DAMAGE TOLERANCE IN CRITICAL COMPONENTS

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The paper describes the application of the Retirement For Cause approach in critical engine components of a turbofan engine. Results of fatigue life predictions are presented. Fatigue crack growth data obtained in laboratory specimens taken from the actual components was used in the analysis. Typical mission profiles of the engines were introduced in the fatigue life program. For each critical component inspection curves were obtained for different mission profiles and counting methods. The results have shown that the rainflow method gave slight pesimistic results for crack growth prediction from an initial flaw.

INTRODUCTION

The main objectives of the RFC programme are to increase the potential fatigue life of critical components (compressor and turbine disks) and establish safe inspection intervals.

The list of critical components was supplied by the manufacturer of the engine (1). The potential fatigue life for crack initiation was also given and this was obtained from a low cycle fatigue analysis. Life for crack initiation was defined as the number of equivalent usage in hours, to develop a crack with a depth of approximately 0.8mm (0.025 in.).

In the RFC approach a damage tolerance analysis is done in each component and if a flaw is detected a fatigue crack growth analysis is carried out and a decision is made about to scrap that component or put it back in service till the next inspection. The number of cycles for the next inspection is called the reusage interval (2) and its value is obtained by computer simulation of the fatigue crack growth life.

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The turbine and compressor disks of the engine can be seen in Fig.1 which shows a longitudinal view.

Details about operational rotational speeds and temperature distribution were obtained in previous work and are reported by Pires (3).

In this paper results of a fatigue life prediction of crack growth in one of the critical components of the engine shown in Fig.1 are presented. The analysis was made with linear integration and hence does not take into account load interaction effects. It is based on a typical mission mix load spectra.

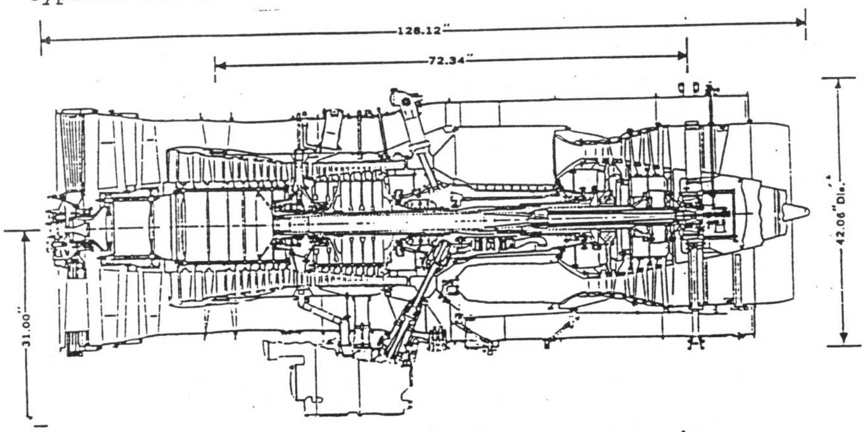

Fig.1 - Longitudinal view of the turbofan engine.

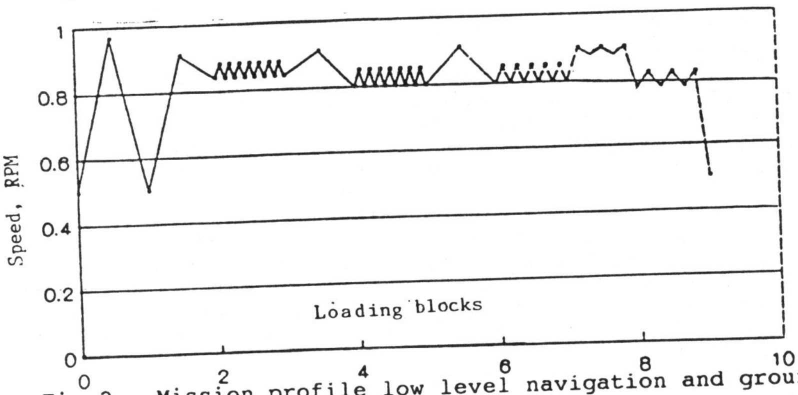

Fig.2 - Mission profile low level navigation and ground attack.

RESULTS AND DISCUSSION

MISSION PROFILES

Mission analysis was able to identify several typical mission profiles. Each mission was defined by a mission profile where rotational speed of the engine is plotted against number of loading blocks. An example of a mission profile is plotted in Fig.2.

From the mission profiles mission mix was established attributing certain percentages of usage to each mission profile type supposed to represent typical conditions of aircraft usage.

STRESS ANALYSIS

The stress values were obtained using the PAFEC 2DFE code. Only the mechanical stresses in the disks induced by the centrifugal forces of the disk rotation were computed. The mechanical stresses take about 80% of the total stresses. The thermal stresses due to temperature differences and expansion gradients were not considered in the analysis. In Fig.3 the FE mesh for the 3rd stage turbine disk is shown.

EXPERIMENTAL PROGRAMME

Fatigue crack growth data was obtained for some of the materials of the critical components. The tests were carried out in CT and SENT specimens taken from used disks. Hence the fatigue crack behaviour of the material could be assessed taking into account the influence of prior fatigue damage introduced in the material. Fig.4 shows the layout of CT specimens in the 2nd stage turbine disk.

The materials tested included the nickel based superalloys IN718 and Incoloy 901, the Ti-6Al-4V alloy and two different types of martensitic stainless steels.

The fatigue crack propagation tests were conducted in accordance with the ASTM specification (4). A high stress ratio, R=0.5 was used in order to give a reasonable approximation of the mission profile load cycle where a high mean stress component exists. The tests in the nickel based superalloys were carried out at 600ºC in a closed loop computer controlled servo hydraulic fatigue testing machine fitted with a cam shell type resistance furnace.

Crack growth was monitored with a pulsed DC potential drop PD equipment fitted to the testing machine control system. The PD system was provided with appropriate software for data analysis.

A calibration curve of the potential drop ratio, against crack length was used to obtain the crack length values (5). This calibration curve was obtained at room temperature with the crack length readings obtained optically. In the high temperature tests the AGARD recommended testing procedure was used (6), i.e. a reference specimen was fitted in the furnace. Using this method, by Wilkinson (7) the calibration curve technique was shown not to depend on the testing temperature.

Appropriate Paris law curves were obtained for each material from 10^{-6} up to crack growth rates close to 10^{-3}mm/cycle.

FATIGUE LIFE PREDICTION RESULTS

The first input of the program is the stress distribution at the location where the crack is due to grow. This is obtained from the results of the stress analysis FE program. The load spectra is introduced in the program by the user who defines the mission mix in

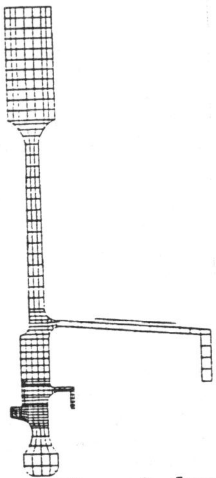

Fig.3 FE mesh for stress computation

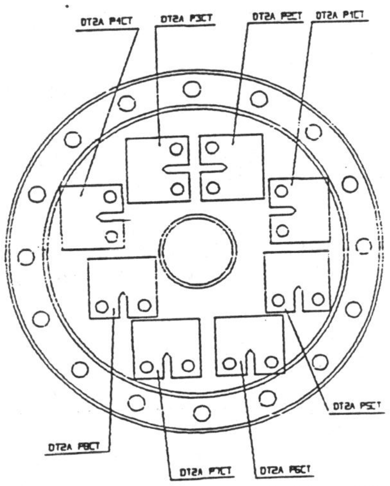

Fig.4 Layout of the CT specimens in the turbine disk.

detail . Then the cumulative frequency curves (stress level against number of cumulative cycles) are obtained by two counting methods; rainflow and peak to peak. Finally a cycle by cycle integration of the appropriate Paris law is carried out providing crack length against number of cycles plots.

An example of the application of this fatigue life assessment program is given below for a quarter-circular crack located at the base of the 2nd stage turbine disk (Fig.5). The crack propagation plane shown in Fig.5 is cut through the disk and the size of the initial crack was a=c=0.5 mm. The Paris law parameters experimentally obtained for IN718 used material were m=3.22 and $C=1.82 \cdot 10^{-14}$ ($Nmm^{-3/2}$; mm/cycle).

The stress intensity factor solution was the Pickard formulation (9) for semi-elliptical surface cracks.

A mission mix with the highest probability of occurrence for a total fatigue life of up to 10 years was used. To assess the influence of the counting procedures on the fatigue damage, the crack growth curves were obtained using four methods:

- rainflow method with the stress ranges in increasing order in the cumulative frequency curve.
- the same with the stresses decreasing
- the same with a random setting of stresses
- peak-to-peak method with the stress ranges set in increasing order.

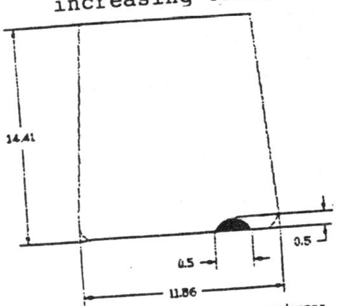

Fig.5 Defect geometry assumed in the analysis.

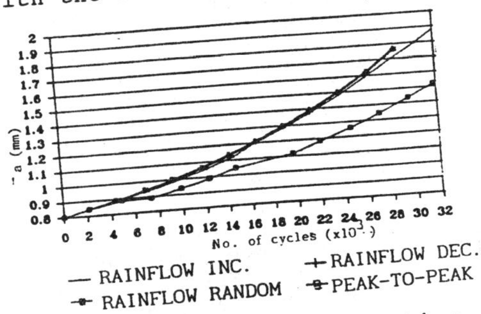

Fig.6 Results of counting procedures for Fig.5.

The fatigue crack growth curves can be compared in Fig.6 for a crack growth from 0.8 to 1.8mm. It is seen that the rainflow method gives the more conservative results for the fatigue life in comparison with the peak-to-peak method.

CONCLUSIONS

It was shown that the fatigue crack propagation life program developed to carry out a damage tolerance analysis of critical engine components is able to get safe results to compare the fatigue behaviour of the components. Further development work is in progress for the analysis of individual missions and also to take into account load interaction effects.

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