PROBABILISTIC ASSESSMENT OF THE PROPELLER BLADE PRIMARY FAILURE

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ABSTRACT

Proposed computational equations which use Palmgren-Miner law for service life calculation are implemented into AntHill commercial software package. The next important input parameters are data from the S-N diagram with function of variable standard deviation and also evaluated stress ranges and cycles by Rain Flow Method from blade steady and vibratory stress analysis during aircraft ground and flight operation. AntHill software based on Monte Carlo simulation method is used to analyze probability of the blade failure and obtain the results in tables and graphs forms [1]. Failure probability assessment and deterministic calculation with appropriate safety coefficients were performed and relationship between safety coefficients and required failure probability is evaluated.

Keywords: S-N diagram, probabilistic assessment, propeller blades, failure.

INTRODUCTION

Civil aviation agencies around the world require propeller safety analysis. Fault Tree Analysis and Failure Mode and Effects Analysis are standard use in the safety analysis. Failure of the propeller blade is a primary failure; it means a failure which is not the result of the next failure of another propeller part. Very low probability of this failure occurrence per propeller flight hour is required by Civil Aviation Agencies around the world. Probabilistic assessment is based on Monte Carlo method which uses input data from the blade fatigue tests and steady/vibratory stress analysis of the propeller blades.

RESULTS AND CONCLUSIONS

A total twenty-nine propeller blades were tested by using special test equipment which uses pressure air like an excitation force and blade natural frequency of the blade first flatwise. The goal of the fatigue tests was also cover conditions of blade service deterioration. The experimental results were plotted in to diagram and classified according to history of blade service conditions. Four selected stress levels are shown in Fig. 1. Two parametric model for the S-N curve approximation were used and the slope of this curve were evaluated. Approximation of the standard deviation is an important input in to probabilistic assessment of the blade failure. The function (1) was found and used in the range from $1 \times 10^5$ to $1 \times 10^9$ cycles, where $a$ and $b$ are coefficients based on minimum square method.

$$s = \left( \frac{1}{(a + b \cdot \sigma_a)} \right) \cdot (log(Ni) - 5) \cdot 0.03 - 0.01$$  \hspace{1cm} (1)
Finite Element Analysis was used for modal analysis to found the blade natural frequencies and locations with maximum stress for each blade natural shape as a function of propeller rotational speed. The results of the modal analysis were plotted in to Campbell frequency diagram by reason of to find possible resonance propeller rotational speed based on intersection between blade natural shape and excitation frequencies. The excitation frequencies are generated by engine dynamic characteristics or aircraft airframe configuration or ground/flight regimes. The correct results from modal analysis are verified during the laboratory frequency test with simulated boundary conditions of the blade retention in propeller hub. The final confirmation of the correct modal analysis is done during ground and flight steady and vibratory stress analysis of the propeller installed on the engine at aircraft operation. The detail evaluation of the selected strain gages and regimes are performed by Rain Flow Method and frequency analysis based on Fast Fourier Transform (FFT). Probabilistic assessment uses the measured stress histograms and variability of these histograms to consider the all possible stress values during propeller service operation. Stress histogram of the whole flight are shown in Figure 2..

Random background of the fatigue characteristics and propeller loading allow to using probabilistic modeling based on random variables with appropriate distributions to obtain probabilistic assessment of the blade primary failure. A series of probability models were designed with the aim of evaluation of different input parameters.

Very low failure probability per one propeller flight hour is required by aviation agencies for primary failure of the propeller critical parts such as the propeller hub, blade retention and blades. Detailed assessment of the results from the fatigue tests and steady and vibratory stress loadings during ground and flight operation will allow us to obtain inputs for stochastic method of service life calculation. Stochastically calculated flight hours are a function of failure probability and combination with the results from deterministic method which are using series of safety coefficients has resulted in linkage between safety coefficients and failure probability.

REFERENCES