Design and Optimization of Fuselage of an aircraft for Static and dynamic loads

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Abstract— **Fuselage forms the main structure of the aircraft that accommodates the passenger and cargo. The fuselage is continuously subjected to various loads during flight as well as after landing. The integrity of the fuselage-structure is very important for the safety of the aircraft.**

This project describes a conceptual design of fuselage structure for small 50 passenger capacity aircraft by using CAD software as the design tool; Specific size, performance, the number of competing designs and the commonality of features with existing small capacity aircraft to be considered in the design process.

This project aims to design and optimize the fuselage-structure for static and dynamic loads for optimal stiffness. For this purpose, CAE simulations will be performed on a fuselage model using static and dynamic conditions. According to the static and dynamic analyses results, a significant comparison is conducted in order to supply the necessary information for predicting the response of structures when working in an over limit situations that is very difficult to simulate by experiments. Based on the response of the model, topology optimization would be performed using CAE software. Based on the optimization runs, the best-fit design of the fuselage will be identified.

Keywords— Aircraft structure design, finite element analysis, fuselage structure and optimization.

I. INTRODUCTION

Aircraft are members and transverse frames to enable it to resist bending, compressive and vehicle which are able to fly by being supported by the air or in general the atmosphere of a planet. Aircraft are generally built up from the basic components of wings, fuselage, tail units and control surfaces and each component has one or more specific functions and must be designed to ensure that it can carry out their specific functions safely. Any small failure of any of these components may lead to catastrophic disaster causing huge destruction of lives and property.

In the development of modern aviation reflects the characteristic features of scientific technological progress: an integrated use of the results of the scientific research, engineering and manufacturing experience is widely used computer technology, which provide an opportunity to the creators of aircraft design as a scientific discipline, which in turn will promote the development of theories of reliability, efficiency, weight and design etc.

It is known that virtually no aircraft in the air transport system in the world, which would have no modifications. There was a tendency at the same time creating a family of aircraft that includes the modification of varying range and varying passenger capacity. The economic effect is provided by the maximum common basic structure and system. This approach is based on the maximum uniformity, reduces the cost of developing new models and price serial products as well as maintenance cost of their operation. Therefore, the creation of the modern competitive aircraft is impossible without the use of integrated computer systems, CAD / CAM /CAE.

During the conceptual design of aircraft, many alternative configurations must be evaluated in multidisciplinary design trades to determine the characteristic of a candidate configuration which will best meet specific measures of overall vehicle performance and/or cost. Airframe weight is the main parameter that is required from the structure discipline. The airframe should be lightweight but also have sufficient strength and stiffness necessary to satisfy the entire requirement throughout the flight envelope.

Using Finite Element (FE) models to predict the static and dynamic properties of the structures becomes more and more significant in modern mechanical industries, such as in the aviation industry. Whenever there is a new design or modification of an existing design, the structural dynamic properties of the product must be examined to fulfill some criteria proposed either by the industry itself and/or external agencies, before the product can be launched onto the market.

The traditional way for evaluating the structural properties of the product is to perform a series of static and dynamic tests on prototypes of the product and to demonstrate its capacity to withstand these tests. Until the experimental results show the prototypes are in compliance with the relevant criteria, the product has to be redesigned and another design-test loop has to be followed. In this design-test redesign loop, much time and money is spent on producing prototypes and performing tests. Therefore, manufacturers are confined to in order to create a new model with reflecting the desired properties from the structures. With the growing capabilities and facilities of computing techniques and the strength of competitions between the companies, FE model predictions are used more and more to take the place of practical static and dynamic test data.

In the frame of this thesis, the paper describes a conceptual design of fuselage structure for a small 50 passenger jet aircraft by using CATIA v5 software as the design tool. A first step for the application of Finite Element Method in fuselage Manufacturing process is carried out. In HYPERMESH (OPTISTRUCT Classic), a reliable and robust FE model is generated with respect to the data of the fuselage manufacturer and DLR. According to the static and dynamic analyses results, a significant comparison is conducted in order to supply the necessary information for predicting the response of structures when working in an over limit situations that is very difficult to simulate by experiments.

II. PRINCIPLES

2.1 . Fuselage

In an aircraft the main body structure is the fuselage to which all other components are attached. The fuselage contains the cockpit or flight deck, passenger compartment and cargo compartment. While wing produce most of the lift, the fuselage also produces a little lift. A bulky fuselage can also produce a lot of drag. For this reason the fuselage is streamlined to decrease the drag due to which the obstacle to the oncoming wind is reduced. It has a sharp or rounded nose with sleek, tapered body so that air can flow smoothly around it.

Unlike the wing, which is subjected to large distributed air loads, The fuselage is usually subjected to small air loads. The primary loads on the fuselage include large concentrated forces from the wing reaction, landing gear reaction and pay loads. For airplanes carrying passengers, the fuselage must also withstand internal pressures. Because of the internal pressure, the fuselage often has a circular cross-section.

The design of the aircraft may be divided into two classes:

1. Monocoque
2. Semimonocoque

The Monocoque (single shell) fuselage relies largely on the strength of the skin or covering to carry the primary loads.

The true monocoque construction uses formers, frame assemblies and bulkheads to give shape to the fuselage. The heaviest of these structural members are located at intervals to carry concentrated loads and at points where fittings are used to attach other units such as wings, power plants and stabilizers. Since no other bracing members are present, the skin must carry the primary stresses and keep the fuselage rigid. Thus, the biggest problem involved in monocoque construction is maintaining enough strength while keeping the weight within allowable limits.

To overcome the strength/weight problem of the monocoque construction, a modification called semimonocoque construction was developed. Nowadays this type of construction is adapted for airframe construction. This semimonocoque construction consists of a thin shell stiffened by longitudinal axial elements (stringers and longerons) supported by many traverse frames are rings (bulkhead) along the length. The fuselage skin carries the shear stress produced by torque and transverse forces. It also bears the hoop stress produced by internal pressure. The stringers carry bending moments and axial forces; they also stabilize the thin fuselage skin.

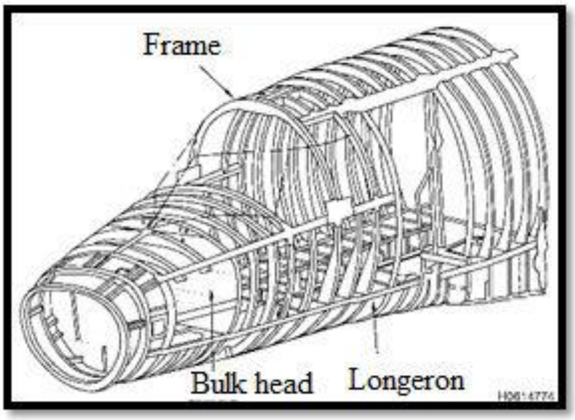

Fig 2.1Semi-monocoque construction

2.2 Fuselage Frames

Fuselage frames are ring structures used to maintain the shape of the fuselage and to shorten the span of the stringers between supports in order to increase the bulking strength of the stringer.

To distribute large concentrated force such as those from the wing structure, heavy bulkheads are needed. Bulkheads are a transverse partition or a closed frame in a structure separating one portion from another and are used to designate solid, webbed or trussed members to dissipate concentrated loads into monocoque and semimonocoque structure especially a fuselage.

Members approximately parallel to semimonocoque structure are called longitudinal stiffeners or also known as stringers which are designed to stiffen the skin and assist the resisting shear and bending loads and hold the frames in position. Stringers are used to carry direct load in the direction of its length.

Longerons are the main structural members of the fuselage. It is generally used when there is big cut-out to be provided.

Floor beam – they represent the floor structure of the aircraft, with longitudinal beams, traversal beams and supporting beams. These beams can be machined or formed depending of the strength involved. They represent the basic structure of the floor.

2.3 Fuselage loads

The fuselage will experience a wide range of loads from the number of sources. The weight of the fuselage structure and payload will cause the fuselage to bend downwards from its support at the wing, putting the top portion in tension and the bottom, portion in compression. The landing loads may be significant. The bending loads are higher when the weight is distributed towards the nose and tail. Therefore, the aircraft are loaded close to the centre of gravity.

Pressurization of the aircraft cabin is an accepted method of protecting occupants against the effects of hypoxia. Within a pressurized cabin, occupants can be transported comfortably and safely for a longer period of time, particularly if the cabin altitude is maintained at 8000 feet or below, where the use of oxygen is not required. Particular problems occur in areas where the fuselage is required to be non cylindrical.

Internal pressure will generate large bending loads in fuselage frames. The structures in these areas must be reinforced to withstand these loads. Because fuselages are pressurized for safety, the designer must consider what will happen if the pressurization is lost. The damage due to depressurization depends on the rate of pressure loss. For very high rates, far higher loads would occur than during normal operation.

Doors and hatches are a major challenge when designing an aircraft. Windows are having small cut-out; hence do not create a severe problem. Depending on their design, doors will or will not carry some of the load of the fuselage structure. Also very high localized loads can occur on the floor of the fuselage, especially from small-heeled shoes. Therefore floors need a strong upper surface to withstand high local stresses.

2.4 Aircraft Requirement and Safety

Specifications of the requirements .are the first step in designing an aircraft. An aircraft part must execute its function in all circumstances mainly in critical situations.

The strength of a structure is compute by the acceptance that the structure will fail in extreme condition. Standard for such risk is sets by the society. This means we agree that all structure fail in certain condition. Ultimate load is the maximum load which will cause the structural fail.

The main factor of structural failure is metal fatigue. Metal fatigue is a fracturing process of a material due to a very large series of normal repetitive loads. As a consequence, it is significant to identify the rate of crack growth and the residual strength of a structure. Residual strength is the strength in the presence of the crack.

Furthermore, a set of Joint Airworthiness Requirements which are based on American Federal Airworthiness Requirements have been devised by several European countries. The reason of this is to determine the primary structure, those that would endanger the aircraft upon failure. Besides that, we need to recognize secondary structure, which do not cause immediate danger upon failure and non-load bearing structure that do not carry load according to these requirements.

There are several techniques in considering safety part. Based on fail-safe principle there is a possibility that part of the structure fail. Though there should be no chance for the entire structure failing. Additionally, the stiffness of a structure is compute of its resistance to a change in shape when subjected to forces. It includes a combination of its material properties and its geometry.

As a conclusion, designer and manufacturer play an important role and hold responsibility in safety issue of the aircraft to ensure the structure have certain criteria to perform its function.

2.5 Weight

As we know, in development of Small passenger capacity aircraft, weight is one of our main focuses. So, to minimize the weight, material with a high strength to weight ration can be employed. Below is the equation that is formulated to show the relationship between tensile strength and specific weight.

$$L_t = \frac{\sigma_t}{w}$$

L_t Is referring to the length at which a bar of constant cross section will fail caused by its own weight, It is also feasible to select materials which go well with thin wall structure. The stiffness of the material consumed and specific weight are important in the development of thin walled structure. The specific modulus of elasticity $\frac{E}{w}$is compute of a structure in relation to its weight.

Buckling is a phenomenon that occurred in compression which causes a special form of deformation.

The buckling of a metal sheet happened at critical stress. It can be written as the equation below.

$$\sigma_{t=}C.\frac{Et^2}{a.b}$$

Where ‘C’ is a constant, ‘t’ is the thickness, ‘a’ is the length and ‘b’ is the width. The crisis needs to be approached schematically by designer either computational or experimental. Analyzing the problem is not possible without simplification.

However, the simplification will make the model less applicable in real life and affected their accuracies. This is why the design of a structure has a built-in safety factor. Other than that, enhance the predictive tool will lower the safety factor necessary as well as lower the final weight of the structure.

III. LITERATURE SURVEY

1. Design & Vibration Analysis of Fuselage Structure Using Solid works & ANSYS (Volume 1, Issue 3, September – 2014) By

1. K Vishal Sagar, 2.hattiproluahasenadipathi Rao 3. Dr. Allam Purushotham.

Abstract: 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. In this paper structural and model analysis of A320 fuselage structure, we aim to learn the process to solve many engineering problems with the help of a solver commonly known as SPARSE directs solver which is the default solver in ANSYS without preparing the prototype model and caring the actual experiments.

2. “Preliminary Fuselage Structural Configuration of a FLYING-WING TYPE AIRLINER” (MSc by research Academic Year: 2011 – 2012) By

Yung Cheng from CRANFIELD UNIVERSITY

Abstract: 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.

According to these outstanding advantages, many aircraft companies did a great deal of projects on the flying-wing concept. However, the application was only for sport and military use; for airliner, none of them entered production.

3. “Recent experiences in load analysis of aircraft fuselage panels”
(Volume 1, Issue 2, December – 2013) By
Prof. Dr.-Ing. Wilhelm Rust1 and Dipl.-Ing. M.Kracht2
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Abstract: 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. The problem of finding the correct load path in the vicinity of bifurcation points is discussed. Presented solutions include standard perturbation by single force imperfections, empirically proved displacement difference method and the Eigen value tracking method. A material model for meso-Marco coupling of nonlinear panel and barrel analysis is presented which introduces nonlinear effects into a coarse meshed FE barrel model for preliminary design purposes.

4. “A Review on Stress Analysis of the Fuselage Structure and Study of the Effect of Overload on Fatigue Crack Growth” (January 2014) By Dr M. M. NADAKATTI, VINAYAKUMAR. B. MELMARI.
Abstract: 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. A structure will have a finite fatigue life during which fatigue cracks initiate and propagate to critical sizes leading to catastrophic failure of the structure. Therefore fatigue life consists of two parts: the first part is the life to the initiation of fatigue crack and the second part is the fatigue crack propagation to final fracture. On the other hand fatigue crack growth is the dominant phase for more ductile structures or material.

5. “Design- oriented analysis of aircraft fuselage structure” by Gary L. Giles (NASA Langley Research Center, Hampton, Virginia).
Abstract: 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.
Typical fuselage analysis results are presented for two analytical models. Results for a ring-stiffened cylinder model are compared with results from conventional finite-element analysis to assess the accuracy of this new analysis capability. The connection of plate and ring segments is demonstrated using a second model that is representative of the wing structure for a channel-wing aircraft configuration.

6. “Experiences with ANSYS in Ultimate-Load Analyses of Aircraft Fuselage Panels”(January 2009) by
WILHELM RUST (Fachhochschule Hannover–University of Applied Sciences)
And
MARTIN KRAHT, JOSEF OVERBERG (CAD-FEM GmbH, Hannover Office).

Abstract: Wider parts of the fuselage of a commercial aircraft are subject to shear and compression loads in such a way that this is relevant for dimensioning. First elastic, later plastic buckling can appear. The ultimate load is reached when a combined buckling of skin and longitudinal reinforcements (stringers) leads to failure of a panel.
This behavior is tested physically, but over years CAD-FEM and Airbus Deutschland worked together to simulate the test and analyze further configurations under aircraft-like conditions with ANSYS.
The paper describes which difficulties had to be overcome to achieve convergence and obtain reliable ultimate loads. The advantages and disadvantages of different load and solution control features such as force or displacement control, arc-length method, different ways of incrementing are lined out as well as different kinds of imperfections. Furthermore, the use of linear buckling and Eigen value extraction at some stages of non-linear analysis is considered.
It is shown that ANSYS is an appropriate tool for such kind of analysis, but the importance of some missing features becomes evident.

7. “Conceptual Design of Fuselage Structure of Very Light Jet Aircraft” by KHAIRI YUSUF, NUKMAN Y., S. Z. DAWAL, DEVI CHANDRA, N. SOFIA.

Abstract: This paper describes a conceptual design of fuselage structure for very light jet aircraft by using CAD software as the design tool. Specific size and performance, the number of competing designs and the commonality of features with existing light jet aircraft are factors need to be considered in the design process. This conceptual design develops the first general size and configuration for a new light jet aircraft fuselage structure. The model of the fuselage structure is then undergoing engineering simulation programmed which is based on the finite element method. In this analysis, problems with multiple components are modeled by associating the geometry defining each component with the appropriate material model and specifying component interaction. Besides that, the load increments and convergence tolerance are continually adjusted to ensure an accurate solution is obtained.

IV. FUSELAGE DESIGN AND CONFIGURATION

1. FUSELAGE CONFIGURATION

The reference aircraft used in my project is "Bombardier CRJ 200". General characteristics of the designing aircraft resulted from aerodynamic and aircraft analysis is as table 1, and the performance is as table 2. The configuration of fuselage is as fig 2 and fig 3.

TABLE 4.1, GENERAL CHARACTERISTICS

Crew	2 Members
Capacity	50 passenger
Length Overall	87.10 ft (26.77 m)
Wing span	69.7 ft (21.21 m)
Height	20.5 ft (6.22 m)
Maximum payload	5,942kg (13,100 lb)
Maximum takeoff weight	23,133kg (51,000 lb)
Fuselage Maximum Diameter	8.10 ft (2.69 m)
Cabin Length	40.6 ft (12.6 m)

Basically fuselage structure can be divided into three sections which are cockpit section, tail section and the cabin section. For this study, the conceptual design is focusing on the cabin structure of the fuselage.

In the first stage of design, we develop a basic concept for the fuselage structure. The configuration of each component is simplified in order to produce new ideas based on the structure arrangement.

TABLE 4.2 PERFORMANCES

Maximum Speed	860 km/hr (464 KTS)
Normal Cruise Speed	785 km/hr (424 KTS)
Range	2,491 km (1,345 NM 1,548 SM)
Surface Ceiling	12,496 m (41,000 ft)
Cabin Pressure	Maximum 8.4 pound per square inch

2. CHOSEN STRUCTURE

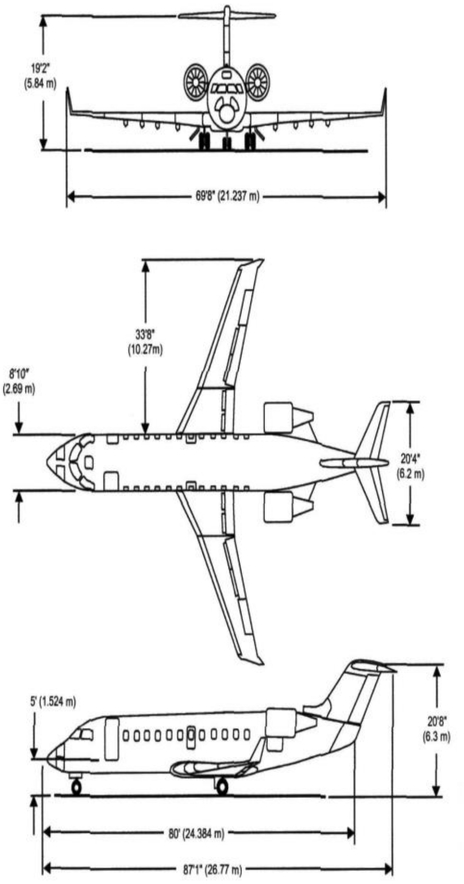

Fig.4.1 Configuration of aircraft

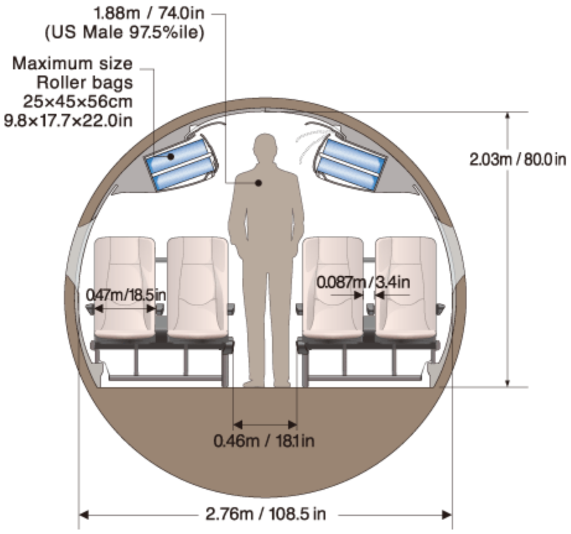

Fig.4.2 Configuration of fuselage

The concept is the structure with the number of frame and stringers are equal. In this concept, the spacing for both frames and stringers is approximately equal. The reason for this idea is to provide a great stiffness of the structure. Loads subjected to this structure are carrying equally by both components. Usually the number of components and joints are increased compared to the aircraft structure concepts where stringer and frame spacing not being the same. The diameter and length of fuselage is approximately 2.69m and 12.6m.

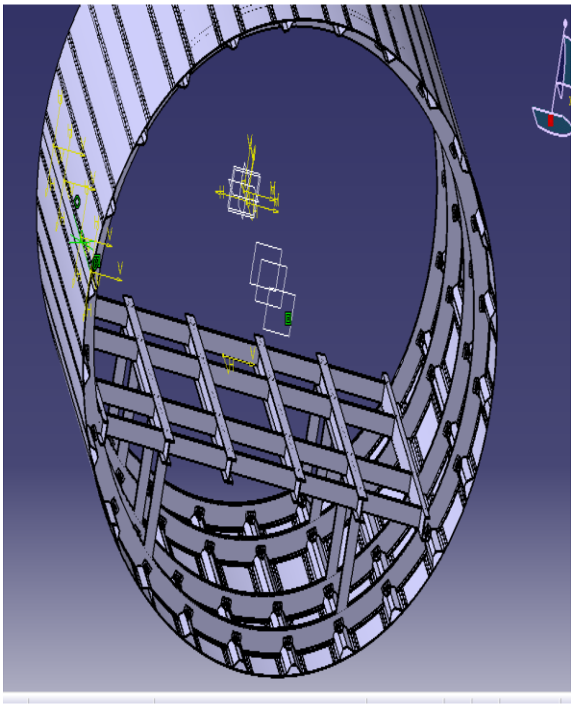

Fig4.3 the Chosen Fuselage Structure

3. MATERIAL SPECIFICTION

Material considered for I section of fuselage frames and rivets joint is in table 4.3.

Table 4.3

ALUMINIUM - 2024 T3	
Young's Modulus	70000 N/mm2
Poisson's Ratio	0.3
Density	2800 Kg/mm3
Yield Strength	275 MPa
ultimate Strength	460-483 Mpa

4. LOADS IN THE MODEL

A differential pressure of 7 psi (0.0480MPa) is considered for the current case. Due to this internal pressurization of fuselage (passenger cabin) the hoop stress will be developed in the fuselage structure. The tensile loads at the edge of the panel corresponding to pressurization will be considered for the linear static analysis of the panel.

Hoop stress is given by

$$\Sigma \text{ hoop} = \frac{p * r}{t} \qquad (5.1)$$

Where

Cabin pressure (p)=7 psi=0.04806 MPa.

Radius of curvature of fuselage(r) = 1500 m

Thickness of skin (t) = 2 mm

After substitution of these values in Eqn (5.1) we will get

σhoop = 3.675 Kg/mm2
=36.05175 MPa

We know that

$$\sigma\text{hoop} = \frac{P}{A}$$

Above equation can be written as

$$P = \sigma \text{ hoop} * A \qquad (5.2)$$

1) Uniformly distributed tensile load is applied on either side of the stiffened panel in Y axial direction.

Load on the skin

Here

Ps=Load on skin

σhoop =3.675 Kg/mm2

A=Cross sectional area of skin in mm2

i.e. Width *Thickness(2800*2)=5600

Substituting these values in the Eqn.5.2 we get

Ps=20580 Kg

Ps=201889.805N

Uniformly distributed load on skin will be

Ps =201889.80 /2800

=7.35Kg/mm=72.1035N/mm.

5. FINITE ELEMENT ANALYSIS

5.1. Introduction To FEA

Finite Element Analysis is a way to simulate condition on a design and determine the design's response to that condition. The design is modeled using discrete building blocks called elements.

In this method of analysis, a complex region defining a continuum is discretized into simple geometric shapes called elements. The materials properties and governing relations are considered over these elements and expressed in terms of unknown values at element corner. An assembly process, by considering the loading and constraints, results in a set of equations; solution of these equations gives us the approximate behavior of the continuum.

A. A

B.

C.

D.

5.2. Stages Involved in FEA

a) Pre-processing

It is the act of preparation of data such as nodal locations, element connectivity coordinates imposing boundary conditions applications of load and providing material information to element etc. one can decide in this stage regarding the number of nodes, elements, type with their order and pattern of element mesh.

b) Processing

This stage involves stiffness generation, strain energy calculation and solution of equations resulting in the evaluation of nodal variable, induced elemental forces, strain and stress.

c) Post-processing

This stage involves geometric deformation, distribution of forces, stresses and strains in the structure. Here the results can be viewed in the form of graph, tables and plots etc.

5.3. Procedure

In the fuselage structure, the frames are stiffening elements, acting in circumferential direction that can be viewed as closed curved beams whose role may vary in dependence of their location along the fuselage and their interaction with the neighboring structures.

In this study, the frame and the skin with stringers at first are modeled and analyzed separately in order to see the stress working over every node on them. Then the analysis of combination of them is done. All of them are drawn by using software's CAD and OPTISTRUCT for finite element analysis. Figure 6 shows the frame under several loading working on it, and figure 7 shows the part of fuselage structure which analyzed by finite element method.

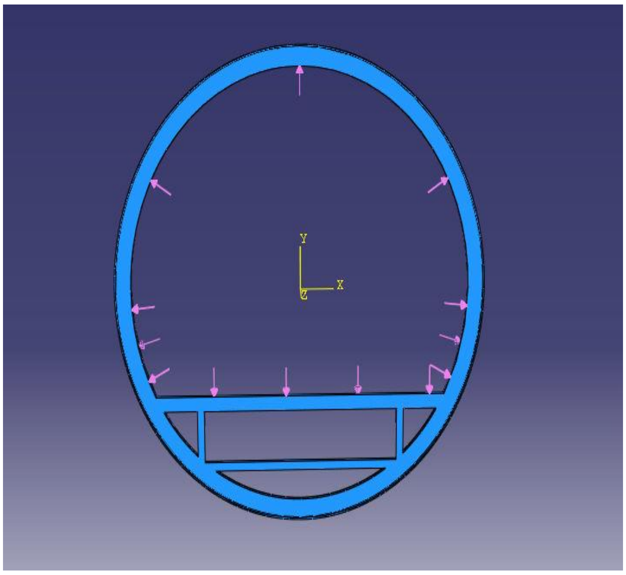

Fig 4.4 Loads on fuselage structure

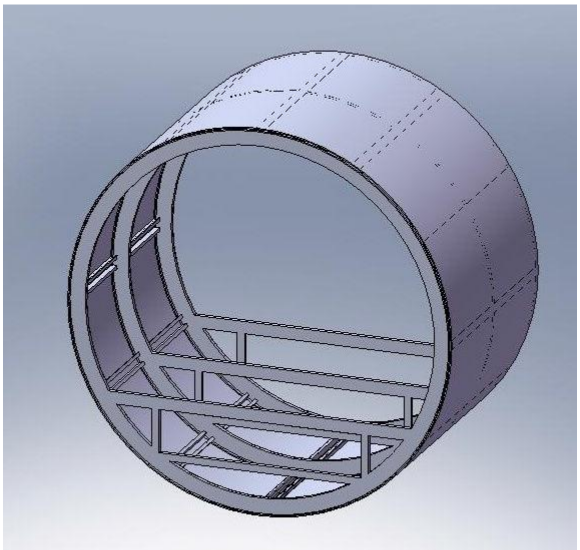

Fig 4.5 Part of fuselage structure which analyzed by finite element method

V. RESULT AND DISCUSSION

The finite element analysis model results show that the design structure is rigid and safe. It can be shown in three kind of result of the analysis. The first is the stress distribution of frame in the unit of Mpa as shown in figure 12 under several loads (concentrated force and pressure).

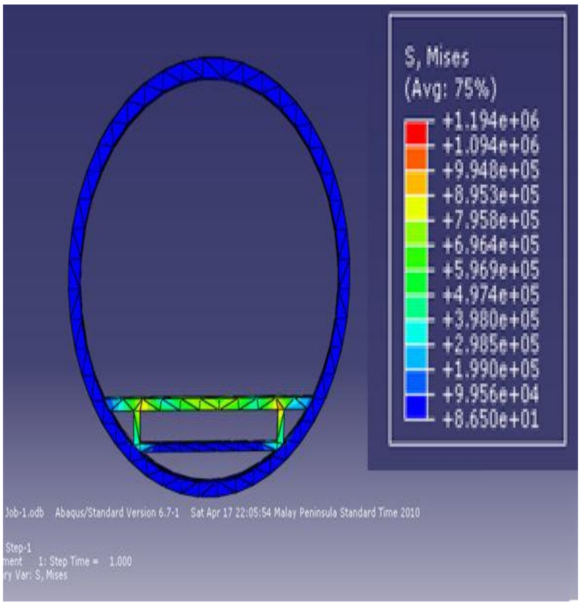

Fig 4.6 The stress distribution of loaded frame.

The second result is the fuselage skin with the stringers which loaded by the internal pressure as 1 atm. The meshing of it and the stress distribution are shown in figure 4.7.

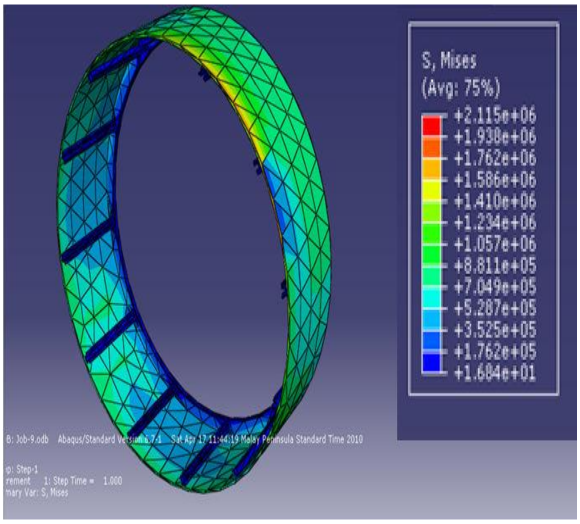

Fig. 4.7 Stress Distribution Of The Fuselage Skin With The Stringers

The third result is the combination of frame and skin with stringers. The meshing and the stress distribution are shown in figure 4.8.

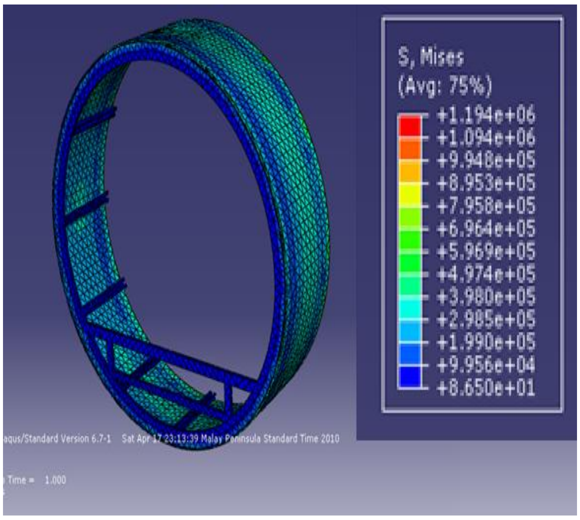

Fig.4.8 stress distribution of the fuselage with frame, stringers and skin

The result at this stage, i.e. using finite element Analysis, is satisfied since the stress occurred is far below the yield strength of the material (345 Mpa). However, the frame geometry is quite complex.

It is characterized by a variable cross-section along its perimeter and, generally, it is not built in one single piece, but by assembling a number of subelements; the external flange is connected to the skin that presents a varying thickness along the frame perimeter. Furthermore, the solution of the stringer crossing problem produces different structural configurations: from the simple floating frames up to the more complex frames with integral or separate shear ties.

Such that, more detail analysis is needed in order to get the more fine result. Besides that, the experimental testing and analysis would be done after for validating the result.

VI. CONCLUSION

The conceptual design of fuselage structure of light jet has been presented. The result shows that the fuselage structure is rigid and safe according to the failure theory analysis, which means the working stress is far below the yield strength of the materials.

The result at this stage is satisfied but it needs more attention to the critical area of the structure since the fuselage is not as one body but consist of assembly parts Constructed it. The critical area in this study also includes the kinds of joins which assembled the whole parts.

In turn, the design needs validation by experimental test and analysis with static and dynamic loads in order to get the good and safety result before producing the small passenger capacity aircraft.

VII. ACKNOWLEDGEMENT

I would like to thank Dr. Shantakumar.G.C Professor and Head of Department of Mechanical Engineering T. John Institute of Technology, Bangalore and PG coordinator Dr. Sujithprasad.E Professor Department of Mechanical Engineering T. John Institute of Technology, Bangalore for their expert guidance and support.

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