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Prescience Life of Landing Gear using Multiaxial Fatigue Numerical Analysis

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Abstract

Fatigue failure, which occurs in many engineering components and structures in service, is actually attributed to the multiaxial loads. This study is aimed to estimate/ prescience life of main landing gear of a medium multi-utility aircraft under multiaxial loadings. In this analysis we studied the various loading conditions among them few are the spin-up, spring-back and lateral drift loading.The equivalent stress based multiaxial fatigue criteria (Sines and Crosslands) is employed for the determination of equivalent stress due to multiaxial loading and Palmgren Miner's theory used for calculating total damage and consequently the fatigue life. It is seen that the multiaxial fatigue numerical analysis render lower life than the maximum uni-axial life value.

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Keywords: Prescience Life; Landing Gear; FESimulation; Multiaxial Fatigue; Spectrum

1. Introduction

In many engineering components and structures in service, their failure is actually attributed to the multiaxial fatigue loads. Designing a landing gear structure against the fatigue-limit state, the aim is to ensure, that the integrity of the structure is satisfactory throughout its planned service life. Multiaxial stresses do exist even under uniaxial loads for the geometrical complexity [1] as in the case of a landing gear. The design, monitoring and management of the landing gear are the fundamental aspects of aircraft. About 60% of aircraft failures are related to the landing gear and fatigue failure is the leading failure style [2]. To realize the landing gear's long life, high reliability and low maintenance cost, the fatigue characteristic of the structure should be analyzed and evaluated at initial phase of an aircraft development. The medium multi-utility aircraft considered in this article has a tricycle, retractable landing gear consisting of two Main Landing Gears (MLGs) and a Nose Landing Gear (NLG). The loading cases considered involve landing, taxiing and ground handling cases. These loading cases confirm to the requirements of FAR 25 [3]. Among the various landing loads viz., (i) Tail down landing (6.65 deg.) for main gear

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analysis, (ii) Level landing with nose and main wheels (iii) Normal landing first on the MLG and later NLG touching the ground, (iv) Lateral drift landing and (v) Side – load condition. Among the various loading cases the most severe landing load case is lateral drift landing case. In this article mostly we have chosen the lateral drift landing condition for the multiaxial loading case as it has all the three loads acting simultaneously as shown in table 1.

The three loads X, Y and Z correspond to longitudinal along the length of an aircraft from nose to tail, transverse along the width of an aircraft and vertical i.e., the height of the aircraft respectively. The load data as per the FAR 25 requirement is shown in fig. 1 for X and Z directions only. Figure 1 data has 3,40,622 data points for each of two load components viz., X and Z. The third component Y has not been shown here as this renders poor visualization. From this load we arrive at the corresponding stresses in all the three directions, based on the material and the component chosen for the study. In the landing gear chosen for this study have two types of materials. Mainly it is made up of steel except the toggle links are of aluminum material. Steel material and Aluminum alloy 7075-T7351 has Young's modulus, Poisson's ratio, allowable yield strength as 210GPa, 0.25, 1080 MPa and 72 GPa, 0.3, 490 MPa respectively. For the multiaxial analysis, three stresses used for the computation of equivalent stress using Sines and Crossland theory [4,5]is as shown in equation (1).Computation of equivalent stress carried out by neglecting mean stress effect hence thereby hydrostatic stress. An in-house program has been developed to compute the equivalent stress, damage and life.

2. Fatigue Spectrum for Landing Gear

The reaction forces at the ground during landing for different sinking speeds have been calculated for MLG and NLG by the landing gear design group. These loads or forces have been used for deriving fatigue spectra for different landing cases. Lateral drift landing is the most severe combination of loads that are likely to arise during a landing is been considered in this article. A vertical load equal to 75% of the maximum ground reaction of vertical load (FAR 25.473 [3]) must be considered in combination with a drag and a side load of 40% and 25%, respectively, of the vertical load. The spectrum generated is based on the assumption that this condition is 30% of the total cumulative occurrences for main gear and 60% of the total cumulative occurrence of nose gear. The spectrum for lateral drift landing is shown in table 1 for main gear.

Table 1: Lateral drift landing loads for Main Gear

Sinking speed Ft/sec	Loads Kgf			Cumulative occurrence
	Vertical (Z)	Drag (X)	Side (Y)	
1	2307	923	±577	299
2	2307	923	±577	240
3	2307	923	±577	159
4	2307	923	±577	90
5	2307	923	±577	39
6	2700	1080	±675	17
7	3150	1260	±788	5.7
8	3750	1500	±938	1.5
9	4200	1680	±1050	0.27
10	4754	1901	±1188	0.03

The three load factors G_x, $G_y$and G_z correspond to longitudinal along the length of an aircraft from nose to tail, vertical i.e., the height of the aircraft and transverse along the width of an aircraft respectively. The original or pristine data as received from the aircraft is shown in fig.2. The figure 2 data has 3550 data points for two load factor components viz., G_x, and G_y. The third component G_z has not been shown here as its magnitudes are small (varying between 2 to -2) compared to G_x, and G_y. These data are directly derived from the Flight Data Recorder (FDR) from the service usage of an aircraft.

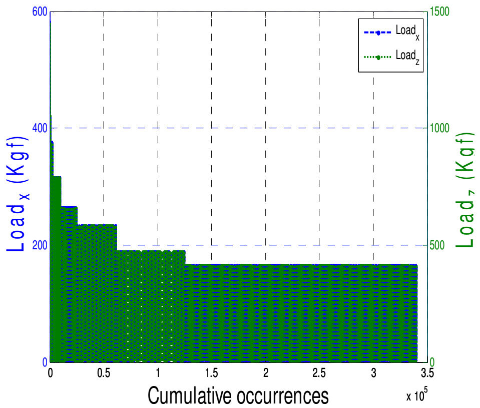

Fig. 1 Block loading for x-z direction

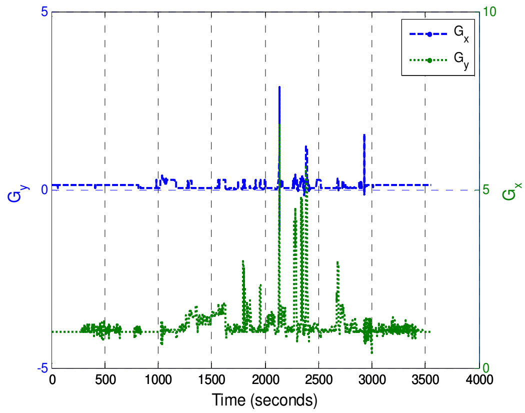

Fig.2 FDR data plot for x-y direction

3. Fatigue Life Assessment of the Main Landing Gear

3.1 The Landing Gear Strength Calculation

Before the fatigue life analysis of the main landing gear, the loads of the landing gear is as shown in Table 1 need to satisfy the requirement of strength;only then the fatigue life analysis will be performed. The geometric and finite element models of the main landing gear are as shown in figures 3 and 4 respectively. The strength calculation has been carried out using Finite Element Analysis using commercially available package ABAQUS. In this analysis, the beam elements has been used. The boundary condition used is the upper yoke assembly only a single line is fixed in all six degrees of freedom. The default stress output points in the case of a beam section integrated during the analysis is on the vertices of the section.

The load applied is uniform among all the nodes. After the analysis checked for equilibrium of the forces has been done.Even line edge loads are applied and numerical analysisrender same results as that of uniform load.In this analysis studied the different loading conditions among them are the spin-up, spring-back and lateral drift loading conditions. At present the model is developed using beam elements only, efforts are on to build a three dimensional model to check the accuracy of the results obtained. In many situations only the beam elements are being used and reported to render good results. In order to check the accuracy of the results the numerical simulation were done with linear and quadratic beam elements(336), performing p-type of convergence study. The degree of freedom were increased from 2004 (nodes 334) to 4020 (nodes 670). With the p-type of convergence the stress variation were within 1% deviation. Figure 5 shows the deformation fringe pattern for the spin-up loading case.

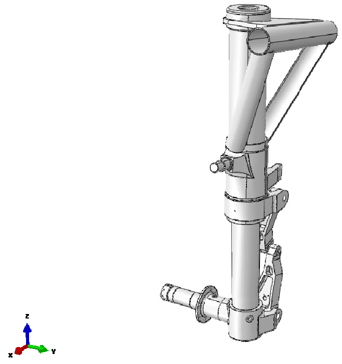

Fig.3 Solid geometry of the MLG

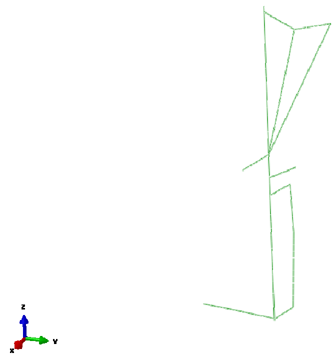

Fig. 4 Finite Element model of the MLG

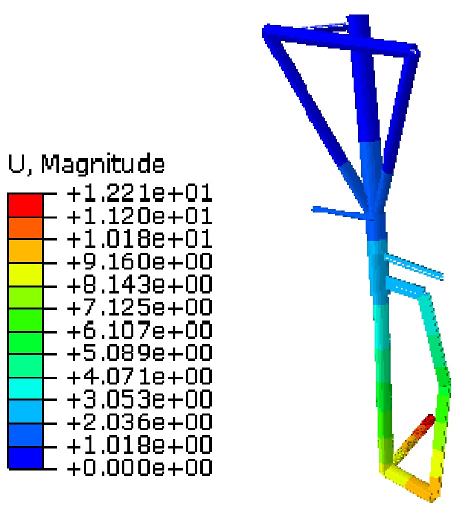

Fig.5 The deformation fringe pattern

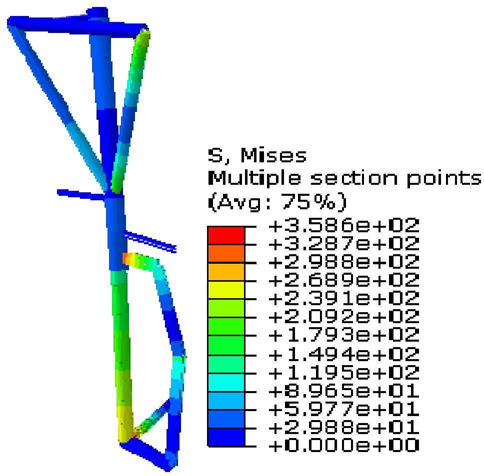

Fig.6 The von-Mises stress fringe pattern

Figure 6 shows the stress fringe pattern for the spin-up case, here the maximum stress is 358.6 MPa. Its strength limit is 1080 MPa and its safety factor is defined to 2; thus the design of main landing gear meets the strength requirement.Figure 6 also depicts maximum stress is located in toggle fork portion which connects toggle link to cylinder tube and axle portion which is not clearly visible unless this figure is enlarged.

3.2 Fatigue Life Assessment

For the fatigue analysis, corresponding to the stresses obtain number of cycles to failure from the S-N data for Aluminum alloy 7075-T7351. From the number of cycles applied (n_i) to the number of cycles to failure (N_f) obtained for the cumulative blocks of loading forms the nonlinear damage accumulation. The novelty of this approach is to evaluate equivalent stress and compare the prescience life obtained from other three stresses. The equivalent stress is computed from Sines and Crossland theory [1] neglecting mean stress effects and obtained from the equation (1).

$$\sigma_e = \frac{1}{\sqrt{2}}\sqrt{(\sigma_x - \sigma_y)^2 + (\sigma_y - \sigma_z)^2 + (\sigma_z - \sigma_x)^2 + 6(\tau_{xy}^2 + \tau_{yz}^2 + \tau_{zx}^2)} \qquad (1)$$

At any time during variable amplitude loading, the summation of damage increments for the various stress cycles,

$$D_f = \sum \frac{n}{N} = \frac{n_1}{N_1} + \frac{n_2}{N_2} + \frac{n_3}{N_3} \ldots\ldots\ldots\ldots\ldots, \tag{2}$$

is termed the cumulative damage ratio and is given the symbol D. A value of D at failure may be given the symbol Df. The cumulative damage hypothesis is also known as Miner's hypothesis [6] or the Palmgren-Miner hypothesis, states that failure is expected to occur when the cumulative damage ratio reaches unity. Routines for calculation of the accumulated damage according to the Palmgren-Miner and multiaxial equation (1) have been implemented using an in-house program to compute Df [7].

$$T_f = \frac{1}{D_f} \tag{3}$$

Reciprocal of the damage growth renders component life (3) and multiply by the number of hours, we prescience the life in hours. The life of a typical component computed for individual stress in x, y, z and equivalent stress are 4.17E+06, 2.33E+07, 1.57E+03 and 2.94E+04 hours respectively. It is seen that the multiaxial fatigue numerical analysis render lower life than the maximum uni-axial life values which are 2.94E+04, 4.17E+06 respectively.

4. Concluding Remarks

In this article studied the prescience life of landing gear under multiaxial loading. First the component has been cleared from strength consideration point of view for the numerical stress analysis using ABAQUS software. The equivalent stress has been computed using Sines and Crossland stress equation. Lastly the life is computed using the Palmgren-Miner's rule. For these numerical calculations in-house programs are developed. In this study a maximum of three order of magnitude difference is observed in the results between uniaxial and multi-axial approach analysis. It is planned to do three-dimensional numerical analysis using critical plane approach of virtual lab package.

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References

1. Zhi-Rong Wu, Xu-Teng Hu, Ying-Dong Song, Multiaxial fatigue life prediction for titanium alloy TC4 und er proportional and non-proportional loading, International Journal of Fatigue (2013), doi: http://dx.doi.org/ 10.1016/j.ijfatigue.2013.08.028.
2. C J Xue, J H Dai, T Wei and B. Liu, Structural optimization of a nose landing gear considering its fatigue li fe, Journal of aircraft, Vol. 49, Nr. 1, January-February 2012.
3. FAR part 25, Airworthiness Standards Transport Category Airplanes, May 2009 Edition.
4. Bong-Ryul You and Soon-bok Lee, A critical review on multiaxial fatigue assessments of metals, Int. J. Fat igue Vol. 18, No. 4, pp. 235-244, 1996.
5. Mirosaw Mrzygod and Andrzej P. Zieliski, Numerical implementation of multiaxial high cycle fatigue crite rion to structural optimization, Journal of theoretical and applied mechanics, 44,pp. 691-712, 2006.
6. Jaap Schijve, Fatigue of Structures and Materials, Kluwer Academic Publishers, 2004.
7. www.mathworks.com (accessed on October 2013).