Design and Stress Analysis of Wing Structure for a Military Transport Aircraft - Cessna Citation V (560)

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ABSTRACT

This project deals with the structural analysis of wing. The aim of this project work is to design and analyze the wing of a military transport aircraft, and to obtain the Stress and displacement due to the applied loads. For this we did a comparative study on particular transport aircraft. The optimum design parameters for a transport aircraft are suitably selected based on the classical method of calculations and then a 3-Dimensional model of the wing structure will be designed using the CATIA-V5 software, which is developed by Dassault systems and is very famous for its 3D modeling capabilities. The Major loads acting on the aircrafts wing are determined and the bending moments, shear force etc. The methodology of finite element method and the detailed description about various FEM tools have been studied and implemented in this work. The linear static analysis carried out using MSC Nastran and Patran, Patran is used for carrying out operations like importing the geometry, Finite element modeling, defining material properties, Loads and cross sectional properties of the structure, whereas Nastran is used for as a solver. When carrying out a linear static analysis, in the finite element method the stress and displacement of a wing structure is determined.

Keywords:

Composite wing, CATIAV5, Finite Element Modeling, MSC PATRAN & NASTRAN, linear static analysis, Compressive stress, Torsion, shear force bending moment.

Objective:

The objective of this project work is design and analyses the wing of a military transport aircraft, to obtain the Stress, and displacement due to the applied loads and is to determine the natural mode shapes and frequencies. Major loads acting on the aircrafts wing are determined and the bending moments, shear force etc., are also determined.

Detailed Methodology used for carrying out the study:

- The wing design parameter values calculated.
- A conceptual design and 3D modeling of the wings design to be carried out in the CATIA V5 R 19.
- FE modeling of the wing structure is carried out using the PATRAN .Linear static and modal analysis is carried out using MSC Nastran and results will be plotted.

Tools used:

CATIA V5 R19;Patran 2012; MSC Nastran 2012; MS office 2007

INTRODUCTION:

An aircraft's main lifting surfaces are the wings. Other than generating lift the wing has to sustain the loads and stresses imposed and corresponding deformations during different mission segments and this demands the requirement of employing an effective material and thereby enhancing its overall efficiency. Previously metals and metal alloys where employed for major loads and stress carrying wing components, but as the requirement for transporting more payload and high measurability came into limelight the metals proved to be heavy and unreliable limiting the overall efficiency of the aircraft so the more advanced metals had been developed.

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The bending stresses encountered during wing loading demand the major stress carrying components to be strong and flexible enough.

1.1 CESSNA CITATION V (560)

The Cessna Citation V (Model 560) is a turbofan-powered small-to-medium sized business jet built by the Cessna Aircraft Company in Wichita, Kansas. A stretch of the Cessna Citation II series, the Citation V aircraft was evolved into the Citation Ultra, the Citation Encore, and the Citation Encore+ models.In 1993, Cessna decided to update the Citation V design, and announced the Citation Ultra Powered by Pratt &Whittney.In 1994, the Ultra was named Flying magazine's "Best Business Jet".

Figure 1 CESSNA CITATION V (ULTRA)

1.2 Objective

The objective of this project is to design the wing taking the required wing design parameters into consideration and analyze the stresses and deformations encountered in the structural components of the wing. For this wing design of midsize and super mid-sized Military Transport aircrafts are taken as the reference and the design is carried out with the available design parameters which is then analyzed for the optimum results.

LITERATURE SURVEY

2.1 Introduction to Literature Survey

The aircrafts from the early ages have developed to a very advanced stage where the overall efficiency in terms of reduced fuel consumption and weight savings with minimum usage of resources available determine its viability and reliability The wing which is the major lifting surface also had its remarkable changes incorporated into the design and so do the materials employed in its construction.Fig: -1 shows the basic components of Aircraft in which we can easily specialize the Wing components. Majorly the project deals with the Wing Structure and the construction, so the Wing attachments to Fuselage and control surfaces are not discussed here. As the wing cross section is the Airfoil. The Airfoil plays a vital role in the wing construction.

2.2 Wing

2.2.1 Airfoil

The main lift generating surfaces of the aircraft are the wings. The wings consist of two essential parts. The internal wing structure, consisting of spars, ribs and stringers and the external wing, which is the skin.the locus of these upper and lower surfaces called as the mean camber line which is considered to be one of the major design parameters, and the distance between the upper and lower surfaces is called the thickness which varies from leading edge to trailing edge.

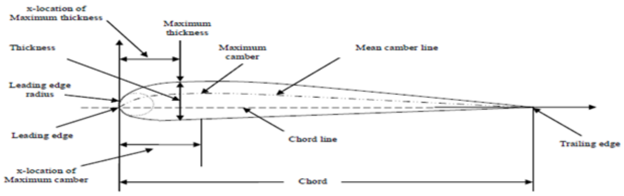

Figure 2: Schematic of an airfoil

NACA Airfoil

The NACA airfoils are airfoil shapes for 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".

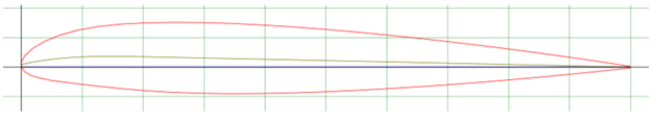

Figure3NACA 23012 airfoil

Max thickness 12% at 29.8% chord;Max camber 1.8% at 12.7% chord

2.3Types of Wing Designs

Wings are airfoils that, when moved rapidly through their, create lift. They are built in many shapes and sizes.

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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.

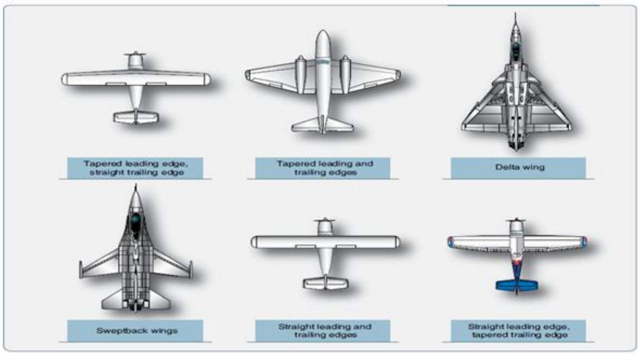


Figure4: Various wing designs shapes

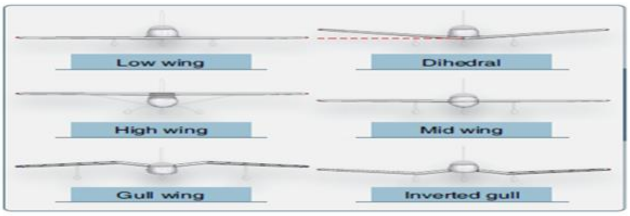


Figure 5: Wing attach points and dihedral

DESIGN METHODOLOGY

DESIGN OF WING

An aircraft design is a separate discipline of Aeronautical Engineering. It needs to be in good consensus with the analytical disciplines such as aerodynamics, structures, controls, propulsion and many other specialties. In the modern world design, it is computer aided drafting/designing (CAD) that drives the advancement in the design. design is one such thing which needs to meet the requirement of generating lift along with being structurally strong enough so as to support the engines (in the case of jumbo jets) and also to sustain the aerodynamic loads.

5.1 CATIA

Computer Aided Three-dimensional Interface Application (CATIA) is multiplatform CAD/CAM/CAE commercial software suite developed by Dassault Systems of France in 1970s for the Dassault's mirage fighter jet but later acquired its importance in the aerospace, automotive and marine industries as it supports multiple stages of product development. As of 2014 the latest version is CATIA V6, but we employ CATIA V5R19 for the desired design of the wing.

5.2 Structural Analysis of the Wing

As these individual fixed components are made to function as one single structure the uniform distribution of the stresses induced due to the loads and the overall structural deformation plays a major role in defining the structure's overall integrity and the fatigue life. Generally, there are three approaches employable to do the structural analysis of the structure, they are

1) Mechanics of Materials approach
2) Elasticity Theory approach
3) Finite Element approach

5.3 Linear Static Analysis

Linear static analysis represents the most basic type of analysis. The term "linear" means that the computed response displacement or stress, A series of assumptions are made with respect to a linear Static analysis. They are- Deflections should be small relative to structure, Rotations should be less than 10 degrees to 15 degrees, Boundary conditions should be constant

5.4 MSC Nastran & Patran

The Mac Neal-Schwendler Corporation (MSC)was one of the principal and original developers of the public domain NASTRAN code. NASTRAN is an acronym formed from NASA Structure Analysis. Structural analysis application used by engineers to perform static, dynamic, and thermal analysis across the linear and nonlinear domains. Creating airfoil geometry, Extruding the airfoil geometry to a 3D wing surface, Assembling the all the parts after linking them to the original design file The main design parameters of CESSNA CITATION V (560)wing.

Figure 6: Design of airfoil in catia

Figure 7: Wing skin surface

Figure 8: Ribs

Figure 9: Ribs and spars as solid surface

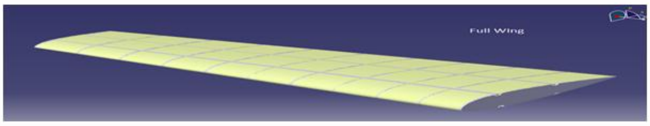


Figure 10: Final design of the wing

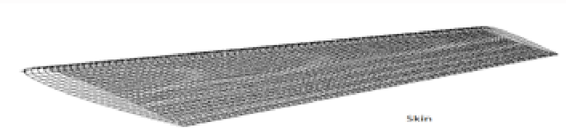
ANALYSIS OF WING

6.1 Importing the Design to Patran

The design is imported into the patran for defining the material assigning the properties and meshing them. A.importingB.meshing the design C.defining the material nature D.typre of material used (aluminium)

6.2 Meshing the Wing

The wing is mesh manually by a special tool available in the patran software called mesh seed by which the number of node points can be given by trial and error method checking for any failures of the elements during the meshing. the meshing could be of quad elements (quad 4 node) or tri elements. The meshing is done for the top surface, bottom surface, ribs and spars.



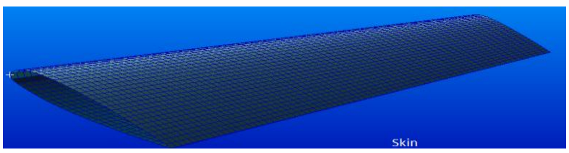


Figure 11: Quad mesh of the skin surface

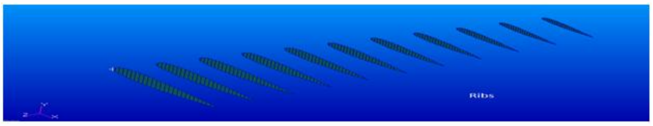


Figure 11: Quad and Tri mesh of the ribs

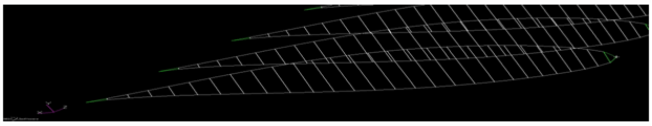


Figure 12: Closure view of the Tri and Quad elements

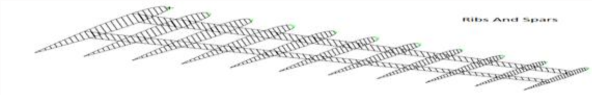


Figure 13 Ribs and Spars

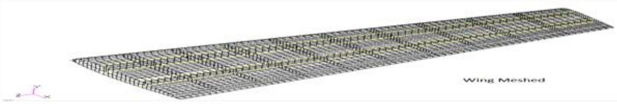


Figure 14Meshed Wing

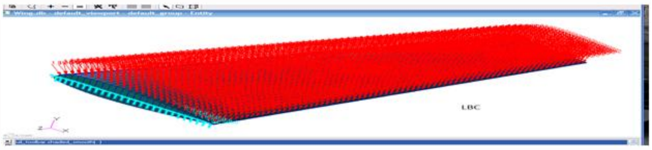


Figure 15Loads and Boundary Conditions (LBC)

The elements of the design are supposed to satisfy the below failures modes -Aspect ratio, Skew angle, Normal offset, Tangent offset, Warp Angle, Taper.

RESULTS AND DISCUSSIONS

CALCULATION OF SHEAR FORCE & BENDING MOMENT:

Formula used for calculating the shear stress is,

Shear force = Pressure Load × area = (Pressure × Area $_{(0\ to\ n))}$ N

Since Bending Moment = (Shear Force * C. $G_{0\ ton}$) N-m

Table-1:TABLE IS SHOWN BELOW FOR BENDING MOMENT:

Distance b/n root to tip (mm)	Percentage load acting on front spar	Percentage load acting on rear spar	Bending moment N-mm	Bending moment on front spar N-mm	Bending moment on rear spar N-mm
X0=7000	0	0	0	0	0
X1=6300	45.94	54.15	5112386.125	2346585.231	2765800.894
X2=5600	85.51	100.7878868	21142919.93	9704600.247	11438319.68
4900	117.41	138.396642	50002209.41	22951014.12	27051195.29
4200	146.0381662	172.1277732	93992185.74	43142413.25	50849772.48
3500	175.7956725	207.2014354	155303912.9	71284496.02	84019416.88
2800	209.3230637	246.7184695	235645815.6	108161429.3	127484386.2
2100	247.4403577	291.6453889	336112827.9	154275788	181837039.9
1400	289.4943742	341.2123234	457273440.6	209888509.2	247384931.4
700	334.0231636	393.696147	599359190.2	275105868.3	324253321.9
X10=0	379.635775	447.4574168	762439985.4	349959953.3	412480032.1

Moment of Inertia Distribution:

$I = M \times y/\sigma$,

Moment of Inertia on Front Spar, $I_{FS} = (M_{FS} \times y_{FS}) / \sigma$

$= 462472.38\ mm^4$

Total SF on RS = q x $SF_{R.S\ 1}$ = 8159.888925 N

FLANGE: $MOI_{flange} = MOI_{Front\ Spar} - MOI_{Web}$

7.2 Practical Calculation:

Results of stress & displacement values for trails with Aluminum

S. No	Trails	Structural components	Materials
1	Trail 1	Upper Skin	Al 2024 T3
2	Trail 2	Bottom Skin	Al 2024 T3
3	Trail 3	Ribs	Al 7075 T6
		Front Spar Web	Al 7075 T6
		Rear Spar Web	Al 7075 T6
		Front Spar Flange	Al 7075 T6
		Rear Spar Flange	Al 7075 T6

Table 2: Assigning of materials to the structural components

The three trails are done with thickness being the least

Table 3: Results of Trail 1

Trail 1						
Parts	Material	Young's Modulus (GPa)	UTS (MPa)	Thickness	Max stresses	Max Displacement
Upper Skin	Al 2024 T3	71	485	0.8	769	948
Bottom Skin	Al 2024 T3	71	485	0.8	576	805
Ribs	Al 7075 T6	72	572	2	678	805
Front Spar Web	Al 7075 T6	72	572	4	576	758
Rear Spar Web	Al 7075 T6	72	572	6	609	774
Front Spar Flange	Al 7075 T6	72	572	50*20	672	774
Rear spar Flange	Al 7075 T6	72	572	50*20	672	774
Torque Box	Al 7075 T6	72	572		662	779

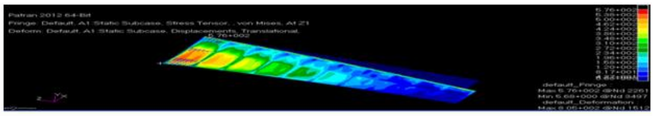


Figure 16: Stress and displacement on Skin Surface in trail 1

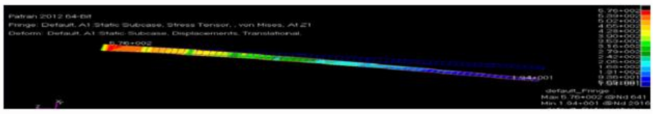


Figure 17: Stress and displacement on front Spar in trail 1A

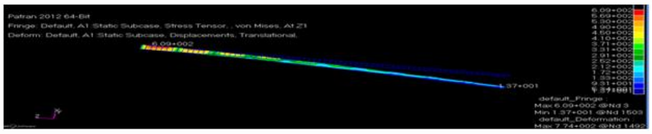


Figure 18: Stress and displacement on Rear Spar in trail 1A

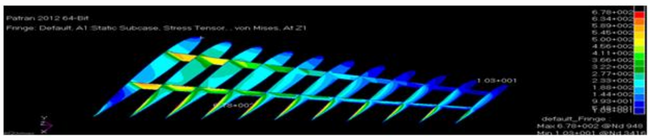
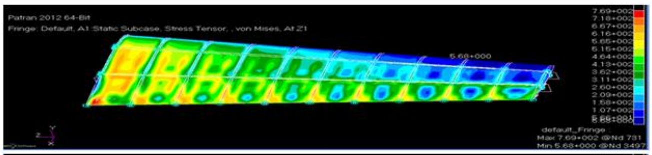


Figure 19:Ribs and Spar Combined Stress and displacement in trail 1A



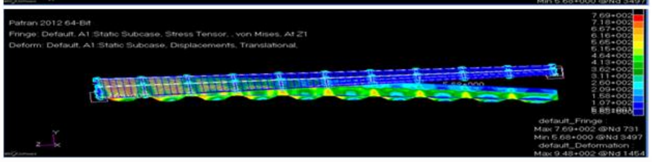


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Figure 20: Stress distribution and displacement on entire wing in trail 1A

Table 4: Results of trail 2

Trail 2						
Parts	Material	Young's Modulus (GPa)	UTS (MPa)	Thickness	Max Stresses	Max Disp
Upper Skin	Al 2024 T3	71	485	1.0	547	548
Bottom Skin	Al 2024 T3	71	485	1.0	407	456
Ribs	Al 7075 T6	72	572	5	461	453
Front Spar Web	Al 7075 T6	72	572	8	320	420
Rear Spar Web	Al 7075 T6	72	572	12	389	432
Front Spar Flange	Al 7075 T6	72	572	70*30	389	432
Rear Spar Flange	Al 7075 T6	72	572	70*30	389	432
Torque Box	Al 7075 T6	72	572		404	433

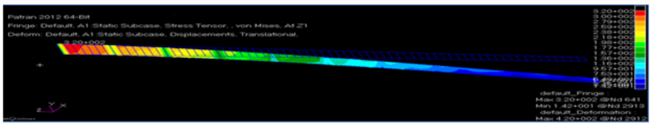

Figure 21: Stress and displacement on front spar in trail 2

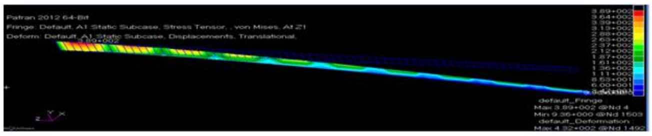

Figure 22: Stress and displacement on Rear Spar in trail 2

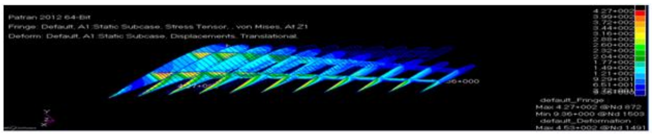

Figure 23 Ribs and Spars combined Stress and Displacement

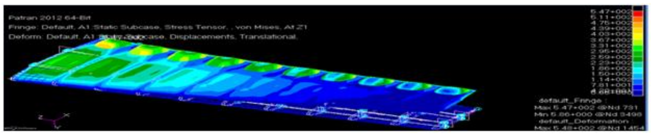

Figure 24: Stress distribution and displacement on entire wing in trail 2

The trail 2 has far more desirable results with the maximum stress induced in the upper skin are at 112.7% of UTS of the Al 2024 T3, ribs at 74.6 %, rear spar at 68% and spar flanges which are of Al 7075 T6are the only components at nearby the UTS value which is again not desirable.

Table 5: Results in trail 3

Trail 3						
Parts	Material	Young's Modulus (GPa)	UTS (MPa)	Thickness	Max Stresses	Max Disp
Upper Skin	Al 2024 T3	71	485	1.5	348	428
Bottom Skin	Al 2024 T3	71	485	1.5	294	397
Ribs	Al 7075 T6	72	572	8	223	397
Front Spar Web	Al 7075 T6	72	572	12	283	376
Rear Spar Web	Al 7075 T6	72	572	12	319	384
Front Spar Flange	Al 7075 T6	72	572	70*30	319	384
R.S flange	Al 7075 T6	72	572	70*30	319	384
Torque Box	Al 7075 T6	72	572		329	384

Figure7.17: Stress and Displacement on Skin Surfaces in trail 3

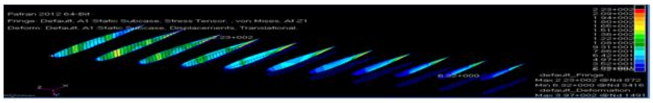

Figure 25: Stress and Displacement on ribs in trail 3

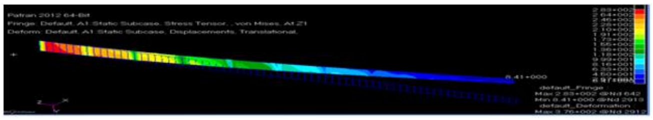

Figure 26: Stress and Displacement on Front Spar in trail 3

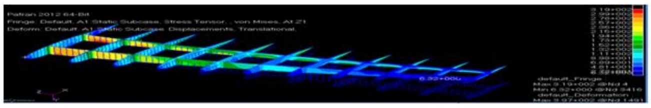

Figure 27: Ribs and Spars combined Stress and Displacement in trail 3

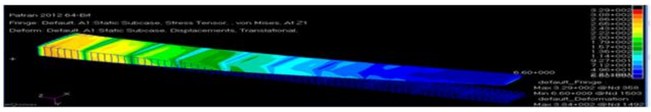

Figure 28 Torque box Stress and Displacement in trail 3

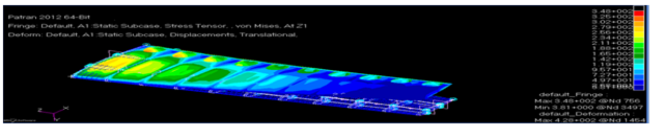

Figure 29: Stress distribution and Displacement on entire wing in trail 3

The trail 3 has far more desirable results with the maximum stress induced in the upper skin are at 71.52% of UTS of the, Al 2024 T. Ribs at 38.98 % and rear spar at 55.76%. Even the stresses at the spar flanges reduced to considerable amount of around

55.76% of UTS of Al 7075 T6which indicate the desirable results. The displacement for the entire wing has also reduced when compared with the trail

CONCLUSION:

Providing lift is the main function of the wings of an aircraft. The wings of an aircraft are designed to lift it into the air. We had come up with a wing design of a mid-sized military transport aircraft for we had made the design in CATIA and analysis by MSC NASTRAN PATRAN. In first trail the Von-misses stress tensor is so high that the wing structure deforms Max-Stress-769,Max-Displacement-948 In third trail the Von-misses stress tensor is satisfied by the wing structure. Max-Stress-348,Max-Displacement-428 The materials used are been common aircraft materials and we extend our work by applying composites to the designed wing structure. The stress tensor (von-misses) and displacement of the wing would be calculated. Development the wing design can change the whole concept of Aircraft Structural Design. For which we need to think and design a variety of wing structures and do analysis so that we could have complete advancement in wing designs. The practical results are a bit closer to the theoretical results

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