ISSN: 2277-3754
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 1, Issue 4, April 2012

A Review on Stress Analysis of the Fuselage Structure and Study of the Effect of Overload on Fatigue Crack Growth

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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. Large structure like an aircraft has a large number of components which are mechanically fastened together to form the total airframe. Service experience indicates that designing airframes against fatigue failure is better served if it is assumed that the airframe has crack-like flaws right from day-one when it enters the service. Airframe will experience the variable loading during the service. If damage is present in the structure in the form of a crack then one needs to calculate the fatigue crack growth life. This is essential to properly schedule the inspection intervals to ensure the safety of the structure during its service.

***Index Terms*—Aircraft, Pressurization, Fuselage Structure, Fatigue, Fatigue Crack Growth, Load Spectrum, Overload Effect, Finite Element Analysis.**

I. INTRODUCTION

Aircraft are members and transverse frames to enable it to resist bending, compressive and vehicles which are able to fly by being supported by the air, or in general, the atmosphere of a planet. An aircraft counters the force of gravity by using either static lift or by using the dynamic lift of an airfoil, or in a few cases the downward thrust from jet engines. An aircraft is a complex structure, but a very efficient man-made flying machine.Aircrafts is generally built-up from the basic components of wings, fuselage, tail units and control surfaces. Each component has one or more specific functions and must be designed to ensure that it can carry out these functions safely. Any small failure of any of these components may lead to a catastrophic disaster causing huge destruction of lives and property. When designing an aircraft, it's all about ending the optimal proportion of the weight of the vehicle and payload. It needs to be strong and stiff enough to withstand the exceptional circumstances in which it has to operate. Durability is an important factor. Also, if a part fails, it doesn't necessarily result in failure of the whole aircraft. It is still possible for the aircraft to glide over to a safe landing place only if the aerodynamic shape is retained-structural integrity is achieved.

The basic functions of an aircraft's structure are to transmit and resist the applied loads; to provide an aerodynamic shape and to protect passengers, payload systems, etc., from the environmental conditions encountered in flight. These requirements, in most aircraft, result in thin shell structures where the outer surface or skin of the shell is usually supported by longitudinal stiffening torsion loads without buckling. Such structures are known as semi-monocoque, while thin shells which rely entirely on their skins for their capacity to resist loads are referred to as monocoque.

The load-bearing members of these main sections, those subjected to major forces, are called the airframe. The airframe is what remains if all equipment and systems are stripped away. In most modern aircrafts, the skin plays an important role in carrying loads. Sheet metals can usually only support tension. But if the sheet is folded, it suddenly does have the ability to carry Compressive loads. Stiffeners are used for that .A section of skin, combined with stiffeners; Called Stringers is termed a thin-walled Structure. The airframe of an aircraft is its mechanical structure, which is typically considered to exclude the propulsion system. Airframe design is a field of engineering that combines aerodynamics, materials technology, and manufacturing methods to achieve balances of performance, reliability and cost. The fuselage will experience a wide range of loads from a 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 in tension and the bottom in compression. In maneuvering flight, the loads on the fuselage will usually be greater than for steady flight. During negative G-maneuvers, some of the loads are reversed.

Also landing loads may be significant. The structure must be designed to withstand all loads cases. The bending loads are higher when the weight is distributed towards the nose and tail. Therefore, aircraft are loaded close to the canter of gravity.

The larger part of passenger and freighter aircraft is usually pressurized. The cabin altitude is usually changed quite slowly, beginning pressurizing long before 2500m, which is the normal cabin pressure altitude during cruise, is reached. Combat aircrafts have no need for pressurization of large areas of the fuselage. 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 structure 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, being small, do not create a severe problem. Depending on their design, doors will or will not carry some of the load of the fuselage structure. On the floor of the fuselage also very high localized loads can occur, especially from small-heeled shoes. Therefore floors need a strong upper surface to withstand high local stresses.

II. AIRCRAFT CABIN PRESSURIZATION

Aircraft are flown at high altitudes for two reasons. First, an aircraft flown at high altitude consumes less fuel for a given airspeed than it does for the same speed at a lower altitude because the aircraft is more efficient at a high altitude. Second, bad weather and turbulence may be avoided by flying in relatively smooth air above the storms. Many modern aircraft are being designed to operate at high altitudes, taking advantage of that environment. In order to fly at higher altitudes, the aircraft must be pressurized. It is important for pilots who fly these aircraft to be familiar with the basic operating principles.

In a typical pressurization system, the cabin, flight compartment, and baggage compartments are incorporated into a sealed unit capable of containing air under a pressure higher than outside atmospheric pressure. On aircraft powered by turbine engines, bleed air from the engine compressor section is used to pressurize the cabin. Superchargers may be used on older model turbine-powered aircraft to pump air into the sealed fuselage.

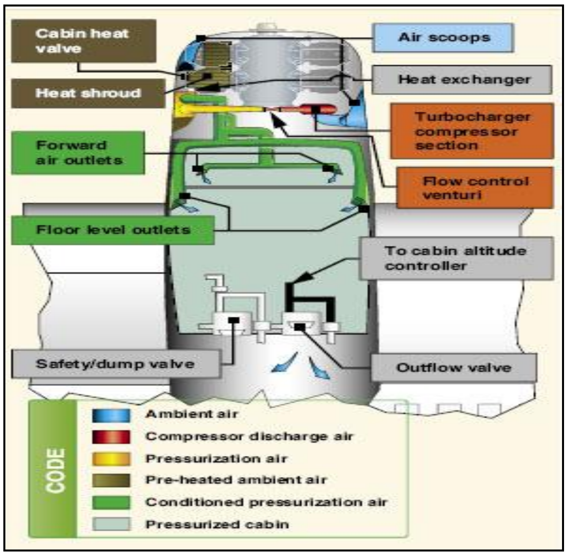
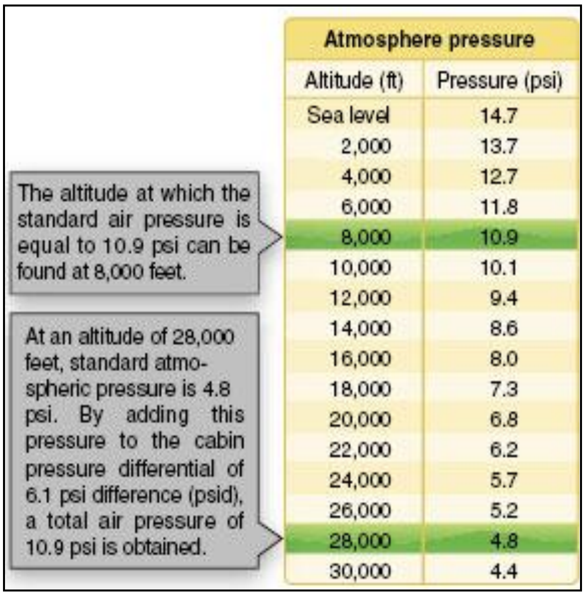


Fig.1.High Performance airplane pressurization system [11]

Piston-powered aircraft may use air supplied from each engine turbocharger through a sonic venture (flow limiter). Air is released from the fuselage by a device called an outflow valve. By regulating the air exit, the outflow valve allows for a constant inflow of air to the pressurized area. Fig 1 a cabin pressurization system typically maintains a cabin pressure altitude of approximately 8,000 feet at the maximum designed cruising altitude of an aircraft. This prevents rapid changes of cabin altitude that may be uncomfortable or cause injury to passengers and crew. In addition, the pressurization system permits a reasonably fast exchange of air from the inside to the outside of the cabin. This is necessary to eliminate doors and to remove stale air. Fig 1

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 long periods of time, particularly if the cabin altitude is maintained at 8,000 feet or below, where the use of oxygen equipment is not required. The flight crew in this type of aircraft must be aware of the danger of accidental loss of cabin pressure and be prepared to deal with such an emergency whenever it occurs.



Atmosphere pressure

Altitude (ft)	Pressure (psi)
Sea level	14.7
2,000	13.7
4,000	12.7
6,000	11.8
8,000	10.9
10,000	10.1
12,000	9.4
14,000	8.6
16,000	8.0
18,000	7.3
20,000	6.8
22,000	6.2
24,000	5.7
26,000	5.2
28,000	4.8
30,000	4.4

The altitude at which the standard air pressure is equal to 10.9 psi can be found at 8,000 feet.

At an altitude of 28,000 feet, standard atmospheric pressure is 4.8 psi. By adding this pressure to the cabin pressure differential of 6.1 psi difference (psid), a total air pressure of 10.9 psi is obtained.

Fig.2.Standard atmospheric pressure chart [11]

III. GEOMETRIC CONFIGURATION OF THE FUSELAGE

A segment of the fuselage is considered in the current study. The structural components of the fuselage are skin, bulkhead and Longerons. Geometric modeling is carried out by using SOLIDWORKS 2012 software. The total length of the structure is 1500mm and diameter is 2200mm. It contains 4nos Z section (Bulkhead) and 40nos L section (Longerons).

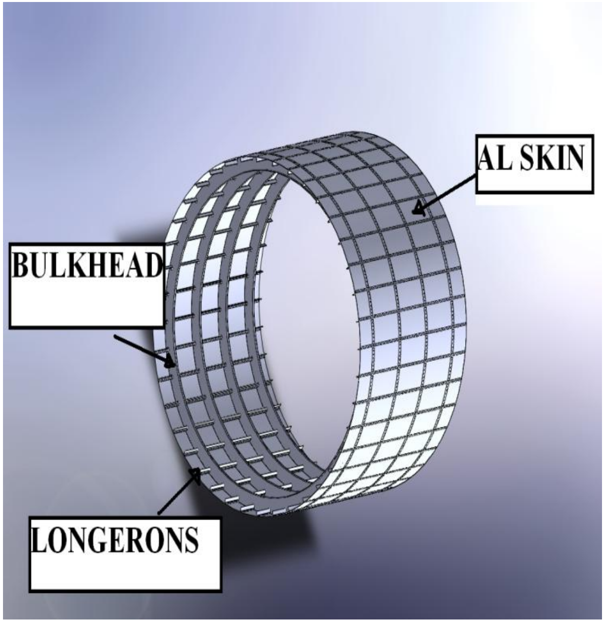


Fig.3.CAD model of the Fuselage part

IV. LITERATURE REVIEW

Aircraft structure is the most obvious example where functional requirements demand light weight and, therefore, high operating stresses. An efficient structural component must have three primary attributes; namely, the ability to perform its intended function, adequate service life, and the capability of being produced at reasonable cost. Attention is now focused on propagation of crack. The review summarizes the previous effort on the 'Damage tolerance assessment of stiffened structures. There were many researches being carried out on effect of overloading on fatigue growth behavior of different structures. Here are few papers referred in this project and are listed below.

Full-scale testing of fuselage panels by Dr. John G. Bakuckas,Dr.Catherine a [1].They using by the experimental setup the test fixture features a novel adaptation of mechanical, fluid, and electronic components and is capable of applying pressurization, longitudinal, hoop, frame, and shear loads to a fuselage panel. A high-precision, Remote Controlled Crack Monitoring (RCCM) system was developed to inspect and record crack initiation and progression over the entire fuselage panel test surface. A detailed description of the FASTER facility along with representative results from a variety of experimental test programs will be presented. Experimental/numerical techniques for fuselage structures containing damage by Padraic E. O'Donoghue, Jinsan Ju [2]**.** They taken finite element analysis approach used to calculate stress intensity factors for a number of curved test panel configurations. Using the methodology, it is possible to consider a wide variety of issues relating to the test panel configurations. Some of these have been illustrated here including (i) crack location, (ii) crack orientation, (iii) skin material, (iv). Tear straps as crack growth inhibitors**"** New techniques for detecting early fatigue damage accumulation in aircraft structural components" by Curtis A. Rideout and Scott J. Ritchie [3] they are going to detect the crack initiation in aircraft structures. Using by some of the destructive tests like Induced positron analyzer. Elangovan.R [4] they taken on Airplane fuselage has a large number of riveted joints and is subjected to a major loading of differential internal pressure at cruise altitude and zero pressure on the ground. This constitutes one of the major load cycle on the fuselage often referred to as ground air ground (G-A-G) cycle. Due to presence of large number of rivet holes, the fuselage skins have a large number of high stress locations and these are locations of potential crack initiation. Thus at the skin joints of the fuselage shell one can have a number of cracks as it ages (i.e. used over a period of time). The practice in earlier time was to consider the largest sized crack and consider its acceptance or otherwise. But in fuselage panels one may have one dominate crack and number of smaller secondary cracks. The understanding the safety of a panel with multi site damages is of concern to airline operations. Garcia A N [5] a probabilistic model that Incorporates continuing damage assumption as a MSD modeling simplification is presented and its output is compared to other work from the literature. The model is used to demonstrate how MSD onset behavior is prevented when high rivet squeeze force employed. "The computational post-buckling analysis of fuselage stiffened panels loaded in shear" by A. Murphya, M. Price, C. Lynchb, A. Gibsona [6] they are Using the Finite Element method and employing non-linear material and geometric analysis procedures it is possible to model the post-buckling behavior of stiffened panels without having to place the same emphases on simplifying assumptions or empirical data. Previous work has demonstrated that using a commercial implicit code, the Finite Element method can be used successfully to model the post-buckling behavior of flat riveted panels subjected to uniform axial compression. This paper expands the compression modeling procedures to flat riveted panels subjected to uniform shear loading, investigating element, mesh, idealization and material modeling selection, with results validated against mechanical tests. The work has generated a series of guidelines for the non-linear computational analysis of flat riveted panels subjected to uniform shear loading, highlighting subtle but important differences between shear and compression modeling requirements.

Application of the cohesive model for predicting the residual strength of a large scale fuselage structure with a two-bay crack by A. Cornec, W. Schönfeld, and K.-H. Schwalbe, I. Schneider [7]. They invented on the residual strength of a curved and stiffened panel containing a two-bay crack was assessed using the cohesive model. This panel represents a section of a wide-body airplane fuselage. The tests were conducted at IMA GmbH Dresden in cooperation with Airbus Industries Germany. The structural panel was modeled using 3D finite elements and a layer of cohesive elements ahead of each crack tip allowing for 70 mm crack extension. Identification of the cohesive parameters was done on small laboratory test pieces. Special effort was made for the transfer of these parameters to the structure. Reasonably conservative predictions of the residual strength of the panel were achieved. The boundary conditions of the loading devices of the test rig are shown to have substantial influence on the predictions.

Andrzej Leski [8] studied the implementation of virtual crack closure technique in engineering FE calculation. Equations for three-dimensional brick elements are given. Algorithms of applying the VCCT are presented and precisely explained. General conditions and limitations for using the VCCT with commercial software are provided. An example of implementing the VCCT in the MSC Patran follows. The presented example consists of two PATRAN-dedicated procedures. In this way a useful tool for fracture mechanics calculations has been created. He concluded that the virtual crack closure technique is a convenient tool for stress intensity factor investigation. The main advantage of the VCCT is that it does not require a special mesh arrangement around the crack front. The major limitation of the VCCT is that it can only be applied to linear elastic fracture mechanics problems. The VCCT can be easily implemented in any commercial FE software.

Multiple interacting cracks in an infinite plate are analyzed to determine the overall stress field as well as stress intensity factors for crack tips and singular wedges at crack kinks. The problem is formulated using integral equations expressed in terms of unknown edge dislocation distributions along crack lines. These distributions derive from an accurate representation of the crack opening displacements using power series basis terms obtained through wedge Eigen value analysis, which leads to both polynomial and non-polynomial power series. The process is to choose terms of the series and their exponents such that the tractions on the crack faces are virtually zero compared to the far field loading [9].

An interaction (energy) integral is derived for the computation of mixed-mode stress intensity factors (SIFs) in non homogeneous materials with continuous or discontinuous properties. This method is based on a conservation integral that relies on two admissible mechanical states (actual and auxiliary fields). In general, the interaction energy contour integral is converted into an equivalent domain integral in numerical computations. It can be seen from the equivalent domain integral, the integrand does not involve any derivatives of material properties. Moreover, the formulation can be proved valid even when the integral domain contains material interfaces. Therefore, it is not necessary to limit the material properties to be continuous for the present method. Due to these advantages the application range of the interaction integral method can be greatly enlarged. The numerical implementation of the derived expression is combined with the extended finite element method (XFEM). Using this method, the influences of material properties on the mixed-mode SIFs are investigated for four types of material properties selected in this work. Numerical results show that the mechanical properties and their first-order derivatives can affect mode I and II SIFs greatly, while the higher-order derivatives affect the SIFs very slightly [10].

V. CONCLUSION

Damage tolerance design philosophy is generally used in the aircraft structural design to reduce the weight of the structure. Stiffened panel is a generic structural element of the fuselage structure. Therefore it is considered for the current study. A FEM approach is followed for the stress analysis of the stiffened panel. The internal pressure is one of the main loads that the fuselage needs to hold. Stress analysis is carried out to identify the maximum tensile stress location in the stiffened panel. A local analysis is carried out at the maximum stress location with the rivet hole representation.

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