Static Stress Analysis For Aircraft Wing and Its Weight Reduction using Composite Material

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***Abstract*—Aircraft Wing is the complicated structure found over aircraft because of its complicated behavior towards different loads and maneuvering. Aircraft design becomes more complicated because of limitation over weight and flexibility. Nowadays, in order to achieve the objectives all design is shifting towards composite, because of limitation of knowledge in composite behavior; it's very difficult to predict the results when the composite component is loaded. A safe aircraft wing is designed under static loaded condition during a steady level decelerated condition.**

Using CATIA V5, the wing model is generated. All the dimensions are obtained by conventional methods. Loads are generated by conventional approaches. FEM is generated using MSC Nastran and Patran 2010. SOL 103 free-free run is carried out to confirm the model. SOL 101 analysis is carried out by considering a model as metallic under given load. For modification, composite is implemented in the model aiming to weight reduction and more load bearing capability. Both Vonmises theory and Tasi-Hill criteria implemented while executing analysis.

Keywords*— *Aircraft wing, Composite material, Weight reduction, Vonmises stress.

I. Introduction

The aircraft wings are the primary lift producing device for an aircraft. The aircraft wings are designed aerodynamically to generate a lift force which is required in order for an aircraft to fly. Besides generating the necessary lift force, the aircraft wings are used to carry the fuel required for the mission of the aircraft, can have mounted engines or can carry extra fuel tanks or other armaments. The basic goal of the wing is to generate lift and minimize drag as far as possible. When the airflow passes the wing at any suitable angle of attack, a pressure differential is created. A region of lower pressure is created over the top surface of the wing while, a region of higher pressure is created under the surface of the wing. This difference in pressure creates a differential force which acts upward, which is called lift. For most aircrafts, where, the wings are the primary structures to generate lift, the aircraft's wings must generate sufficient lift to carry the entire weight of an aircraft. In modern commercial, fighter and jet aircraft, the aircraft wings are not only designed to provide the necessary lift during the different phases of flight, but also have a variety of other roles and functions. Commercial jet aircraft, the aircraft's wings are used as the primary storage system for the jet fuel required for the flight. The jet fuel is normally carried in a structure placed on the outer surface of the wing called a wing box. The fuel carried inside the wing box directly delivers fuel to the jet engines. Modern commercial airplanes like the Boeing 747 and the Airbus A380 amongst many other aircrafts also have podded engines which are placed on the wing. The fuel inside the wing box feeds these jet engines.

The aircraft wing has to deal with aerodynamic, gust, wind and turbulence loads. Also, the aircraft wings have to deal with aero-elastic and structural loads as well. Therefore, the aircraft wings must be designed structurally and aerodynamically well for providing good overall performance in all phases of flight. The weight of the wing is a considerable parameter while considering the overall performance. Weight reduction of aircraft wing will increase the flight performance. Use of isotropic material will add more weight while comparing to the composite material. Composite materials are materials made from two or more constituent materials with significantly different physical or chemical properties, that when combined, produce a material with characteristics different from the individual components. The individual components remain separate and distinct within the finished structure.

II. Nomenclature

The NACA airfoils are airfoil shapes of aircraft wings developed by the National Advisory Committee for Aeronautics (NACA). The shape of the NACA airfoils is described using a series of digits following the word "NACA." Here NACA 65206 series is used. It has minimum drag and maximum thrust. The parameters in the numerical code can be entered into equations to precisely generate the cross-section of the airfoil and calculate its properties.

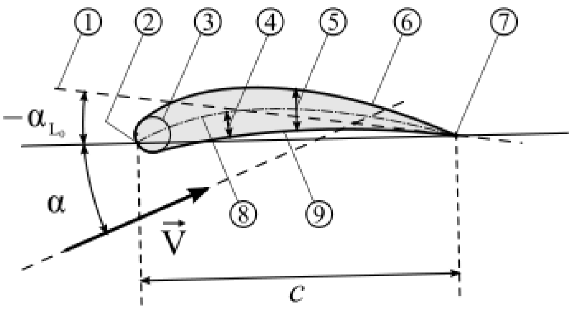

Fig. 1 Airfoil

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1. Zero lift line; 2. Leading edge; 3. Nose circle; 4. Camber; 5. Max. Thickness; 6. Upper surface; 7. Trailing edge; 8. Camber mean-line; 9. Lower surface

III. MODELLING OF WING

The solid modeling of the airfoil was made with the help of CATIA v5 as shown in figure 2.

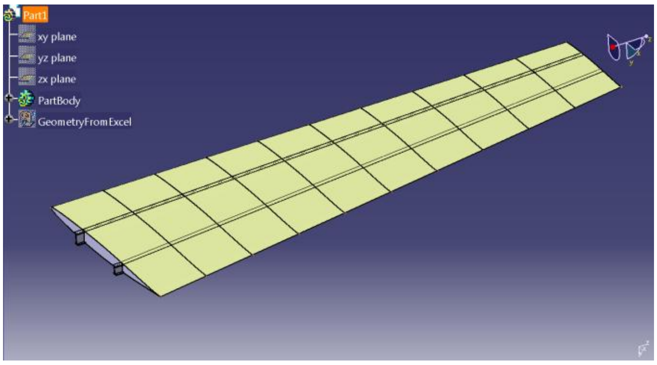

Fig. 2 Wing model

IV. FEM GENERATION

FEM is prepared using Msc Patran and Nastran, Consist of 1D and 2D combination of elements. Skin, rib and spar web of wing defined using the shell element. Spar flange is constructed using rod element. Skin is made of aluminium and remaining structure is made of Steel.

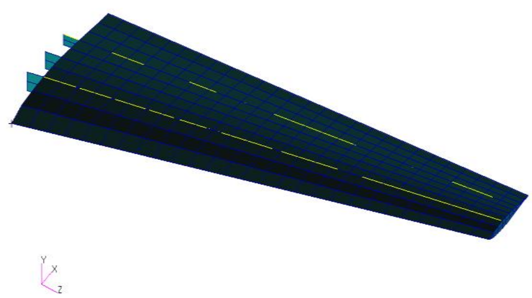

Fig. 3 FEM generation of skin

Generalized Finite Element Method is followed in the generation of FEM in order to capture all the structural behavior. If Detailed Finite Element Method is generated, high configured system is required to solve the model. Generalized Finite Element Method standards are followed by keeping 1D and 2D elements. All the structures are defined only using 1D and 2D elements and all the fasteners are avoided from the model.

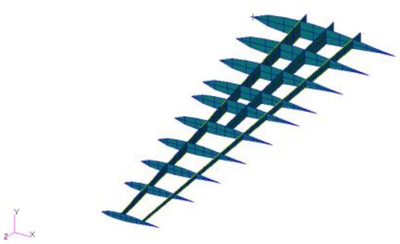

Fig. 4 FEM generation for ribs and spars

V. LOADING CONDITION

Span wise bending loads are calculated on the basis of the total weight of the aircraft. The total weight of the aircraft is divided into two, because we are considering half of the total owing. Wing configuration is applied under heavy bending loads because of symmetric load distribution on steady unaccelerated flight condition. Above loading has captured by considering half of the total take off weight. Total bending loads are divided on the basis of the spar location based on conventional method.

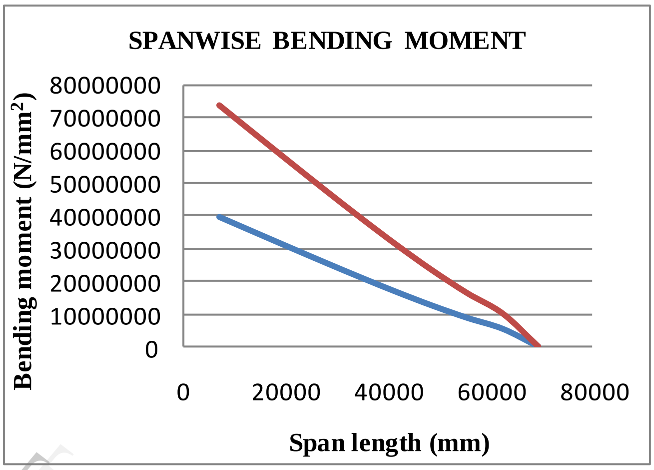

Fig. 5 Spanwise bending moment

The result taken from the hand calculation is explained in the graph. The result shows, from tip to root the bending moment of the spar increases. The front spar having more bending moment compared to the rear spar, because the front spar projected into the air and more drag is acting on it.

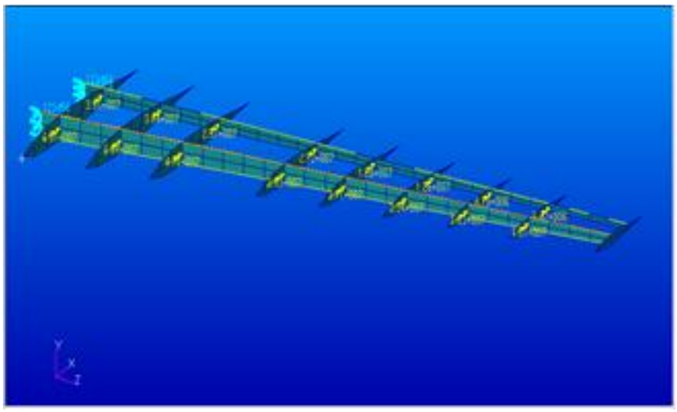

Fig. 6 Applied all the moments over specified position according to the calculation above made.

Bending moments are applied over the corresponding location. All the 6 DOF is constrained at the root location in order to avoid rigid modes displacement. The moments applied to the structure can twist the model and generates the stresses on various regions. All the forces results heavy reaction forces on the attachment location and the root fitting region will undergo heavy loading.

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VI. Result and Discussion

A. *Results for Isotropic Materials*

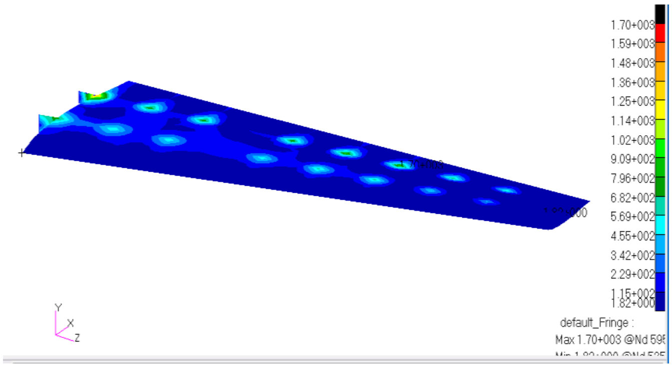


Fig. 7 Vonmises stress (stress tensor)

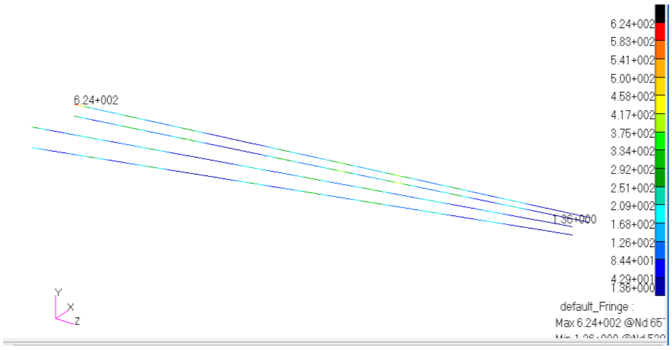
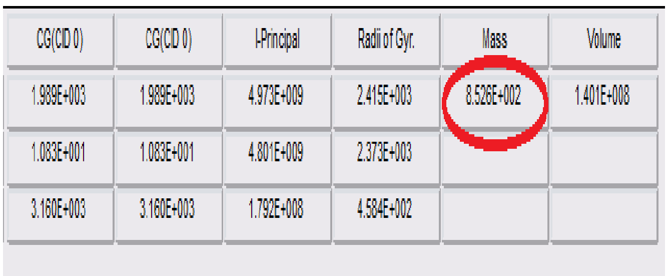


Fig. 8 Vonmises stress (bar stress)

TABLE I
Vonmises Stress For Isotropic Material

Output	Stress Obtained (N/mm^2)	Allowable Limit (N/mm^2)
Vonmises stress (stress tensor)	1700	2400
Vonmises stress (bar stress)	624	2400

Above figure 7 and 8 shows the stress tensor and bar stress values. From the figures it is so clear that the root region is under tremendous stress, but it is still under control. The maximum stress value shows 1700 N/mm^2 and 624 N/mm^2 and the allowable is so ahead of the value. It is clear that the structure is safe enough to take the loads. This structure is safe enough to withstand this particular maneuvering with enough factor of safety.



CG(CID 0)	CG(CID 0)	I-Principal	Radii of Gyr.	Mass	Volume
1.989E+003	1.989E+003	4.973E+009	2.415E+003	8.526E+002	1.401E+008
1.083E+001	1.083E+001	4.801E+009	2.373E+003		
3.160E+003	3.160E+003	1.792E+008	4.584E+002		

Fig. 9 Mass of wing in isotropic material

The results from Nastran showing the stress is less than the allowable limit, but the weight of the wing 852.6 kg which will decrease the total flight performance and by using composite materials can reduce the weight and also able to achieve structural aerodynamic efficiency of the wing.

B. *Results for Composite Materials*

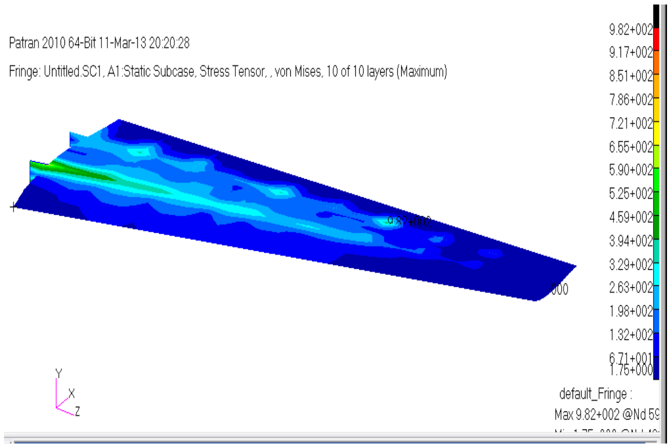


Fig. 10 Vonmises stress (stress tensor)

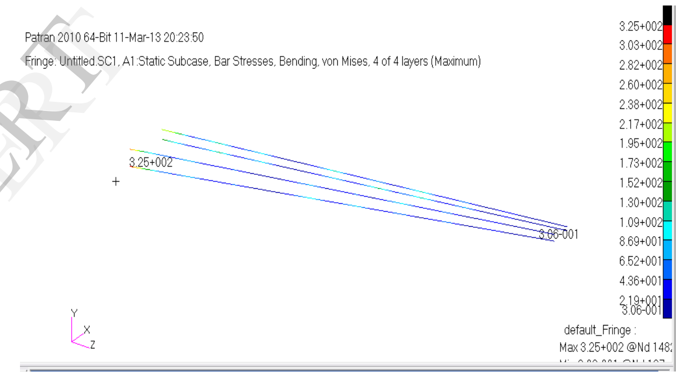
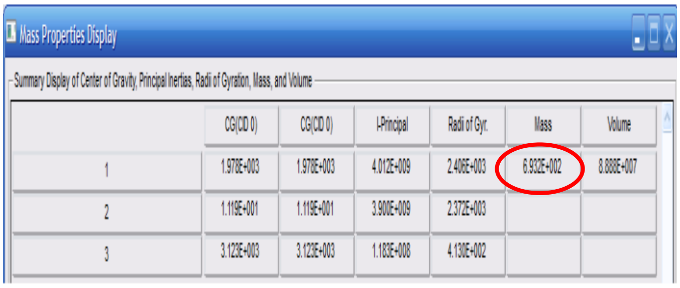


Fig. 11 Vonmises stress (bar stress)

TABLE II
Vonmises Stress For Composite Material

Output	Stress Obtained (N/mm^2)	Allowable Limit (N/mm^2)
Vonmises stress (stress tensor)	982	2400
Vonmises stress (bar stress)	325	2400

Above figure 10 and 11 shows the stress tensor and bar stress values. From the figures it is so clear that the root region is under tremendous stress, but it is still under control. After introducing composite material the maximum stress value shows 982 N/mm^2 and 325 N/mm^2 and the stresses are below the allowable the value. It is clear that the structure is safe enough to take the loads. This structure is safe enough to withstand this particular maneuvering with enough factor of safety.


Mass Properties Display

Summary Display of Center of Gravity, Principal Inertias, Radii of Gyration, Mass, and Volume

	CG(CID 0)	CG(CID 0)	I-Principal	Radii of Gyr.	Mass	Volume
1	1.978E+003	1.978E+003	4.012E+009	2.408E+003	6.932E+002	8.888E+007
2	1.119E+001	1.119E+001	3.900E+009	2.372E+003		
3	3.123E+003	3.123E+003	1.183E+008	4.130E+002		

Fig. 12 Mass of wing in composite material

The implementation of composite materials gives better structural result and also reduced mass to 693.2 kg, almost 9% weight reduction compared to isotropic material.

VII. CONCLUSIONS

The typical wing for business jet aircraft was considered. Most of the aircraft industry is going for composite technology, because of an increase in fuel efficiency and high structural thrust to weight ratio. The result from Nastran, Patran shows composite materials have better structural efficiency and decrease in weight compared to the isotropic materials. According to the assumption and considerations the design is capable of taking all kinds of bending loads without undergoing failure.

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