FATIGUE LIFE ESTIMATION OF CRITICAL COMPONENTS OF HELICOPTER USING FLIGHT DATA RECORDER (FDR)

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Abstract— Helicopter is a heavier than air machine capable of flying vertically and hover in the air, made of a lot of rotating and non-rotating components which are subjected to highly alternate loading. The source of these loads is harmonic variation of aerodynamic loading of the rotating wing. The critical loading of these components is not static load, to be compared to yield strength, but it is rather fatigue load. Fatigue Life of these critical components has been obtained during the initial design and development stages based on the mission spectrum provided by the users. Any change in mission spectrum usage can have effect on the life of the critical components. So there is a need to re-estimate the fatigue life of these components on a regular basis. User spectrum of Helicopter to be found using the FLIGHT DATA RECORDER (FDR) data. An algorithm to be written to find the spectrum from the FDR data. Based on the spectrum obtained, a fitting load spectrum has to be obtained from the database of prototype helicopter sorties. This paper presents obtained load spectrum of components using Rain flow methodologies. Finally fatigue life to be calculated using Miner's damage calculation method.

Keywords— Helicopter, Loading, Fatigue, Spectrum, Damage.

I. INTRODUCTION

Fatigue life of a component can be determined in terms of an endurance limit, a point where the component does not fail by undergoing an infinite number of cycles. For a given frequency of alternating load, fatigue life is stated in hours rather than cycles.

During its preliminary design, we cannot predict the fatigue life of a component. The fatigue loading of a component can be determined by doing component tests and flight tests [1]. Fatigue life calculation can be done for the component which undergoes finite life as well as infinite life. It is appropriate, however, to identify those fatigue critical components for which the design objective will be infinite life and those for which a finite life will be established.

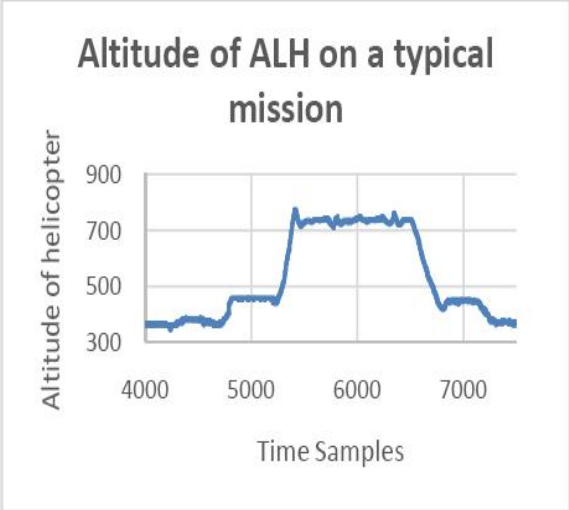
Fatigue life determination can be done on all fatigue critical components. If a component undergoes infinite life, there would be no need to classify the component as fatigue critical component. A new life determination shall be made in case of any change of fatigue loading upon the component. Such changes may result from changes to the mission gross weight, to a mission profile, or to the mission frequency.

The components used to calculate fatigue lives called as fatigue critical components. All rotor system components – blades, grips, hubs, control horns – and all control system components, rotating and non-rotating, between the rotors and a point of load isolation shall be fatigue critical components. All drive shafts shall be fatigue critical components – along with all the drive system support structures including engine mounts and main transmission.

II. MISSION SPECTRUM OF FLIGHT

Fatigue loading varies with flight conditions. The frequency of occurrence of loading depends on the mission profile of helicopter. Following is the procedure to calculate maneuver spectrum:

- Develop a profile for assigned mission.
- List the flight condition and maneuvers.
- Calculate the time per event.
- Calculate the number of occurrences per mission.
- Convert the time calculated per event to percentage of mission time.
- Estimate frequency of performance of assigned mission and its percentage.
- Calculate percentage of total time per event at specified altitude.



Graph 1: the variation between time and altitude of helicopter at different spectrum of flight

From takeoff till landing, the helicopter performs by cyclic, collective and rudder controls with varying load factor as shown above.

III. RAINFLOW CYCLIC COUNTING METHOD

The loads occurring in actual service in helicopters are difficult to predict with high accuracy. Various methods exist to quantitatively assess recorded load time histories. There is one method: range pair or rain flow method for cycle counting.

Typical events that can be observed in a load-time trace are:

- The occurrence of load "peaks" at specific levels
- The exceed or crossing of specific levels
- The occurrence of load changes or "ranges" of a specific size

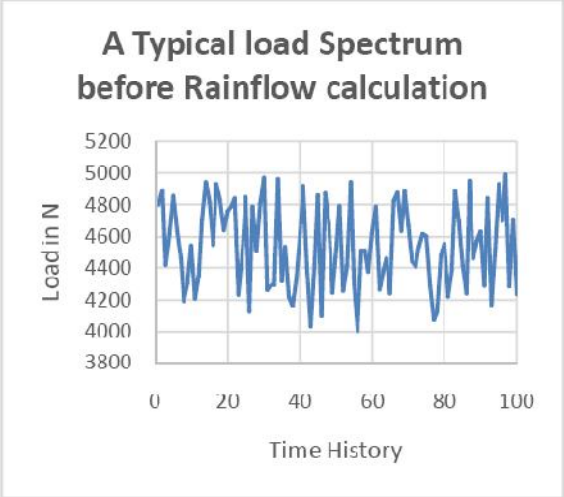
The turning points in a load-time trace are indicated as "peaks" and "troughs" successively. The number of times that peaks and troughs occur at various levels is counted.

The counting of single range usually indicated as range count [2]. In this load history the following ranges are successively counted:

An upward range $r_1 = S_2 - S_1$

A downward range $r_2 = S_3 - S_2$

In the classification of peaks and troughs it is usual to apply a specific "range filter size" R. A peak at a certain level is only recognized as such if the signal has dropped to a level which is "R" lower than the peak level. In the same way a trough is counted is the signal has raised "R" above the trough level.

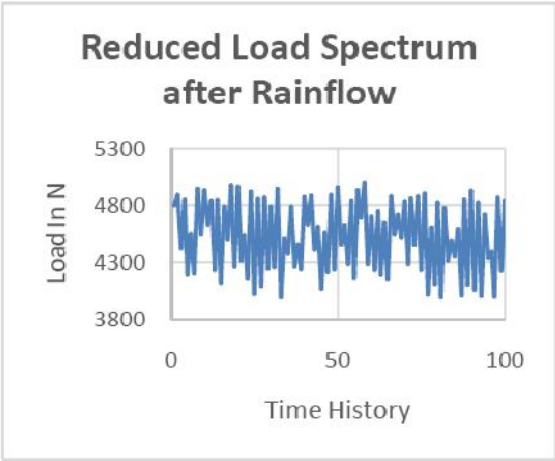


Graph 2: load spectrum before applying rain flow method where load is varying in a large amount with respect to time

The counting procedure is as follows:

- Starting with the first recorded peak/troughs, group of four successive extremes S_{p-3}, S_{p-2}, S_{p-1}, S_p are considered. If the values of the two "inner" extremes S_{p-2} and S_{p-1} fail within the range bound by S_p and S_{p-3}, is counted as range-pair.

  Counting a pair implies that the value is in the "upper" triangle and the opposite element is in the "lower" triangle and is increased by one. Next, the counted extremes S_{p-2} and S_{p-1} are deleted from the record and the procedure is repeated by considering the four extremes again.



Graph 3: load spectrum is reduced with a large amount

IV. MINER'S RULE

Miner's rule is used to calculate the fatigue lives that are subjected to loads which are not of constant magnitude but vary over a wide range. The theory is that component failure will occur when N_1 cycles of a constant alternating stress equal to S_1 have been applied.

If that part is exposed to alternating stresses of unequal magnitude, the fatigue damage at each different stress level is dependent on the number of cycles of stress applied versus the capability of the Part at that stress level.

Hence, if n_1 cycles of stress equal to S_1 are applied, the fatigue damage is equal to n_1/N_1. Likewise, if n_2 cycles of stress equal to S_2 are applied, the fatigue damage is equal to n_2/N_2[3]. Part failure is anticipated when the summation of $n_1/N_1 + n_2/N_2 + \ldots$ Equals unity. According to Miner's rule, failure occurs when:

$$\frac{n_1}{N_1} + \frac{n_2}{N_2} + \ldots + \frac{n_i}{N_i} = 1$$

Where,

n_i = no. of cycles at i stress level

N_i = no. of cycles to failure at i stress level

n_i/N_i = damage ratio at i stress level

The abscissa of the S-N curve for each stress is taken from the appropriate S-N diagram and entered under "allowable cycles". The ratio of elapsed cycles to allowable cycles is the "damage", or fraction of fatigue life used up. The condition tabulated is for 100 hrs of typical operation. The calculated fatigue life is obtained from the following proportion, in which the fatigue life is the length of hours for which damage = 1.00.

$$\frac{\text{Calculated fatigue life}}{100\text{hr.}} = \frac{1.00 \text{ damage}}{\text{Damage Hin 100 hr}}$$

CONCLUSION

- A program has been successfully written for finding the mission spectrum of helicopter and to calculate Rain flow matrices for fatigue prone components.
- Mission spectrum is calculated using the above written programs
- .Fatigue life of a component is calculated using Miner's damage calculation method and is presented in the present work.

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