Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 101 (2015) 227 – 234

Procedia Engineering

www.elsevier.com/locate/procedia

3rd International Conference on Material and Component Performance under Variable Amplitude Loading, VAL2015

Crack growth from naturally occurring material discontinuities in operational aircraft

Rhys Jones*, Daren Peng, Pu Huang, Raman R. K. Singh

Centre of Expertise for Structural Mechanics, Department of Mechanical and Aerospace Engineering, Monash University, Clayton, Victoria, 3800, Australia

Abstract

This paper focuses on problems associated with aircraft sustainment related issues and illustrates how cracks that grow from small naturally occurring material discontinuities in operational aircraft behave. The example discussed in this paper, which is associated with crack growth under a representative maritime aircraft load spectrum, when taken in conjunction with previous studies into cracks growing under combat aircraft load spectra illustrates how for cracks that grow from naturally occurring material discontinuities under such operational load spectra there is generally little crack closure so that the crack growth history from its initial equivalent pre-crack size (EPS) through to final failure can be easily and accurately computed.

Peer-review under responsibility of the Czech Society for Mechanics

Keywords: aircraft sustainment; NASGRO; fatigue crack growth; corrosion-fatigue interaction

1. Introduction

The problems arising as a result of aging aircraft, rail and civil infrastructure have focused attention on tools for predicting the growth of cracks from small naturally occurring material discontinuities. In general the design of aerospace vehicles requires that all structures be designed in accordance with damage tolerance design principles which for military aircraft are detailed in the Joint Services Structural Guidelines JSSG2006 and in the USAF Damage Tolerant Design Handbook [1]. This design philosophy has evolved as a result of a number of high profile incidents some of which are reviewed in [2]. However, as explained in [3] the approaches and tools required for initial design

* Corresponding author. Tel.: 61-3-9905-3809.
*E-mail address:*rhys.jones@monash.edu

Peer-review under responsibility of the Czech Society for Mechanics
doi:10.1016/j.proeng.2015.02.031

and for sustainment purposes differ. When discussing the equations needed to predict the growth of cracks from small naturally occurring material discontinuities it has been shown that there is generally little crack tip shielding (closure, etc.) associated with this problem set and that the ASTM ACR (adjusted compliance ratio) method can sometimes be used to determine an approximate da/dN versus ΔK relationship, see [3] for details.

Nomenclature

a	crack length
a_i, a_f	initial and final crack lengths
a_0	equivalent pre-crack size (EPS)
ACR	adjusted compliance ratio
B	number of load blocks
B_i, B_f	initial and final blocks (or flight hours)
da/dN	increment in crack length per cycle
da/dB	increment in crack length per load block
σ_{max}	maximum applied stress in a load cycle
σ_{min}	minimum applied stress in a load cycle
$\Delta\sigma$	stress range in a load cycle
R	stress ratio
K	stress intensity factor
K_{max}	maximum applied stress intensity factor in a load cycle
K_{min}	minimum applied stress intensity factor in a load cycle
K_{char}	a characteristic stress intensity factor in a load cycle
$K_{char, thr}$	the apparent threshold associated with the characteristic stress intensity factor in a load cycle
ΔK	stress intensity range in a load cycle
ΔK_{eff}	effective stress intensity range in a load cycle
ΔK_{rms}	the rms value of the effective stress intensity range in a load block
K_{op}	stress intensity factor at which a crack will first open
ΔK_{th}	threshold stress intensity range
ΔK_{thr}	apparent threshold stress intensity range
$\Delta K_{eff, thr}$	effective stress intensity threshold
ΔK_{op}	differene between the opening stress intensity factor and K_{min}
ΔK_{opl}	long crack value of ΔK_{op}
β	beta factor, i.e. the geometry correction factor
D, m, p	constants in the NASGRO crack growth equation
ω	constant in the exponential crack growth equation
λ	constant in the McEvily formulation for the decay of ΔK_{op} with crack length
A	apparent cyclic fracture toughness in the Hartman-Schijve crack growth equation
RAAF	Royal Australian Airforce
SFH	simulated flight hours
EIFS	equivalent initial flaw size
LOV	limit of validity

In this context it is now known [4, 5] that for cracks that grow from small naturally occurring material discontinuities in operational aircraft and in full scale fatigue tests there is generally a linear relationship between the log of the crack depth/length and the number of cycles (or flight hours). This is shown in Figure 1 which presents the crack depth/length histories associated with a range of aircraft. This relationship can be written in the form [4], viz:

$$a = a_o\, e^{(\omega\ SFH)} \quad (1)$$