Dynamic and Fatigue Analysis of a Fuselage Structure with Different Materials using FEA

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Abstract: Aircraft are generally built up with the basic components of wings, fuselage, tail units, and control surfaces. In this, the fuselage is the main structural component. It is a semi-monocoque structure with exterior loads carried by the skin, interior fuselage pressurization carried by stringers, frames, and bulkheads. Because of the rising cost of production, the weight of the structure has become increasingly important. It is important to select better material, lightweight, and high strength at a given load. In this project, the fuselage Structure was modeled by using SolidWorks. Dynamic and fatigue analysis on fuselage structure was estimated by using ANSYS to find Material selection, static strength, deformation, and the effect of dynamic loadings on fuselage structure.

Keyword: Fuselage stress, Semi-moncoque, ANSYS, SOLIDWORKS.

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INTRODUCTION

The fuselage is the main structure, or body, of the aircraft. The fuselage is the main body section that holds crew and passengers. The power plant, wings, stabilizers, and landing gear are attached to it. Fuselage must provide the necessary strength and rigidity to sustain the loads and environment that it will be subjected during the operational life of the airplane. The fuselage of a modern aircraft is commonly referred to as semi- monocoque construction. The semi monocoque fuselage is constructed primarily of aluminum alloy, although steel and titanium are found in high-temperature areas. A pure monocoque shell is un stiffened tube of thin skins, and as it is inefficient since unsupported thin sheets are unstable in shear and compression. In order to support the skin, we need to provide bulkheads, frames, stiffening members, stringers and longerons. The fuselage as a beam contains longerons and stringers, frames and bulkhead.

A. Design of fuselage structure

The proposed aircraft fuselage structure is an innovative fuselage concept. The whole fuselage is fabricated with Carbon Fiber and Glass laminate aluminum reinforced epoxy. The main advantages in this new design are:

(1) Very good integration;
(2) Faster fabrication and assembly;
(3) Weight reduction (10-15%);
(4) Possibility of thickness variations;
(5) Less waste of raw material;
(6) Higher passenger comfort level;
(7) Longer structural life (less sensitive to fatigue).

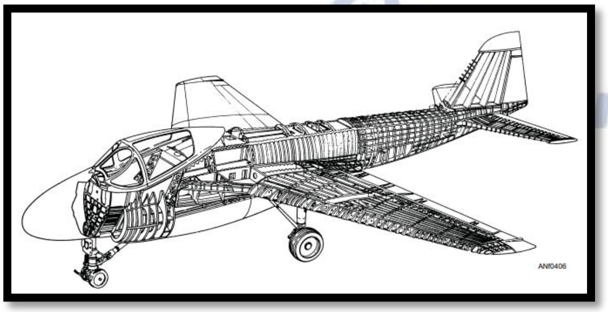


Figure1.Semimonocoque fuselage Construction.

LITERATURE REVIEW

K Vishal Sagar [1] This paper describes a conceptual design and analysis of fuselage structure for A320 NEO (New Engine Option) aircraft by using Solid works and ANSYS software as a design tool. Specific size, configuration arrangements, weight and performance and some commonality of features with existing A320 aircrafts are need to be considered in the design process. This conceptual design develops the first general size and configuration for a new A320 NEO aircraft fuselage structure. The model of the fuselage structure is then undergoing model analysis, linear buckling and fatigue life.

Yung Cheng [2] the flying-wing is a type of configuration which is a tailless airplane accommodating all of its parts within the outline of a single airfoil. Theoretically, it has the most aerodynamic efficiency. The fuel consumption can be more efficient than the existed conventional airliner. It seems that this configuration can achieve the above mentioned requirements.

Dr.-Ing. Wilhelm Rust [3] Experiences in modeling and development of methods for the nonlinear finite element analysis of the loading behavior of aircraft fuselage panels are presented. Simulations were performed using panels with especially developed aircraft like boundary conditions. Detection of maximum load is influenced by the way the load is applied in connection with appropriate imperfections.

Dr M. M. Nadakatti [4] Catastrophic structural failures in many engineering fields like aircraft, automobile and ships are primarily due to fatigue. Where any structure experiences fluctuating loading during service its load carrying capacity decreases due to a process known as fatigue. Fatigue damage accumulates during every cycle of loading the structure experiences during its operation. When this accumulated damage reaches a critical value, a fatigue crack appears on the structure under service loading.

Gary L. Giles [5] a design-oriented analysis capability for aircraft fuselage structures that utilizes equivalent plate methodology is described. This new capability is implemented as an addition to the existing wing analysis procedure in the Equivalent Laminated Plate Solution (ELAPS) computer code. The wing and fuselage analyses are combined to model entire airframes. The paper focuses on the fuselage model definition, the associated analytical formulation and the approach used to couple the wing and fuselage analyses. The modeling approach used to minimize the amount of preparation of input data by the user and to facilitate the making of design changes is described. The fuselage analysis is based on ring and shell equations but the procedure is formulated to be analogous to that used for plates in order to take advantage of the existing code in ELAPS. Connector springs are used to couple the wing and fuselage models.

A. Objective

The model of fuselage is imported to ANSYS to perform finite element analysis. Static analysis is performed on fuselage for aluminum material carbon fiber and glass reinforced aluminum laminated for static loads to determine deflections and stresses.

Modal analysis is performed to calculate natural analysis to see the structure behavior of fuselage. Transient analysis is performed to determine the dynamic response of a structure under the action of any general time-dependent loads for operating loads and deflections, stresses are tabulated. From the analysis, results of materials are tabulated.

From these results, better material is selected based on weight and strength.

MODELING OF FUSELAGE STRUCTURE

In this project, we are taken materials are Aluminum Alloy 7075, Carbon Fiber and Glass laminate aluminum reinforced epoxy (GLARE) for fuselage structure.

A. Aluminum Alloy 7075 The 7000 series aluminum alloys are usable in a variety of applications. The light weight and toughness characteristics of grade 7075 are valued highly by manufacturers and end users. As a strong, Machinable aluminum alloy, it is highly used in the automotive, aircraft and aerospace industries.

B. Carbon Fiber In fiber reinforced composites; fiberglass is the "workhorse" of the industry. It is used in many applications and is very competitive with traditional materials such as wood, metal, and concrete. Fiberglass products are strong, lightweight, non-conductive, and the raw material costs of fiberglass are very low.

C. Glass laminate aluminum reinforced epoxy (GLARE) is a fiber metal laminate (FML) composed of several very thin layers of metal (usually aluminum) interspersed with layers of S-2 glass-fiber pre-preg, bonded together with a matrix such as epoxy. The uni-directional pre-preg layers may be aligned in different directions to suit predicted stress conditions.

GLARE then began to be developed up until the early 2000's, when it was eventually selected for use in the fuselage (main body of an aircraft) of the world's largest airliner, the Airbus A380. GLARE is a composite material comprised of alternating layers of glass/epoxy and aluminum, bonded together. The general composition of GLARE is shown below.

Table: 1 Material Properties.

Materials	Young's modulus(Mpa)	Tensile strength(Mpa)	Poisson's ratio	Density(kg/mm3)
GLARE	30900	798	0.31	0.0000018
Aluminum 7075	71700	280	0.28	0.00000028
Carbon fiber	74000	3900	0.33	0.00000020

Table 2: Design Parameters Of Fuselage Structure

S.No	Parameter	Dimension
1	Length of fuselage	15 m
2	Diameter	5.77 m

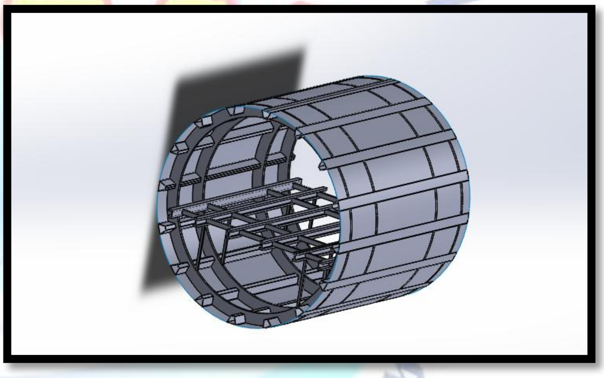


Fig: 2 3d Models of Fuselage Structure

STATIC ANALYSIS OF FUSELAGE STRUCTURE

Static Analysis - Used to determine displacements, stresses, etc. under static loading conditions. ANSYS can compute both linear and nonlinear static analyses. Nonlinearities can include plasticity, stress stiffening, and large deflection.

Total deformation

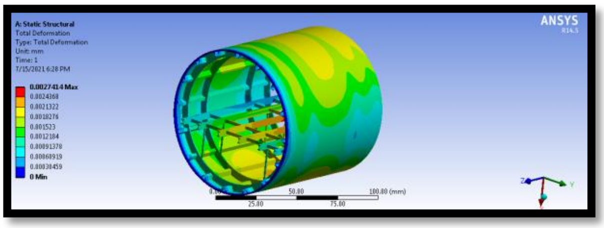


Fig: 3 Total deformation of fuselage structure

Above fig represents the total deformation of a fuselage structure. The maximum and minimum values of total deformation are 0.0027414 mm and 0 mm respectively.

Stress

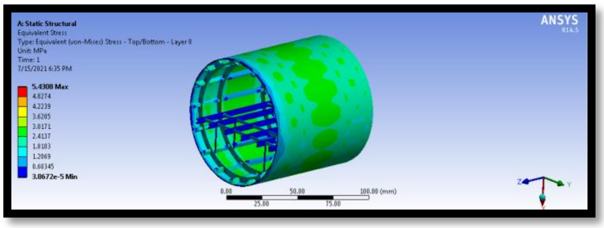


Fig: 4 stress of fuselage structure

Above Fig represents the equivalent stress of a fuselage structure. The maximum and minimum values are 5.4308 Mpa and 3.0672e-5 Mpa respectively.

Hoop stress

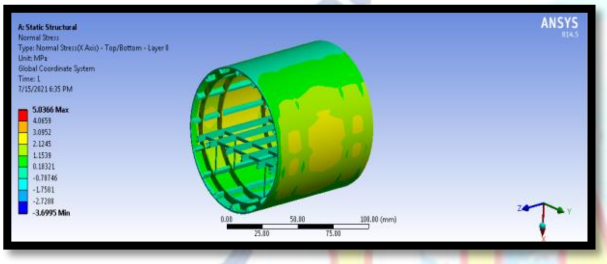


Fig: 5 Hoop Stress of fuselage structure

Above Figure represents the hoop stress of a fuselage structure. The maximum and minimum values of hoop stress are 5.9841 Mpa and -4.3955 Mpa respectively.

Longitudinal Stress

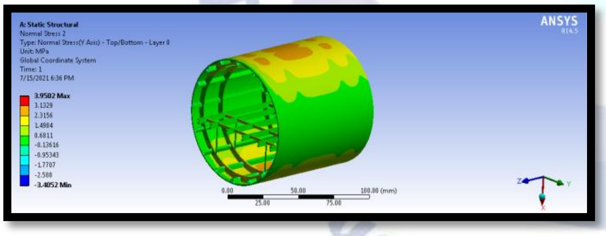


Fig: 6 Longitudinal Stress of fuselage structure

Above Figure represents the longitudinal stress of a fuselage structure. The maximum and minimum values of longitudinal stress are 3.9502 Mpa and -3.4052 Mpa respectively.

Strain

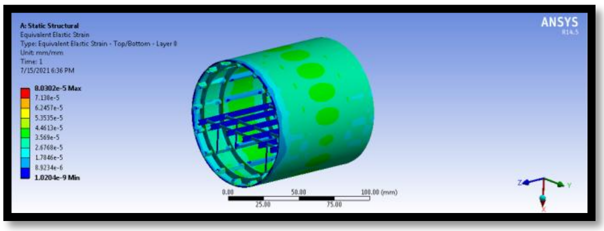


Fig: 7 Strain of fuselage structure

Above Figure represents the stain of a fuselage structure. The maximum and minimum values of strain are 8.0302-5 and 1.0204e-9 respectively.

A. Fatigue analysis

In ANSYS there is a fatigue tool to perform fatigue analysis on component to estimate life, Damage and Safety factor.

LIFE

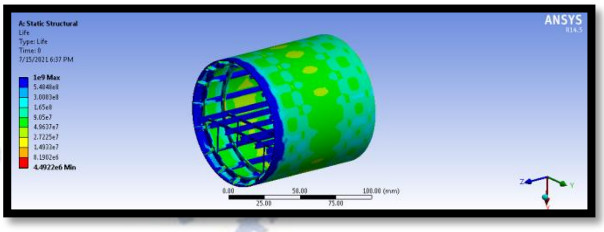


Fig: 8 Life Of Fuselage Structure

Above figure represents the fatigue analysis of a fuselage structure. In fatigue analysis the maximum life of a GLARE fuselage structure is 1e9 cycles and the minimum life of a GLARE fuselage structure is 4.49e6 cycles.

DAMAGE

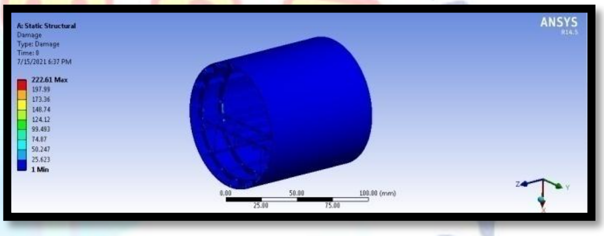


Fig: 9 Damage Of Fuselage Structure

Above Figure represents Damage of a fuselage structure. The Maximum and minimum damage are 222.61 and 1 respectively.

SAFETY FACTOR

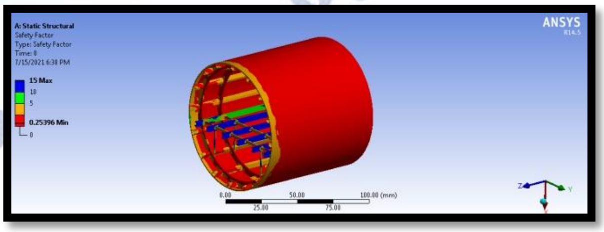


Fig: 10 Safety of fuselage structure

Above figure represents the fatigue analysis of a fuselage structure. In this fatigue analysis safety factor of carbon fiber fuselage structure is 0.25396.

B. Dynamic Analysis

Transient analysis is one of the main branch of dynamic analysis to estimate the problems in which load is a function of a time.

At time -3sec

TOTAL DEFORMATION

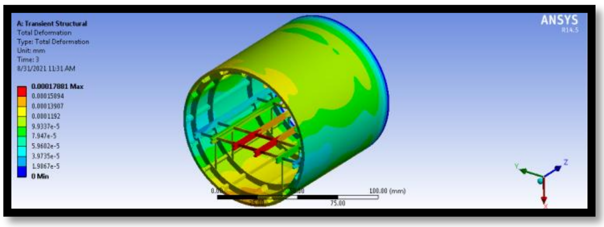


Fig: 11 Total Deformation Deformation of fuselage structure

Above Figure represents the deformation of a fuselage structure under dynamic load at time is equal to 3 seconds. The maximum and minimum deformations are 0.00014305 mm and 0 mm respectively.

STRESS

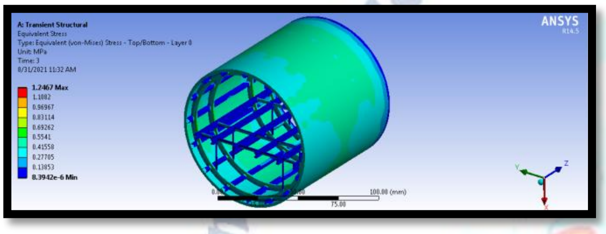


Fig: 12 Stress of fuselage structure

Above figure represent the equivalent stress of fuselage structure under dynamic load at time equal to 3 sec. The maximum and minimum equivalent stresses are 1.7039 Mpa and 1.1472e-5 Mpa respectively.

Hoop Stress

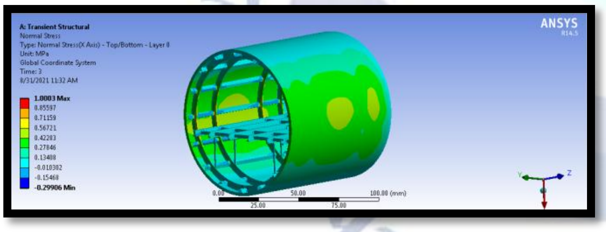


Fig:13 Hoop of fuselage structure

Above figure represent the hoop stress of fuselage structure under dynamic load at time equal to 3 sec. The maximum and minimum hoop stresses are 1.3672 Mpa and -0.4081 Mpa respectively.

Longitudinal Stress

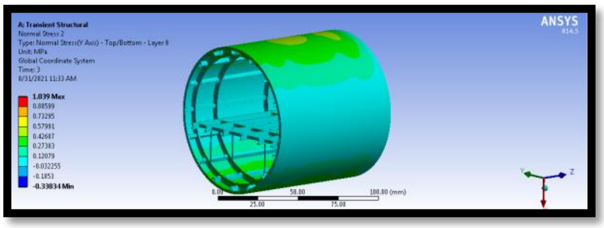


Fig: 14 Longitudinal Stress of fuselage structure

Above figure represent the longitudinal stress of fuselage structure under dynamic load at time equal to 3 sec. The maximum and minimum longitudinal stresses are 1.42 Mpa and -.50749 Mpa respectively.

Strain

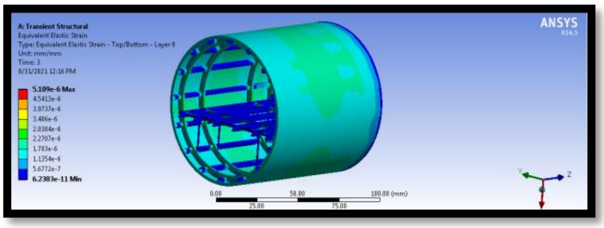


Fig: 15 Strain of fuselage structure

Above figure represent the strain of fuselage structure under dynamic load at time equal to 3 sec. The maximum and minimum strains are 5.109e-6 and 6.2383e-11 respectively.

V.RESULTS AND DISCUSSIONS

Table: 3 Fatigue Analysis Results

Materials	Damage	Safety factor
Aluminum 7075	536.67	1.19022
Carbon fiber	379.27	1.21375
GLARE	222.61	1.25396

From Observing above table it is easy to conclude that GLARE material has less damage i.e more life of fuselage structure.

Table: 4 Static Analysis Results

Materials	Deformation (mm)	Stress (N/mm^2)	Hoop stress (N/mm^2)	Longitudinal Stress (N/mm^2)	Strain
Aluminum 7075	0.0037505	7.4299	6.8905	5.4042	0.000109
Carbon fiber	0.0032571	6.4525	5.9841	4.6933	0.0000954
GLARE	0.0027414	5.4308	5.0366	3.9502	0.0000803

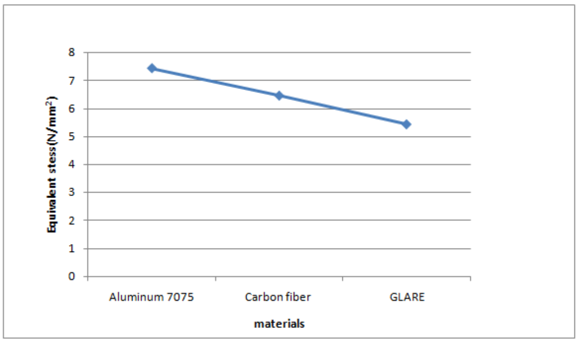
From Observing above table it is easy to conclude that GLARE material has less deformation, stress, longitudinal stress and strain in Static Analysis.

Table: 5 Dynamic Analysis Results

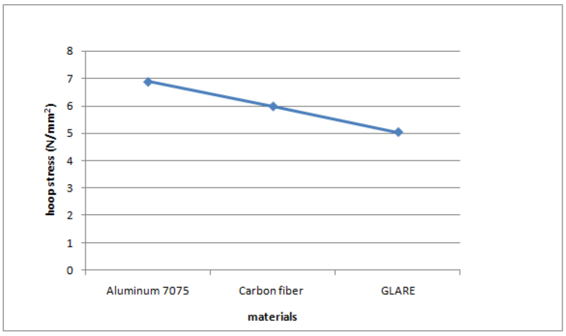
Materials	Time (sec)	Deformation (mm)	Stress (N/mm^2)	Hoop stress (N/mm^2)	Longitudinal Stress (N/mm^2)	Strain
Aluminum 7075	3	0.0016079	1.8701	1.5005	1.5565	5.74e-6
	6	0.00037544	3.3661	2.701	2.8054	1.7243e-5
	10	0.0006613	4.6728	3.701	3.8445	2.361e-5
Carbon fiber	3	0.00014305	1.7039	1.3672	1.42	5.109e-6
	6	0.0004469	2.41403	2.5009	2.597	1.56e-05
	10	0.00062503	4.3635	3.5012	3.636	2.23e-5
GLARE	3	0.0001788	1.2467	1.003	1.039	6.386e-6
	6	0.0004171	2.909	2.3342	2.4244	1.4901e-5
	10	0.0005362	3.7401	3.0011	3.1171	1.91e-5

From Observing above table it is easy to conclude that GLARE material has less deformation, stress, and longitudinal stress and strain in dynamic analysis.

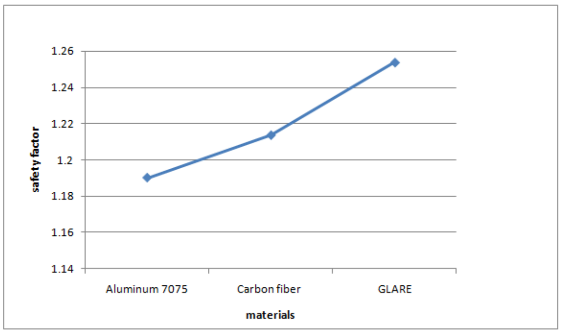
Graph: 1 Materials Vs stress



Graph: 2 Materials Vs Hoop stress



Graph: 3 Materials Vs Safety factor



CONCLUSION

In this Paper, Some of the important aspects in the design and analysis of aircraft fuselage structures.These important aspects are related to material selection, structural configuration, loads evaluation, static stress and deformation, static stability evaluation and influence of dynamic loadings. Analysis of fuselage structure is done for dynamic deformation and dynamic response of optimized material. The fuselage structure was modeled in SOLIDWORKS and Finite Element Analysis (FEA) is carried out using ANSYS software.

By observing the static and dynamic analysis results, the stress (equivalent, hoop and longitudinal stress) and deformation values less at GLARE (Glass laminate aluminum reinforced epoxy) when we compared to other materials such as aluminum alloy 7075 and carbon fiber.

By observing the Fatigue analysis results, the safety factor more at GLARE (Glass laminate aluminum reinforced epoxy) when we compared to other materials such as aluminum alloy 7075 and carbon fiber.

So it can be concluded that Glass laminate aluminum reinforced epoxy material suitable for fuselage structure under given load.

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