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Implications of the lead crack philosophy and the role of short cracks in combat aircraft

R. Jones *, D. Tamboli

Centre of Expertise in Structural Mechanics, Department of Mechanical and Aeronautical Engineering, Monash University, Clayton, Vic 3800, Australia

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ABSTRACT

The Australian Defence Science and Technology (DSTO)/Royal Australian Air Force (RAAF) approach to the management of fatigue cracking in combat and trainer aircraft makes use of the "lead crack" concept. In this approach crack growth is assumed to initiate from small naturally occurring defects/discontinuities with dimensions of approximately 10 μm and growth is assumed to commence from day one. As a result, for certification purposes, we need to address the so called short crack anomaly, whereby for a given ΔK the crack growth rate (da/dN) is significantly greater for short cracks than it is for long cracks. In this paper we reveal that there are several instances where this anomaly vanishes if da/dN is represented as a function of ($\Delta K - \Delta K_{thr}$), where ΔK_{thr} can be thought of as an apparent threshold. We then show that for operational aircraft the "true" da/dN versus ΔK curve is an amalgam of the short and long crack growth curves. We next show that existing test procedures used to establish the effect of composite repairs to cracks in fleet aircraft overestimate their effect. We also show that the growth of cracks from small naturally occurring defects exhibits little, if any, *R* ratio effects.

1. Introduction

The DSTO-RAAF approach to the management of fatigue cracking in combat and trainer aircraft makes use of the "lead crack" concept [1]. In this approach, the life of the fleet is determined by lead fatigue cracks which in [1] were defined to have the following features:

(a) Crack growth initiates from small naturally occurring defects or discontinuities, such as inclusions and pits, which have dimensions that are equivalent to a fatigue crack-like size typically of about 10 μm in depth.
(b) Crack growth essentially starts from the day that the aircraft enters service. (This implies that the fatigue threshold ΔK_{th} is very small.)

As such understanding the growth of fatigue cracks from small naturally occurring defects is of fundamental importance to managing the Australian fleet. Indeed, the central role that small cracks play in understanding the durability of aircraft is highlighted in [2]. Furthermore, as stated by Lados et al. [3]:

> "The use of long crack data can lead to significantly non-conservative estimates of the fatigue response and serious design errors."

* Corresponding author. Tel.: +61 398786265.
E-mail address: rhys.jones@monash.edu (R. Jones).

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The extent of these non-conservative estimates is aptly illustrated in [4] where it is shown that using FASTRAN together with long crack da/dN versus ΔK data to predict the crack growth from a small 0.003 initial defect in a F/A-18 centre barrel crack gave an estimate of the fatigue life that was more 300% greater than that seen in the test. Similarly Appendix C reveals that the use FASTRAN together with short crack da/dN versus ΔK data can also lead to non-conservative estimates for the fatigue life of a structure.

This means that it is important to address, and hopefully overcome, the so called "short crack anomaly" which is one of the basic problems in materials science and particularly in fatigue crack growth prediction. Here it should be noted that as stated in [1] and can be seen from the experimental data presented in [5] that typical "small natural initiating defects" in military aircraft have a size that is of the order of 0.01 mm. This (initiating defect) size is consistent with the work of Merati [6], where it was found that the size of initial defects in civil transport aircraft lie in the range 0.009–0.029 mm and with the paper by Schijve [2] where it was reported that the size of initial defects in civil transport aircraft lie in the range 0.007–0.030 mm. As such when discussing crack growth from small naturally occurring initial discontinuities in aircraft structures we focus on initial defects that are typically 0.01 mm long/deep. (In this context it should be noted that Section 5.3.1 of the USAF Damage Tolerant Design Handbook [7] suggests that cracks growing from initial defects greater than between 1.0 and 1.8 mm long behave like "long cracks". A methodology for modelling crack growth from an arbitrary length initial notch is proposed in [8] and will be discussed later in this paper.)

The short crack anomaly arises as experimental studies have shown that for a given ΔK, R ratio and specimen thickness the increment in the crack length (or depth) per cycle (da/dN) seen in tests on short cracks is significantly greater than that seen in tests on long cracks. An example of this "anomaly" is shown in Fig. 1, from [9], which compared the growth of short and long cracks in 2090-T8E41 at $R = 0.1$. A second example is shown in Fig. 2, from [10], which presents the da/dN versus ΔK relationships obtained for AA7050-T7451, which is used in both the F/A-18 Hornet, the F/A-18 Super Hornet and the Joint

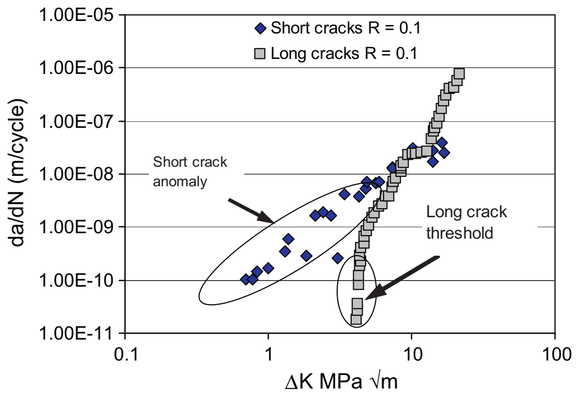

Fig. 1. Short and long crack growth in 2090-T8E41, from [9].

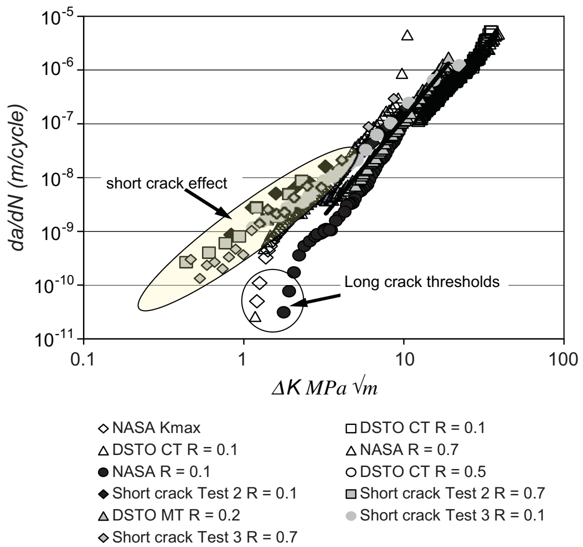

Fig. 2. Comparison of the various da/dN versus ΔK test data for 7050-T7451, from [10,13].