Static and Dynamic Structural Response of Aircraft Wing

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***Abstract*— A wing is a surface used to produce an aerodynamic force normal to the direction of motion by traveling in air or another gaseous medium, facilitating flight. It is a specific form of airfoil. A wing is an extremely efficient device for generating lift. Its aerodynamic quality, expressed as a Lift-to-drag ratio, can be up to 60 on some gliders and even more. This means that a significantly smaller thrust force can be applied to propel the wing through the air in order to obtain a specified lift.**

This study involves finding the method to analyze the structural and dynamic response of aircraft wings. It is required to find an adequate structural model that could subsequently be used to accurately calculate the static and dynamic aeroelastic characteristics.

Effort involves the following tasks:

a) Develop modeling techniques for efficiency and accuracy

b) Compare calculated deflections with experimental data/analytical data

c) Calculate natural frequencies and mode shapes

The overall objectives of this work are to:

a) Select a finite element model and predict failure loads for a damaged wing structure

b) Develop an aerodynamic model based on the finite element model for static aero elasticity, flutter analysis, and dynamic aero elasticity.

For this purpose, CAE simulation will be performed on a wing model using static and dynamic conditions and based on the response of the model, topology optimization would be performed using appropriate software packages

***Index Terms*—Aircraft, Wing box, spars, ribs**

1.INTRODUCTION

Wings are airfoils that, when moved rapidly through the air, create lift. They are built in many shapes and sizes. Wing design can vary to provide certain desirable flight characteristics. Control at various operating speeds, the amount of lift generated, balance, and stability all change as the shape of the wing is altered. Both the leading edge and the trailing edge of the wing may be straight or curved, or one edge may be straight and the other curved. One or both edges may be tapered so that the wing is narrower at the tip than at the root where it joins the fuselage.

The wing tip may be square, rounded, or even pointed The wings of an aircraft can be attached to the fuselage at the top, mid-fuselage, or at the bottom. They may extend perpendicular to the horizontal plain of the fuselage or can angle up or down slightly. This angle is known as the wing dihedral. The dihedral angle affects the lateral stability of the aircraft.

1.1 WING SPAR

Spars are the principal structural members of the wing. They correspond to the longerons of the fuselage. They run parallel to the lateral axis of the aircraft, from the fuselage toward the tip of the wing, and are usually attached to the fuselage by wing fittings, plain beams, or a truss. Spars may be made of metal, wood, or composite materials depending on the design criteria of a specific aircraft. Wooden spars are usually made from spruce. They can be generally classified into four different types by their cross-sectional configuration

(A) solid
(B) Box shaped
(C) Partly hollow
(D) In the form of an I-beam

1.2 WING RIBS

Ribs are the structural crosspieces that combine with spars and stringers to make up the framework of the wing. They usually extend from the wing leading edge to the rear spar or to the trailing edge of the wing. The ribs give the wing its cambered shape and transmit the load from the skin and stringers to the spars. Similar ribs are also used in ailerons, elevators, rudders, and stabilizers. Wing ribs are usually manufactured from either wood or metal. Aircraft with wood wing spars may have wood or metal ribs while most aircraft with metal spars have metal ribs. Wood ribs are usually manufactured from spruce. The three most common types of wooden ribs are the plywood web, the lightened plywood web, and the truss types. Of these three, the truss type is the most efficient because it is strong and lightweight, but it is also the most complex to construct.

1.3 WING SKIN

Often, the skin on a wing is designed to carry part of the flight and ground loads in combination with the spars and ribs. This is known as a stressed-skin design. The lack of extra internal or external bracing requires that the skin share some of the load. Notice the skin is stiffened to aid with this function Fuel is often carried inside the wings of a stressed-skin aircraft. The joints in the wing can be sealed with a special fuel resistant sealant enabling fuel to be stored directly inside the structure. This is known as wet wing design. Alternately, a fuel-carrying bladder or tank can be fitted inside a wing.

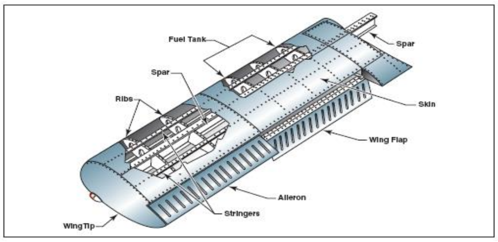

Figure1 Wing nomenclature

2.LITERATURE REVIEW

2.1 Anas El Arras , Chan Hoon Chung , Young-Ho Na and Sang Joon Shin(1) in there paper focuses on the various structural approach to analyze aircraft wing and analyze the possible interaction between the rigid-body degrees of freedom and the aeroelastic modes which will be achieved after the development of a reliable nonlinear beam formulation that would validate theresults as well as enable a thorough investigation of the nonlinearity using cae software packages

2.2 Alberto Varello and Alessandro Lamberti(2) In this paper, the aero elastic static response of flexible wings with arbitrary cross-section geometry via a coupled CUFXFLR5 approach is presented. Refined structural one-dimensional (1D) models, with a variable order of expansion for the displacement field, are developed on the basis of the Carrera Unified Formulation (CUF), taking into account cross-sectional deformability. A three-dimensional (3D) Panel Method is employed for the aerodynamic analysis, providing more accuracy with respect to the Vortex Lattice Method (VLM). A straight wing with an airfoil cross-section is modeled as a clamped beam, by means of the finite element method (FEM)

2.3) Polagangu James, D. Murali Krishna, Gaddikeri Kotresh and Byji Varughese(3) . This paper describes about the finite element analysis of inter spar ribs of a wing at local level against brazier load. This study has been taken place while converting metal wing in to composite wing. The objective of this study is to reduce the weight penalty to the maximum possible extent by removing material wherever feasible. This paper is limited to discuss about the linear buckling analysis of ribs against brazier load. The buckling factor of ribs under consideration are reported in terms of square root times the eigenvalue obtained from finite element analysis, which represent the nonlinear effect of bending moment on brazier load

3.METHODOLOGY,FORMULAE AND PROCEDURE

3.1 Assumptions

- Material is homogenous.
- Material is isotropic.
- Material is elastic
- The stringers carry only axial stresses.
- The skins carry only shearing stresses.
- The spar carry bending load.
- Stress concentration factor is neglected

3.2 Symmetrical bending

If one of the axes is an axis of symmetry, the bending can be determined by,

$$\sigma_b = \frac{M_z}{I_{zz}} y + \frac{M_y}{I_{yy}} z$$

Mz - Bending moment about Z-axis.(Nmm) ; σb - direct stress due to bending (N/mm2)
My - Bending moment about Y-axis.(Nmm) ; z, x- the centroidal distances (mm)

3.3 Unsymmetrical bending

If the section is unsymmetrical, then the Bending can be determined by,

$$\sigma_b = \frac{(M_y I_{zz} + M_z I_{yz})z + (M_z I_{yy} + M_y I_{yz})y}{I_{zz} I_{yy} - I_{yz}^2}$$

Where,
Mz - Bending moment about Z-axis.(Nmm)
My - Bending moment about Y-axis.(Nmm)
Izz, Iyy ,Iyz - are area moment of inertias about z,y and zy(m4)
σb - direct stress due to bending (N/mm2)
z, y - the centroidal distances (mm)

3.4 Bending

σb = M*Y/I

Where, M=Maximum bending moment (N-mm)
Y = Centroidal distance(mm)
I= Moment of inertia (mm4)

3.5 First bending frequency

$$Frequency = \frac{1.875^2}{2 \times \pi \times l^2} \sqrt{\frac{EI}{m}}$$

where, l= span of the wing
E = Young's modulus
I = Moment of Inertia of the wing
m = mass/unit length

4.DESIGN AND ANALYSIS

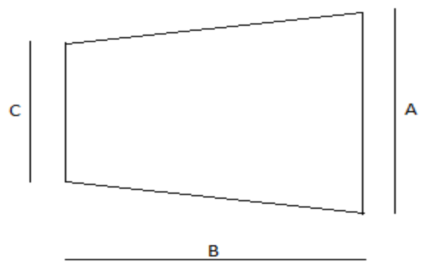

Figure 2 Geometry

A-4800mm
B-10000mm
C-2800mm
Skin thickness- 1.6mm
Rib spaceing-1380mm

Loading details

Given Load -7.4e3N
Pressure on each side -1.98 N/mm^2
Total pressure -3.96N/mm^2

4.1 FE model

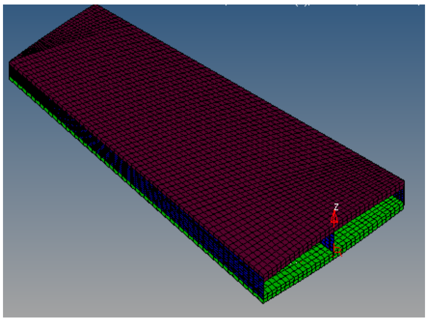

Figure 3 FE model

5. STATIC ANALYSIS RESULTS

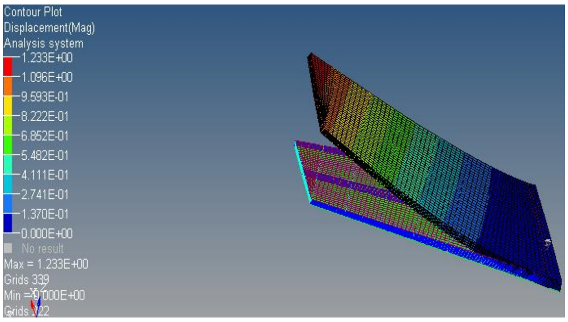

Figure 4 Deformation results

Table1:Summary of results (static analysis)

Iteration	Stress(N/mm^2)	Deformation(mm)
1	41340	1.2
2	35040	.98

6.DYNAMIC ANALYSIS RESULTS

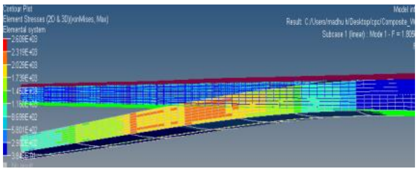

Figure 5 Mode 1

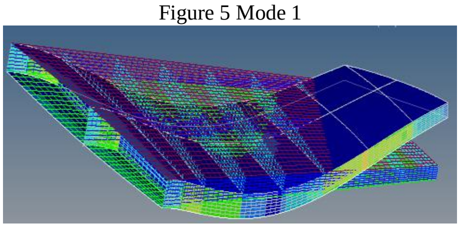

Figure 6 Mode 2

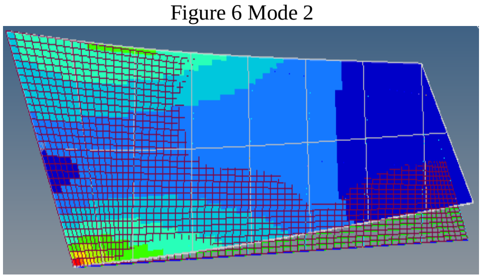

Figure 7 Mode 3

Table 2:summary of results (Dynamic Analysis)

Details	Stress(N/mm^2)	Eigen value
Mode 1	1368	1.287162E+02
Mode 2	3387	1.245158E+03
Mode 3	6948	3.237024E+03

7.CONCLUSION

a)Structure is designed and modeled to satisfy strength criteria
b) FEM and FEA packages are more economical and less complicated tools for testing of components
c)parametric analysis can be done for any number of iterations without experimental cost and the model can be fully optimized

8.SCOPE OF FUTURE WORK

a)Sizing of individual components
b)Thickness variation of individual component can be taken into account

REFERANCES

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[3] Polagangu James, D. Murali Krishna, Gaddikeri Kotresh and Byji Varughese “Finite Element Analysis of Inter Spar Ribs of Composite Wing of Light Transport Aircraft against Brazier Load” National Conference on Scientific Achievements of SC & ST Scientists & Technologists 14–16 April 2009, National Aerospace Laboratories