Conceptual Design of Fuselage Structure of Very Light Jet Aircraft

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***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.

***Keywords*: -** aircraft structure design, finite element analysis, fuselage structure, optimization, very light jet.

I. INTRODUCTION

DESIGNING an aircraft can be an overwhelming task for a new designer. The designer must determine where the wing goes, how big to make the fuselage, and how to put all the pieces together. A sound choice of the general arrangement of a new aircraft design should be based on a proper investigation into and interpretation of the transport function and a translation of the most pertinent requirements into a suitable positioning of the major parts in relation to each other. No clear-cut design procedure can be followed and the task of devising the

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configuration is therefore a highly challenging one to the resourceful designer [1][2].

Several researches of fuselage structure have been conducted to get a good configuration of the aircraft. Marco et al. [3] showed a design and analysis of composite fuselage structure in order to reduce the weight of the fuselage. It presented a new methodology developed for an analytical model of a composite fuselage. It also presented finite element analysis of a simplified model and comparisons with more complete model. This comparison assesses the weight reduction obtained with the use of composite materials for designing fuselage.

Kolesnikov et al. [4]addressed one of the concepts of carbon fiber fuselage for a big passenger airplane. The so-called "Lampasseskonzept" proposed by Institute of Structural Mechanics of the German Aerospace Center (DRL, Braunschweig) within the research program assigned by Airbus, Germany, is used. The proposed concept along with the weight/cost reduction issues addressed the possibility of meeting the additional requirement to carbon fiber plastic fuselage of big airplanes of tomorrow.

Some other investigations have been done regarding the design of fuselage structure; however, most of them are for the big commercial airplanes with heavy weight and big power.

In aviation industry, 'Very Light Jet' or VLJ is the newest innovation. Very Light Jet Aircraft which also known as micro light jet is a small jet aircraft which using single pilot operation. This aircraft consists of 4-8 people seats with a maximum take-off weight of less than 4,540

kg. These modern breed of aircraft designs are lighter than business jets and frequently used as air taxis. They generally have two engines, automated cockpits and cost half as much as the most inexpensive business jet now in service [5].

In this paper, a conceptual design of fuselage structure of very light jet is described. This conceptual design develops the first general size and configuration for a new light jet aircraft fuselage structure. 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

II. PRINCIPLE

A. Function of Fuselage

In development of VLJs, fuselage is an aircraft's main body section that holds crew and passengers (Fig. 1). The functions of an aircraft fuselage include all of the following; support structure for wings and tail, structure that contains the cockpit for the pilot and structure that allow aircraft to carry cargo, passengers, and equipment. It must be able to resists bending moments (caused by weight and lift from the tail), torsional load (caused by fin and rudder) and cabin pressurization. The majority of the fuselage in transport aircraft is cylindrical or near cylindrical with tapered nose and tail section. In order to achieved aircraft stability and maneuverability, aircraft fuselage plays an important role in position control and stabilization surfaces in specific relationships to lifting surfaces. The fuselage can be class into three basic sections which are engine section, cabin section and sheet-metal tail cone section[6].
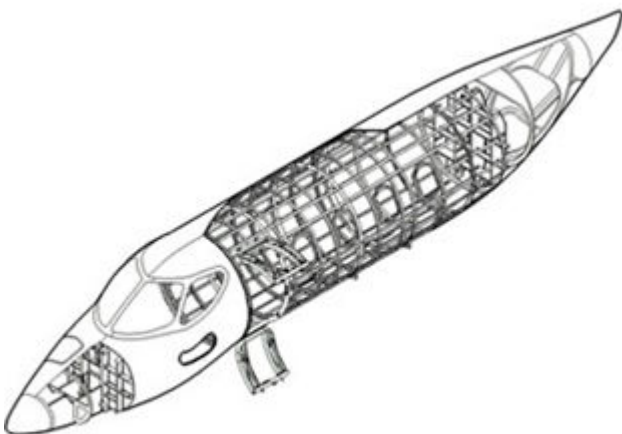
Fig. 1 Fuselage structure

B. Construction of Fuselage

Basically, the purpose of aircraft structure is to transmit and resists all loads applied to it. Furthermore, it also acts as a cover to maintain the aerodynamic shape and protects its content. Fuselage construction can be separate into two types which are welded steel truss and monocoque designs. However, most aircraft used monocoque design in their structure in order to carry various loads. The monocoque design can be categorized into three classes which are monocoque, semi monocoque and reinforced shell.

Standard aluminum fuselage of a big passenger airplane is a semi monocoque construction with shell, stringers and frames. The fuselage contains a cockpit and passenger compartment, both sections experiencing surplus internal pressure i.e. hermetic[4].

B.1 Semi Monocoque Construction

Semi monocoque fuselage design (Fig. 2) usually uses combination of longerons, stringers, bulkheads, and frames to reinforce the skin and maintain the cross-sectional shape of the fuselage. The skin of the fuselage is fastened to all this members in order to resists shear load and together with the longitudinal members, the tension and bending load. In this design structure, fuselage bending load are taken by longerons which are supplemented by other longitudinal members known as stringers. Stringers are smaller and lighter than longerons. They provide rigidity to the fuselage in order to give shape and attachment to the skin. Stringer and longerons are essential to prevent tension and compression stress
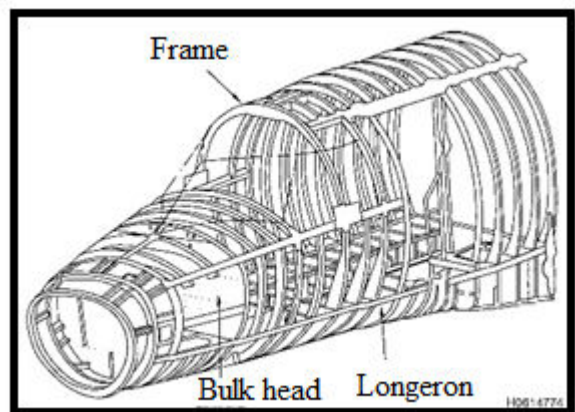
Figure 2 Semi-monocoque construction

from bending the fuselage. The fuselage skin thickness varies with the load carried and the stresses sustain at particular location. Moreover, bulkheads are used where concentrated loads are introduced into the fuselage, such as those at wing, landing gear, and tail surface attach points. Frames are used primarily to maintain the shape of

the fuselage and improve the stability of the stringers in compression. The benefits of semi monocoque design is it overcome the strength to weight problem occurred in monocoque construction.

C. 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 has 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[7]. 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.

D. Weight

As we know, in development of VLJ 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.

$$L_t = \frac{\sigma_t}{w} \qquad (2)$$

L_t is refer 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 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 σ_{cr}. It can be written as the equation below.

$$\sigma_c = c.\frac{Et^3}{a.b} \qquad (1)$$

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.

E. Loads and Pressure

Structure designer need to identify the loads that will be imposed on the aircraft before the structure can be designed. Basically an aircraft required to support two kinds of basic loads which are ground loads and air loads [8]. Ground load is load encounter by the aircraft during movement on the ground such as landing and towing. While air load exerted onto the structure during flight by the maneuvers carried out by the aircraft or wind gusts.

E.1 Fuselage loads

Fuselage loads involved of distributed and concentrated load. The concentrated loads are loads that transferred from the fixing bolts on the wing, tail stabilizers, and the landing gear. These forces are the main force acting on the fuselage Contrast to the loads above, aerodynamic load and dynamic pressure of the fuselage are classes as distributed loads. These forces subject the fuselage to bear shearing force, bending moment and twisting moment. Furthermore, the weight of fuselage structure and payload will cause the fuselage to bend downwards from its support at the wing. Consequently, the top part of the fuselage will experience tension while the bottom part in compression.

III.   DESIGN AND CALCULATION

A.   *Fuselage Configuration.*

General characteristics of the designing aircraft resulted from aerodynamic and aircraft analysis is as table 1, and the performance is as table 2 [1]. The configuration of fuselage as Fig. 3 and Fig. 4.

TABLE I
GENERAL CHARACTERISTICS

Crew	1-2 crew members
Capacity	5 passengers
Length	41.70 ft (12.71 m)
Wing span	39.87 ft (12.15 m)
Height	13.21 ft (4.03 m)
Useful load	644lbs ()
Max takeoff weight	4,173 kg (9,200 lb)

B.   *Chosen Structure*

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 three type of basic concept for the fuselage structure. All the three concepts are distinguished by different number of components. However, the configuration of each component is simplified in order to produce new ideas based on the structure arrangement. The diameter and length of the fuselage is constant for each concept which is 1600mm and 2885mm each.

TABLE II
PERFORMANCE

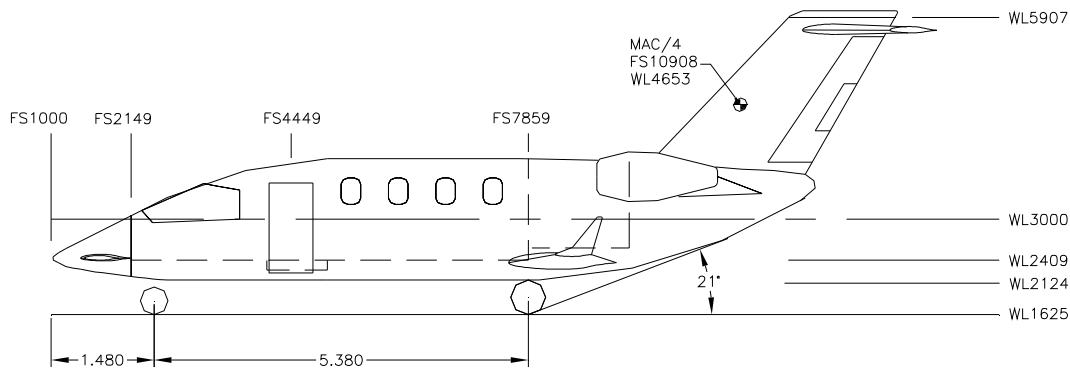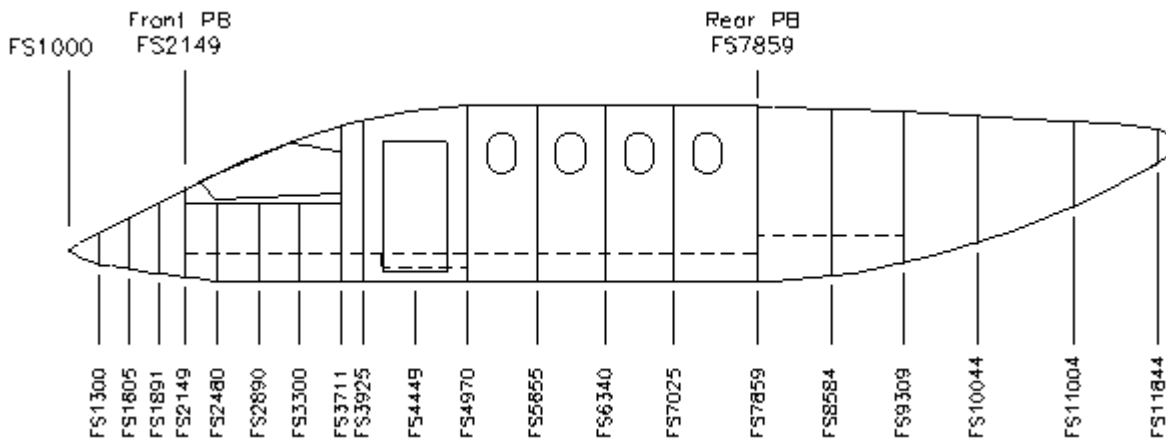| Maximum speed	420 KTAS (778 kmh, 483 mph)
Cruise speed	420 KTAS (FL300)
Range	1400 nm (1611 mi, 2,593 km) (VFR Range)
Surface Ceiling	43,000 ft (13,107 m)
Rate of climb	3990 ft/min (20.27 m/s)

Fig. 3 Configuration of aircraft.

Fig. 4 Configuration of Fuselage

For the first basic concept, the arrangement of the structure comprises of stringers, frame and floor beam. The frame spacing in this concept is smaller compared to the stringers spacing. By increasing the number of frames, the shape of the fuselage will be more rigid due to its function to support the shell.
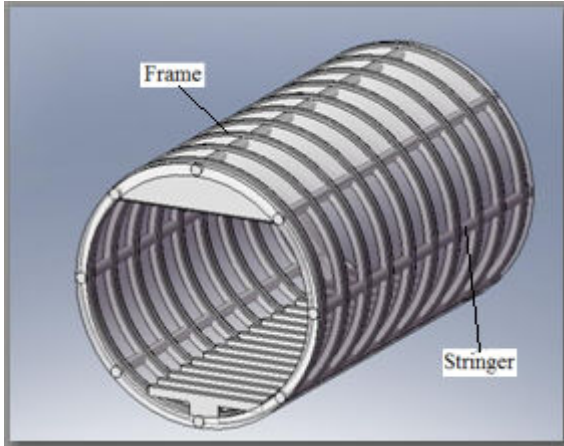

Fig. 5   First concept for the fuselage structure.

Besides that, the capability of the frame in distributing the concentrated load will increase (Fig. 5).

According to the second basic concept, the arrangement of the structure is similar to the first concept but the frame spacing is larger compared to the stringers spacing. This concept provides more efficient resistance to compressive stress since more components carry axial load which cause by bending (Fig. 6)
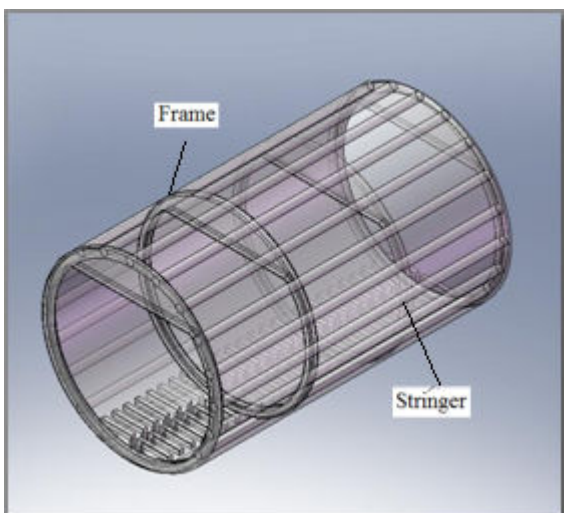

Fig. 6 Second concept for the fuselage structure.

The third concept is the structure with the number of frame and stringers are equal (Fig. 7). 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. However, the number of components and joints are increased compared to the previous concepts.
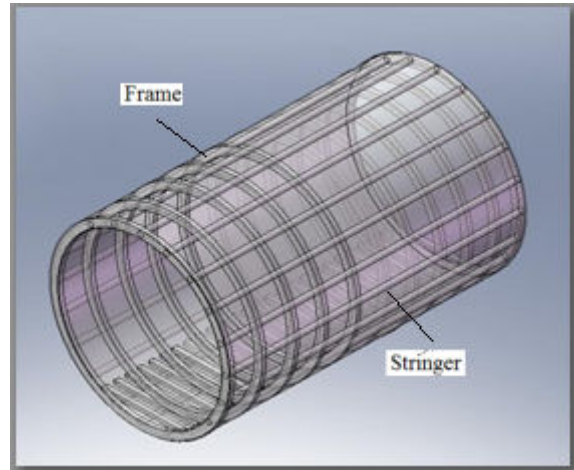

Fig. 7   Third concept for the fuselage structure.

From these concepts, by considering the weight and the strength of structure, the next configuration is chosen. Besides that, the space for window and door which is including in ergonomics point of view also be in consideration. This chosen structure is adjusted by doing optimization regarding the weight and the strength of structure using finite element method. The structure is shown in Fig. 8, and the cabin cross section in Fig. 9.
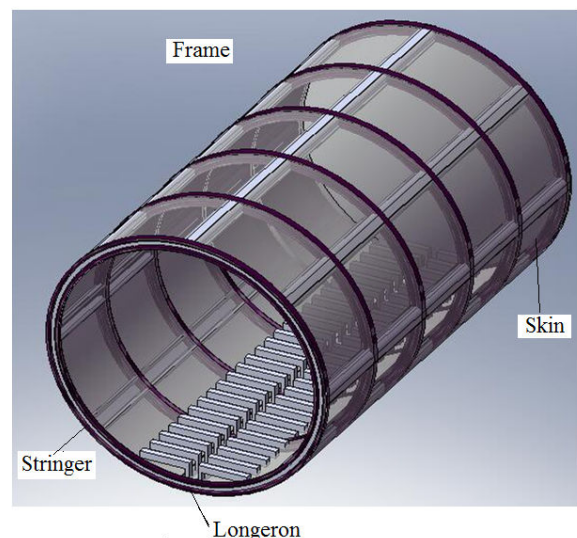

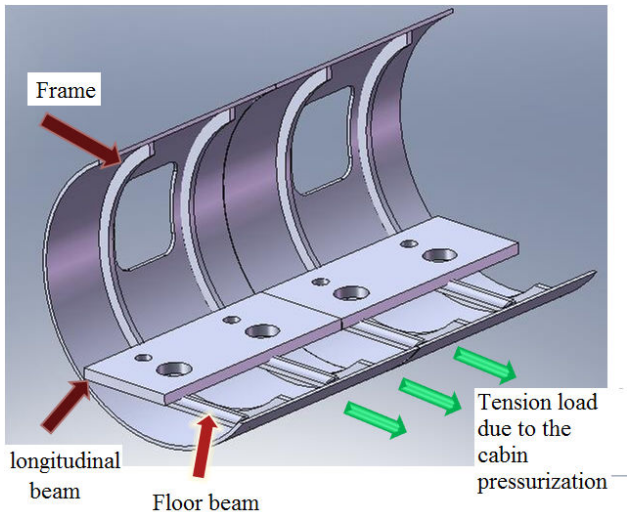Fig. 8 The chosen fuselage structure.

Fig. 9 Cabin cross section.

C.   Finite Element Analysis

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 neighbouring 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 softwares CAD and ABACUS for finite element analysis. Figure 10 shows the frame under several loading working on it, and figure 11 shows the part of fuselage structure which analyzed by   finite element method.
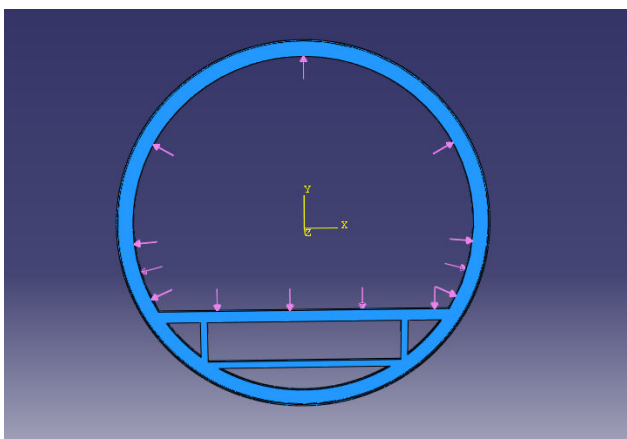

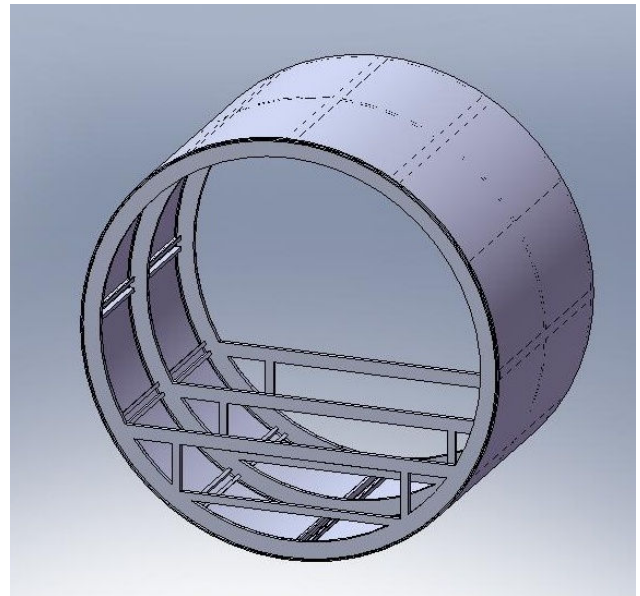Fig. 10 Loads on the frame structure.

Fig. 11 Part of fuselage structure which analyzed
by finite element method.

IV. 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 (consentrated force and pressure).
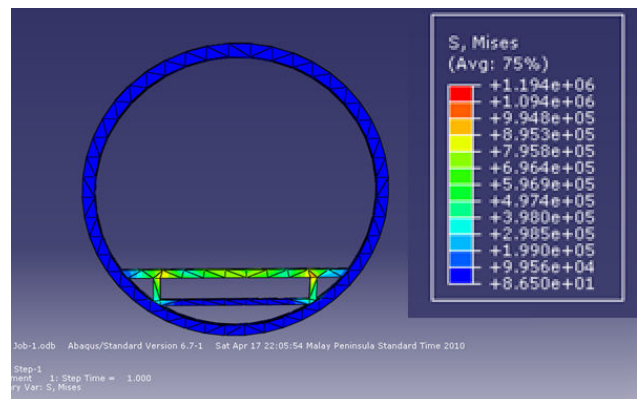

Fig. 12 The stress distribution of loaded frame.

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 13.
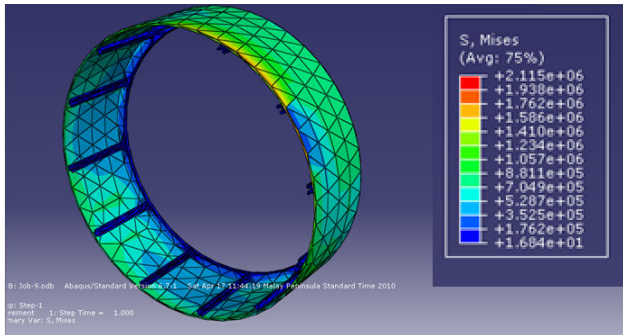
Fig. 13 stress distribution of the fuselage skin with the stringers

The third result is the combination of frame and skin with stringers. The meshing and the stress distribution are shown in figure 14.
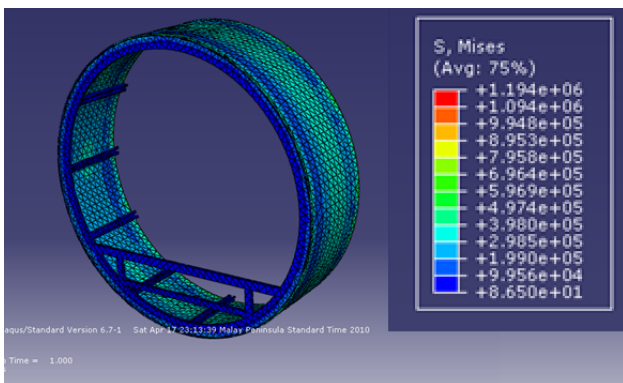

Fig. 14 stress distribution of the fuselage with frame, stringers and skin.

The result at this stage, i.e. using finite element analysis, is satisfied since the stress ocurred 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.

V. CONCLUSION

The conceptual design of fuselage structure of light jet aircraft 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 very light jet aircraft.

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