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Review on the Design and Fatigue Analysis of a Wing Spar

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Abstract- An aircraft's structure is quite complex and involves many intricate interactions between its parts. One of the reasons for its complexity is due to the fact that these said parts are liable to several loads. Among such loads are aerodynamic loads, fatigue loads, torsion loads and many others. An extremely important part of an aircraft which is subject to some of these loads is the wing structure, which is subject to loads like fatigue loads. In this review paper, we will be delving deeper into a wing spar, and analysing its design and how it is affected by the fatigue load acting on it. A wing spar is of great importance in a wing as it is where majority of the loads acting on the wing act on. So, finding an optimum design of the spar with high fatigue life is crucial. A fatigue failure in a structure can led to the deformation of the structure which can in turn jeopardize the entire structure thus the importance of fatigue analysis.

Keywords - Wing spar, fatigue analysis, aircraft's structure, fatigue failure .

I.INTRODUCTION

A wing spar is one of the most salient parts of an aircraft wing. It oversees carrying the loads of the wing when the aircraft is on the ground. It is also susceptible to the bending load acting that is acting on the wing. All the structural parts of awing should be able to stand firm against almost all types of the loads including bending, torsion, tensile and compression and the spar ensures this happens. Spars are one of the reasons why an aircraft wing structure is so strong. They run across the breadth of the wing horizontally. Wing spars can have different cross-sectional areas such as I-cross sectional area, C-cross sectional area and O-cross sectional area. In this review we will be dealing with an I-beam.An aircraft wing has two spars on it. The spar that carries major loads is known as a major spar. One spar is placed close to the front part of the wing and the other is placed at the rear of the wing.

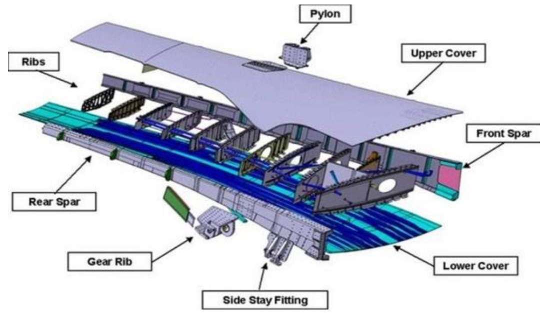

Fig.1 Diagram showing the front and rear spar on a wing structure.

II. Fatigue analysis

Fatigue load is one of the loads that a wing spar is subjected to. Fatigue refers to the commencement and propagation of cracks on a component structure due to cyclic loading. In fatigue failure, cracks are formed in the materials under repeated cyclic loadings.

Majority of the structural failures in an aircraft occur due to fatigue failure in the structure, which is what makes fatigue analysis so important. Fatigue analysis is the process of calculating and deciding whether or not a structure is going to fail after a certain number of repeated loading and unloading, instead of after loading and unloading only once as replicated in a static analysis. Fatigue failure happens in three different stages namely. Crack initiation: this is when the crack has just formed and is still very small. Crack propagation: this is when the crack begins to grow and expand more into the structure. Rapid fracture: this is where the structure completely deforms under the cyclic loads and fractures.

III. LITERATURE REVIEW

A literature review was done toanalyse and study the optimum design of the wing spar. Different information has been studied and gathered with the help of the various research papers by different authors relating to this topic that we have studied. The table below shows the summary of a few research papers that we studied.

Author	Year	Title	Methods and outcomes
Pavan G, Manjunath M V	2018	Static analysis on Wing spar joint for an aircraft using FEM.	The objective of this research paper was to design and analyse a wing spar joint of a transport aircraft structure using FEM. -The spar model was designed in CATIA and analysed in MSC software. The material used was an Aluminium Alloy 2024-T3 due to its fatigue resistance. The author also presented the maximum stress on the rivets found on the spar joint which were within the allowable limit for the material used. -The author considered a tapered span beam the dimensions for each section were also tabulated.
Raphael Bassilio, ThiagoEscossia	2017	Fatigue analysis of an Aluminium airplane spar structure.	The main aim of this paper was to obtain the fatigue life of a nontapered cantilevered aluminium spar for a single engine aircraft subjected to point loads. -The static structural analysis was conducted on a finite element based software ANSYS mechanical so as to obtain fatigue life and other factors. -The CAD model of the spar was designed in ANSYS design modeller and the aluminium alloy used was Al 2024-T3 because of its superior characteristics. - The fatigue life against number of nodes and elements was also considered and a point of minimum fatigue life was obtained implying that a crack would likely start

			initiation at that point. - The analysis was done considering a special condition of cruise flight for more advanced design more condition should be considered.
N. Tulasi Ram	2020	Design, analysis, and fabrication of wing structure of Aluminium 7075-T6	The aim of this paper is to study about the spar design of a four-seater aircraft. This was done by performing pressure analysis using limited finite element method approach in ANSYS. -The results obtained were compared to those obtained from the experimental during fabrication. The material used was Al 7075-T6 for the spar design the cross section considered was an I section using the bending moments the width and depth of the section were obtained. The fabrication was done, and the spar was tested to obtain the displacement stress the load applied was at the free end in succession and the peak value was 1400kg. - The deflection was 22.5mm and the maximum stress was 24.45kg/mm2.

Vishruth Gowda, Chandan R,Shivappa H	2017	Structural analysis and optimization of Spar beam of an aircraft.	His paper based on the analysis and topographical optimization of the spar beam of an aircraft. The cross section considered was an I section. -This analysis was done considering a passenger aircraft, it meant to validate tapered spar beam for higher altitudes flight conditions. Stress, strain and displacement were studied using finite element-based software. -The spar beam designed for analysis was 3.25m long with height of 162mm and tapered end height was 40mm. It was subjected to point load at the centre of the fuel and uniform distributed load on the face of the beam. The topology optimization was so to reduce the volume and mass of the beam so as to ensure lighter structures. Total 40% of web weight was reduced.
MutturajGirennavar, Soumya H V, Subodh H M Tanvi J Heraje, Deepak Raj P	2017	Design, analysis and testing of a wing spar for optimal weight.	This paper based its study on designing and analysing a four-seater aircraft wing spar referencing the PIPER PA28-161. The static analysis was carried out to obtain stress displacement. -The spar beam was of an I section because stress and deflection for I section is less than

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			other sections. The material used for analysis was aluminium alloy 6082-T6. -The load distribution over the wing at each rib station was obtained in XFLR software condition imposed was steady level flight at 2.3 angle of attack. -Calculations were made to obtain dimensions for the cross sections at each station. Weight optimization was done through the design process few iterations were done on the spar to come up with the design that can give less weight.
Khalid Ahmed ELDWAIB, Aleksandar GRBOVIĆ	2018	Fatigue life estimation of damaged integral wing spar using XFEM	In this paper, crack propagation simulation was carried out on the integral wing spar that was to be used to replace the differential wing spar being used in the light aircraft UTVA 75. Different designs of wing spar include differential, equivalent integral, and optimized integral wing spars. The method used was the extended finite element method (XFEM). A numerical model of integral spar was developed in software Abaqus. Stress intensity factors (SIFs) were calculated using add-in Morfeo/Crack for Abaqus and the number of cycles that would propagate the crack to certain length was compared to the experimentally obtained number of cycles for differential spar. Numerical analysis showed that integral spar with the same dimensions as differential spar has significant increase in fatigue life. To increase wing

			fatigue life and hence improve overall performance of light aircraft UTVA 75, integral AA2024-T3 wing spar, with the same dimensions as existing differential spar, was analysed. By comparing the numerical results and experimental values, it was revealed that significant increase in fatigue life can be expected, thus solidifying the idea of replacing the old spar with the integral wing spar.

Petr Augustin1	2018	Simulation of fatigue crack propagation in the wing main spar flange	This paper consists of the simulation of fatigue crack growth in the bottom flange of twin turboprop commuter aircraft wing spar. A crack in the main wing spar flange near the rib No. 8 initiated during the full-scale fatigue test of the wing at Aeronautical Research and Test

			Institute in Prague was selected for the analysis. A computational model of cracked bottom flange was prepared using the software FRANC3D developed at the Cornell University. Calculation of crack propagation was carried out in AFGROW software. Simulation of fatigue crack propagation in the bottom flange of twin turboprop commuter aircraft wing spar was carried out. It utilizes the BEM model of spar flange prepared in the three-dimensional crack propagation software FRANC3D to calculate the crack fronts and stress intensity factor.

IV. CONCLUSION

Fatigue analysis on aircraft materials can be complex due to the application of cyclic loading. And from these various research papers work on designing and analysing an optimum wing spar for a better fatigue life was done. Fatigue failure in a wing spar can occur despite application of stress below the material yield strength continuously during various flight conditions. Most of fatigue analysis works are done basing on one flight condition for complex spar design we require analysis on more flight conditions. Fatigue failure can lead to devastating repercussions in the aircraft components thus its study is of great importance to ensure airworthiness.

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