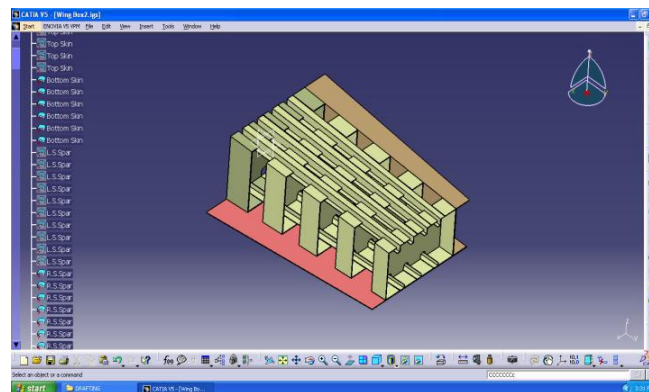


Fig. 3: Cad Model of Wing Box

B. FEA Analysis

The model is extracted using ANSYS 14.5 software, it is a pre-processor and a post-processor. This model is then meshed in ANSYS 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 seventh 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.

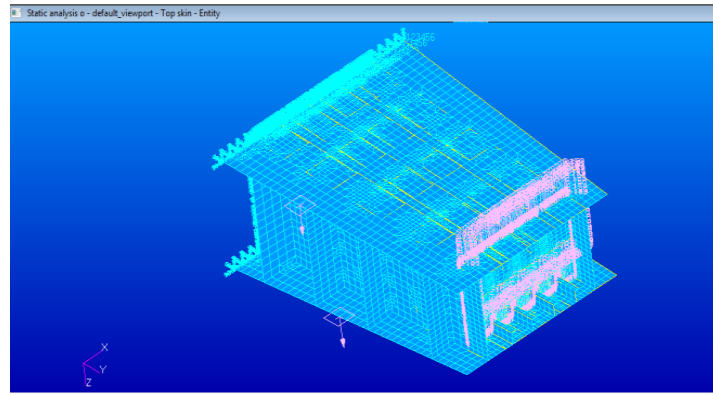
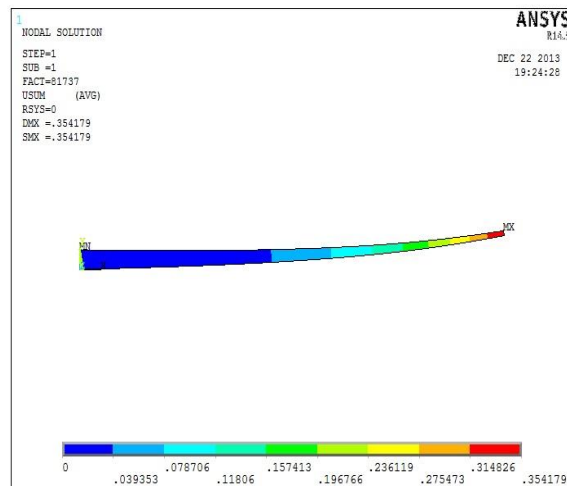


Fig. 4: Wing box with one end constrained and other end loaded

After applying the above mentioned BC's and load the Static analysis of the wing box is carried out using ANSYS, 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.

IV. Results

4.1 Single Mode Buckling Analysis of Wing Spar



Local buckling analysis of each panel between single spars 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 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.

$$BF = P_{cr} / P_{app}$$

The analytical buckling factor = 8.1737

Numerical buckling factor = 8.0631

V. Conclusion

From the static analysis we observe that the maximum stress is 569Mpa is less than the yield strength of carbon epoxy composite material of HS carbon UD fabric G0827-B-1040-is 950Mpa. hence it is safe. Then from the buckling analysis at single modes we obtained the buckling factor as 8.1737 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 analyzed for the wing structure.

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REFERENCES

- [1] Poonam Harakarea* and V.K. Heblikar a(2013) , Evaluation of Static and Buckling load carrying capability of the Wing box through FEM approach, International Journal of Current Engineering and Technology ISSN 2277 – 4106
- [2] A.Srikantha Phani1, Richard Butler2, Stephen Habgood3 and Christopher R. Bowen “Analysis of Wing Morphing via Frame Buckling”
- [3] American Institute of Aeronautics and Astronautics 2009
- [4] Eduard Riks (2000), Buckling and post-buckling analysis of stiffened panels in wing box structures, International Journal of solids and structures 37, Elsevier 6795 ±6824 November.
- [5] International Journal of solids and structures 37, Elsevier 6795 ±6824 November.
- [6] A.Kishore, K. Radhakrishna* and M. Subba Rao^o“Advance Composites Division, NAL” Research article 2009 .
- [7] Sridhar Chintapalli (Aug 2006), Preliminary structural design optimization of an aircraft wing box, Master of applied Science Concordia University, Montreal, Canada.
- [8] E.F. Bruhn (1973), Analysis and Design of Flight Vehicle Structure, J. I. Orlando and J.F. Meyers, USA.
- [9] T.H.G. Megson (2007), An introduction to aircraft structural analysis, Elsevier Ltd, 4th edition.