BUCKLING AND LINEAR STATIC ANALYSIS OF CENTER FUSELAGE STRUCTURE OF A FOUR SEATER AIRCRAFT

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Abstract: Aircraft is a complex mechanical structure and must be designed with a very high structural safety. Aircraft designer needs to ensure the structural integrity of the airframe without compromising on the safety of the structure. In current study a center fuselage structure of a transport aircraft is considered for the evaluation. The linear static and buckling analysis of center fuselage is carried out through FEM approach. Semimonocoque type fuselage structure is modeled using CATIA modeling tool. This type of fuselage structure consists of frame assemblies, bulkheads, and formers as used in the monocoque type fuselage but the skin is reinforced by longitudinal members called longerons. Longerons usually extend across several frame members and help the skin support primary bending loads. They are typically made of aluminum alloy either of a single piece or a built-up construction. Stringers are also used in the semimonocoque fuselage. These longitudinal members are typically more numerous and lighter in weight than the longerons. They come in a variety of shapes and are usually made from single piece aluminum alloy Stringers have some rigidity but are chiefly used for giving shape and for attachment of the skin. Stringers and longerons together prevent tension and compression from bending the fuselage. Fuselage will encounter fundamentally the inertia and pressurization loads. The present study is concerned with compression buckling of center fuselage structure when it is subjected to axial loading along the flight direction of the fuselage also a linear static analysis of center fuselage structure with a circulated air load following up on it.
Keywords: Center Fuselage, Structural Intigratiy, Static Analysis, Buckling Analysis, Buckling Load Factor.

I. INTRODUCTION

Aircraft is a symbol of a high-performance mechanical structure, which has the ability to fly with a very high level of structural safety. Aircraft comprises of basic components such as the wings, fuselage, tail units and control surfaces. Each component has specific functions and should be designed to ensure that it can perform these functions safely. Any small failure of these components can lead to a catastrophic disaster causing great destruction of life and property. 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 fuselage.

A. Fuselage

The fuselage is the main structure, or body, of the aircraft. It provides space for personnel, cargo, controls, and most of the accessories. The power plant, wings, stabilizers, and landing gear are attached to it. There are two general types of fuselage construction: welded steel truss and monocoque designs. The welded steel truss was used in smaller Navy aircraft, and it is still being used in some helicopters. The monocoque design relies largely on the strength of the skin, or covering, to carry various loads. The monocoque design may be divided into three classes: monocoque, semimonocoque, and reinforced shell. The semimonocoque fuselage is constructed primarily of aluminum alloy, although steel and titanium are found in high-temperature areas. Primary bending loads are taken by the longerons, which usually extend across several points of support. The longerons are supplemented by other longitudinal members known as stringers. Stringers are more numerous and lightweight than longerons.

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. The load at which buckling occurs depends on the stiffness of a component, not upon the strength of its materials. Buckling refers to the loss of stability of a component and is usually independent of material strength. This loss of stability usually occurs within the elastic range of the material.

II. OBJECTIVE

To determine the structural integrity of a center fuselage structure through FEA approach.

III. METHODOLOGY

•Creation of geometric Model for the fuselage section of the selected transport aircraft using CATIA v5.
•Generation of FE Model based on the geometric model generated using HyperMesh.
•Assigning Material properties for the generated FE model.

•Application of Loads and Boundary conditions based on the flight condition chosen.
•Analysis of the FE Model using NASTRAN.
•Extraction of results after completion of analysis and documentation using HyperView.

A. Modelling

• In this section, modeling of Fuselage structure has been done using CATIA v5 modeling software.
• The fuselage structure is consists of skin, stringers and bulkheads.
• For model simplification, all fillets and chamfers below 3mm are neglected.
• The skin is divided into different section to allow for thermal expansion
• The total length of fuselage is 3600mm and the diameter of fuselage is 1900mm

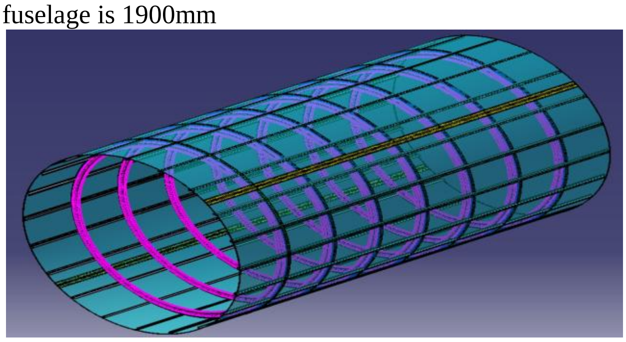

Fig.1. Geometric model of center fuselage structure

Figure 1 shows the geometric model of centre fuselage structure of an aircraft.

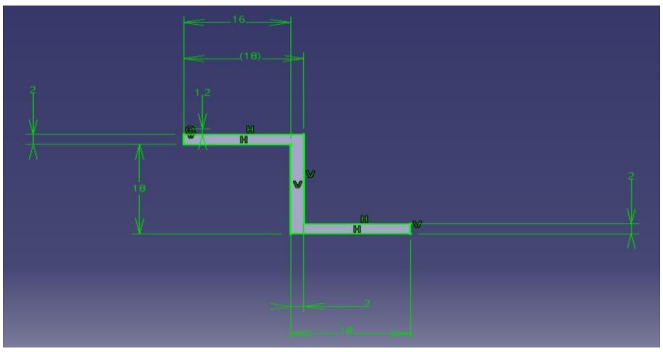

Fig.2.Geometric model of Z section Stinger

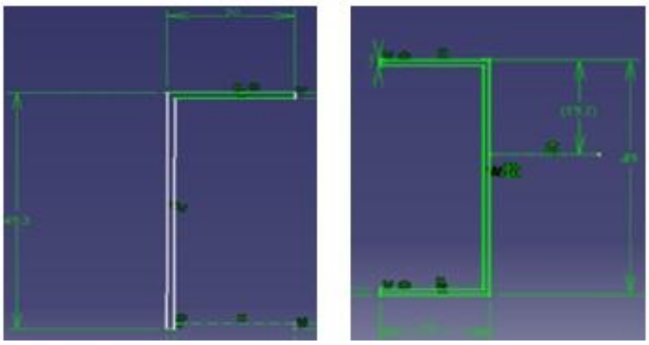

Fig.3. Geometric model of L and C section Bulkhead

Figure 2 shows the geometric details of the sections of stringers and figure 3 shows the geometric details of the bulkheads.

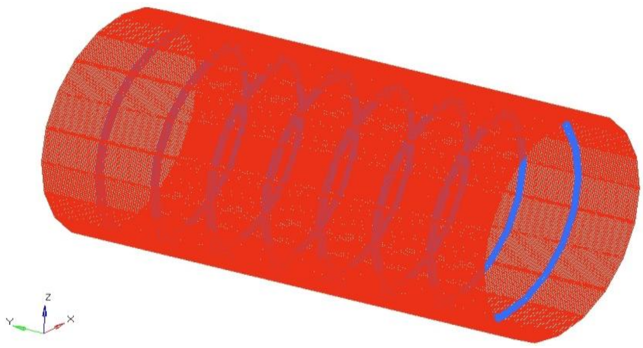

Fig.4. Finite Element Model of the centre fuselage

Figure 4 shows the Finite Element model generated for the geometric model of the fuselage structure using 2D Quad elements. These elements are selected because the large size of the structure and one of the dimensions of all the components are comparatively less than the other two dimensions. Each component is considered as a separate entity and then joined using 1D rigid element which replaces the rivets that are used to connect all the components in the actual model.

TABLE I. ELEMENTS AND NODES COUNT

Nodes	252700
Elements	252000

From the above table it can be seen that the total count of nodes and elements after meshing.

B. Material Properties

The material properties required for the current analysis are Young's Modulus, Poisson's ratio, density and ultimate strength. This is because the analysis is of structural nature and other properties are not considered in the analysis. For the current analysis aluminum alloy [Al7075] is used.

TABLE II. MATERIAL PROPERTIES FOR AL7075

Property	Unit	Value
Young's Modulus	GPa	71.7
Poisson's Ratio	-	0.33
Density	Kg/m3	2820
Ultimate Strength	MPa	572

C. Boundary Conditions and load calculations

For the analysis, the ends of the centre fuselage are fixed and pressure load is applied to simulate the air pressure acting on it when the airplane is moving at a speed of 250 km/h and at a height of 3000 m (10,000 ft.). The load calculations are as given below.
Air density at the height of 3000m = 0.905 kg/m^3
Speed of the aircraft = 250 km/h = 69.44 m/s

Air Pressure acting on the center fuselage is given by

$$P_d = \frac{1}{2}\rho v^2$$

Where,
ρ = Density of the air (kg/m^3)
v = Velocity of the aircraft (m/s)
Therefore,

$$P_d = 0.5 * 0.905 * (69.44)^2$$
$$P_d = 2181.91 \text{ Pa} = 2.1819 \text{ kPa}$$

P_d is the total pressure applied on the skin of the center fuselage for the analysis.

Design load factor considered = 3g
No. of passengers on the aircraft = 4 Nos.
Average load of each passenger = 75kg
Total passenger load = 75 X 4 = 300kg
Mass of other equipment on the aircraft = 300kg

Total load distributed on all bulk heads = (Design load factor) *(Total passenger load) * (Total equipment load)
= 3*300*300
= 1800 kg
Total weight applied = 1800 X 9.81
= 17658N
The total weight calculated above is applied on the bulkheads equally distributing the load among them.

D. Results and Discussion

The analysis was run for the above mentioned FE Model with the loads and boundary conditions attached to it. The following figures give the results obtained from both the static analysis (Displacement and Stresses) and buckling analysis (Buckling mode).

Linear Static Analysis

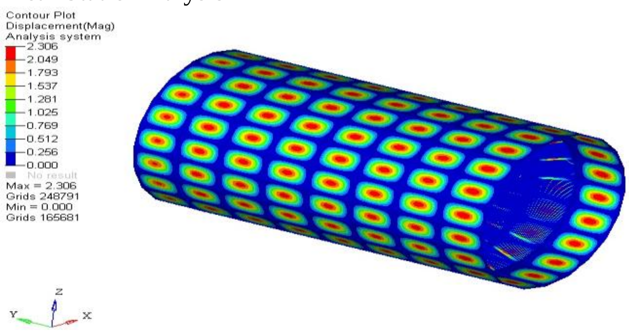

Fig.5. Displacement plot for static analysis

Figure 5 shows the displacement for the load applied on the centre fuselage. It is clear from the above figure that the maximum displacement is seen on the skin (i.e., between the stringers and bulkheads) at a value of 2.306mm.

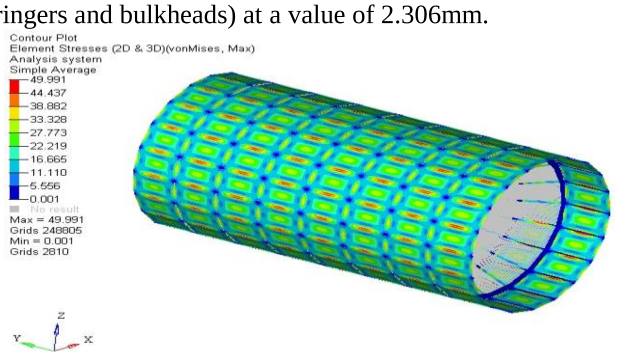

Fig.6. Stress plot for static analysis

Figure 6 shows the Von Mises stress plot for the fuselage structure under the loads applied. It is clear from the above figure that the maximum stress is seen where the skin of the aircraft is joined to the stringers with rivets at a value of 49.99 MPa. This value is very much less than the yield strength of the material and hence it can be said that the centre fuselage structure is safe under the applied load because the value of the stress developed is well within the maximum allowable stress level of 572 MPa and the factor of safety calculated is of the order of 11.44.

E. Buckling Analysis Results

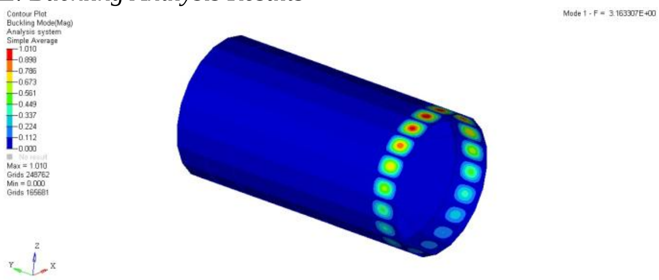

Fig.7. Buckling mode plots

Figure 7 shows the buckling mode plot of the fuselage structure for the applied loads. It is observed that the buckling factor is 3.6 which means that the fuselage structure designed can withstand loads as high as 3.6 times the load applied under the above mentioned conditions. In buckling analysis, the value of buckling factor determines the safety of the component. The table III shows the buckling load factor.

TABLE III. BUCKLING LOAD FACTOR

Buckling Load factor		
Sl. No	***Buckling Factor***	***Remarks***
1	<1	Failure
2	=1	Needs Modification
3	>1	Safe

IV. CONCLUSION

- The displacement occurring in the fuselage structure is minimum and does not affect the strength or performance of the structure for the applied loads.
- The linear static analysis shows that the stress generated in the model due to the applied load is well within the value of the ultimate strength of the material.
- The buckling analysis of the structure revealed that the buckling factor was greater than 1 and hence can be said that the structure can withstand the applied buckling load.
- The structural integrity of fuselage is achieved through static and buckling analysis.

V. SCOPE FOR FUTURE WORK

- Same analysis can be performed to determine whether a composite material can withstand the applied load without any major changes in the structure.

- Dynamic analyses may generate results which could assist in modification of the Fuselage for better performance.
- The analysis can be performed by modifying bulkhead spacing.
- The analysis can be performed by modifying stringers cross section.
- Buckling strength of the panels can be verified by taking into account the different materials.

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