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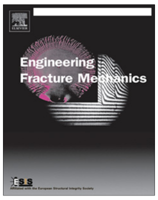

Fleet economic life prediction: A probabilistic approach including load spectrum variation and structural property variation

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ABSTRACT

A probabilistic approach for predicting the economic life of an aircraft fleet is proposed with variation in load spectrum and structural property taken into account. Specimens of TA15M titanium alloy were fatigue tested under three individual load spectra of different damage severities. By using the fatigue test results, a generic equivalent-initial-flaw-size distribution was obtained, and a stochastic crack growth model was developed including the load spectrum variation and the material crack resistant variation. With the number of cracks exceeding the economic repair limit as the economic life criteria, a simple expression was derived for the probability of crack exceedance.

1. Introduction

Economic life as a basis for economical aircraft operation and maintenance action planning, is an essential quantity for designers and operators. Before an aircraft reaches the end of its economic life, operational readiness should be kept by economically acceptable maintenance [1]. In the design stage, the economic life of an aircraft fleet should be analyzed and evaluated based on the results of development fatigue tests, and verified by full-scale fatigue tests in accordance with pertinent standards and specifications [2–4]. After a fleet is put into service, the baseline service life for the fleet needs to be determined; economic life is a representation of baseline service life. Due to various external and internal factors, considerable scatter has been observed in fatigue life of aircraft structures. These factors can be categorized into two types: the structural property variation and the load spectrum variation [5–7]. The former arises from the variation in material property, manufacture and assembly. Specifically, the factors influencing the structural property variation [8,9] include variations in:

- material's fracture toughness,
- material crack resistance,
- initial flaw size as a result of material processing and structural manufacturing operation, and
- residual stress introduced in assembly.

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Nomenclature

a	crack size
a_e	economic repair limit
a_r	reference crack size
$a(t)$	crack size at time t
a_0	crack size at $t = 0$
b	exponent in the crack growth equation
h	value of H
H	lognormal random variable
k	mathematical expectation of $\ln Q$
$p(i,t)$	probability of crack exceedance
$n_{z,\mathrm{R}}$	relative acceleration
N_i	number of structural details
$\overline{N}(i,t)$	mean of number of details with a crack size exceeding a_e
$N_R(i,t)$	number of details with a crack size exceeding a_e corresponding to reliability R
Q	crack growth rate parameter for a load spectrum
Q_i	crack growth rate parameter for the ith specimen
Q_{50}	crack growth rate parameter for the average load spectrum
R	reliability
s_w	integrated standard deviation
t	service time
t_{50}	median fatigue life
u_p	pth percentile of the standard normal variable
u_R	Rth percentile of the standard normal variable
x	EIFS value
y	value of Y
Y	lognormal random variable
z	value of Z
Z	lognormal random variable
μ_t	mathematical expectation of $\ln t$
μ_x	mathematical expectation of $\ln \ln(a_\mathrm{r}/x)$
σ_t	standard deviation of $\ln t$
σ_y	standard deviation of $\ln y$
σ_z	standard deviation of $\ln z$
$\sigma_N(i,t)$	standard deviation of number of details with a crack size exceeding a_e
EIFS	equivalent initial flaw size
EIFS_{50}	median of EIFS
EIFSD	equivalent-initial-flaw-size distribution
EPS	equivalent pre-crack size
IAT	individual aircraft tracking
SCGC	service crack growth curve
TTCI	time to crack initiation
$f_H(\cdot)$	probability density function of H
$f_{\mathrm{TTCI}}(\cdot)$	probability density function of fatigue life
$f_Y(\cdot)$	probability density function of Y
$f_Z(\cdot)$	probability density function of Z
$F(a_\mathrm{e})$	probability of a crack size not exceeding a_e
$F_X(\cdot)$	distribution function of equivalent initial flaw size
$\Phi(\cdot)$	standard normal distribution function

The latter refers to the load history variation of aircraft in a fleet under the same operational requirements. Possible sources of the load spectrum variation include the differences in operational environments, such as gust, maneuver and runway, and in pilots' technique as well as in aircraft's gross weight [10–12]. It is therefore of great significance for aircraft designers to consider these two types of variation when performing economic life prediction for a fleet.

Fatigue life prediction methods under a specific load spectrum usually take the structural property variation into account. The methods fall into two categories: *S*–*N* curve-based or ε–*N* curve-based fatigue analysis methods and fracture mechanics-based methods [13]. However, the research on the load spectrum variation has been relatively limited prior to load monitoring. Extensive service load measurement has been made in the past several decades [10,14,15]. Based on real in-flight load data, Mattrand et al. [12,16,17] developed stochastic models for the generation of load spectra, recreating the scatter of load