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Influence of cyclic stress intensity threshold on the scatter seen in cyclic Mode I fatigue delamination growth in DCB tests

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ABSTRACT

Whilst composite materials are now widely used in aircraft structural components for certification purposes current designs are such that any delamination/disbond will not grow. Despite this limit fleet data and data obtained from full scale fatigue tests reveal that small sub mm initial delaminations/disbonds can grow when subjected to operational flight loads. To account for this the US Federal Aviation Authority advisory circular AC20-107B outlines a slow growth approach for certifying composite/bonded aircraft structures. A key point in AC20-107B is that growth must be both slow and predictable. Since the life of an airframe is determined by the growth of the fastest (lead) crack/delamination/disbond any analysis tool developed for a composite/bonded airframe requires the ability to predict the both the scatter in delamination/disbond growth and thereby the growth of the lead delamination/disbond in the airframe. To this end the present paper reveals that the Hartman-Schijve variant of the NASGRO equation would appear to show promise for capturing the scatter seen in Mode I delamination tests associated with specimens fabricated from nominally identical material supplied by two different suppliers. It is shown that the values of the constants in the Hartman-Schijve equation associated with these two sources are consistent and the scatter in growth can captured by allowing for small variations in the fatigue threshold term.

1. Introduction

The relatively high strength-to-weight ratio of carbon fibre reinforced polymer composites (CFRP) compared to metallic alloys, the potential to tailor the ply configuration, so as to result in increased manoeuvrability, and the potential for weight saving and hence a reduction in fuel consumption, has led to an increased use of CFRP composites in both civil and military aircraft. However, current CFRP airframe designs are based on a ‘‘no growth” criteria. Indeed, this approach to (aircraft) certification is still allowed [1] and is still the most commonly used approach. Despite this there are several instances [2–4] where delaminations have initiated and grown both in service aircraft and in full scale fatigue tests. In this context [4] presented details of a full scale fatigue tests on an F/A-18 centre barrel performed in order to evaluate the effect of a boron epoxy doubler on the fatigue life of the aircraft. The design consisted of an 8-ply uni-directional laminate with a nominal thickness of 1.05 mm located as shown in Fig. 1. The doubler was approximately 403 mm × 58 mm, with 4 mm steps between plies at either end. The tests were performed at DSTO using the Flaw Identification through the Application of Loads (FINAL) test facility described in [5]. The disbond shown in Fig. 2a that arose naturally and grew during this test. In contrast the disbond shown in Fig. 2b occurred as a result of failure of the centre barrel, see [4] for more details.

The inability of the ‘no-growth’ design approach, as aptly illustrated in the above example, to ensure that there is no in-service debond or delamination crack growth has led to the realisation that there is a need to allow for some slow crack growth in the initial design, and thereby determine the appropriate inspection intervals. In 2009 this approach to certifying adhesively-bonded and composite structures was introduced in the US Federal Aviation Administration (FAA) Airworthiness Advisory Circular ac 20–107B [1]. A key point of this approach is that growth must be both slow and predictable [1]. Unfortunately, as first explained in [6] and discussed in [2,7], approaches that relate da/dN to the energy

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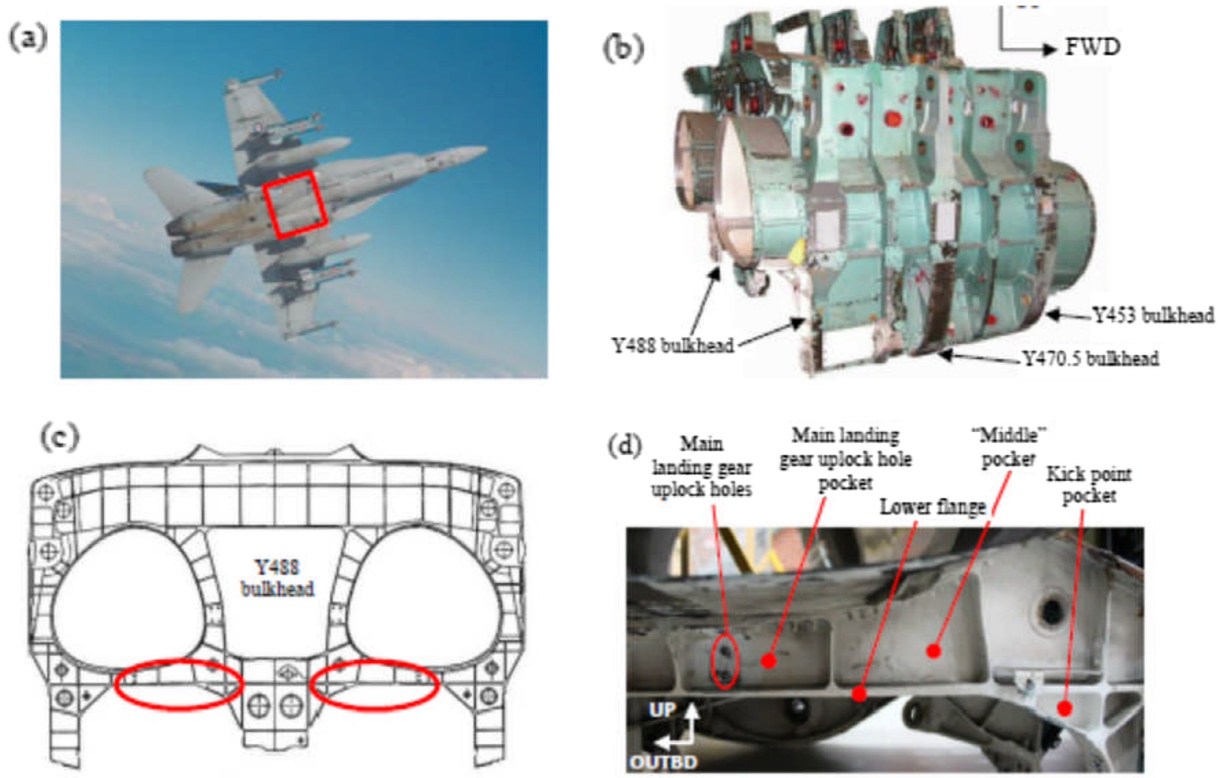

Fig. 1. (a) The location of the CB in the F/A-18A-D aircraft. (b) CB structure showing the location of the Y488 bulkhead. (c) Y488 bulkhead with fatigue critical region of interest circled. (d) Nomenclature and structural details in the Y488 bulkhead fatigue critical region (left hand side, view looking forward), from [4].

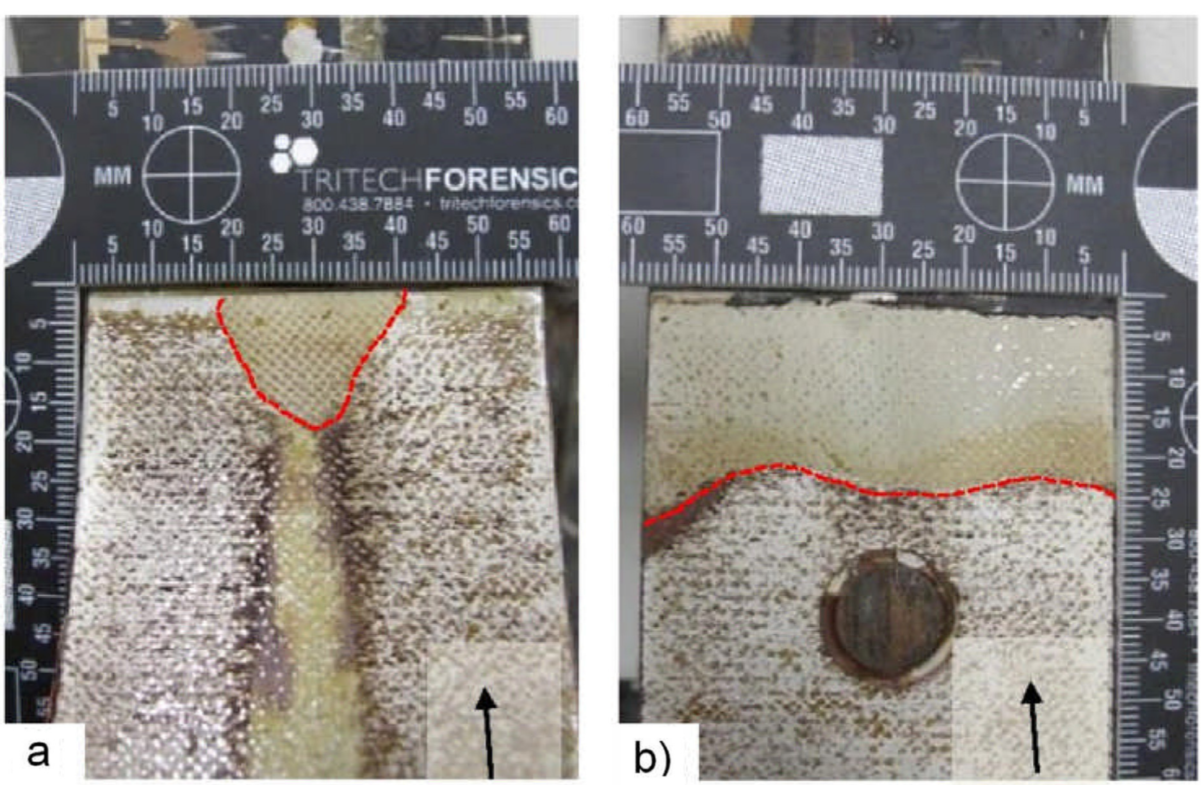

Fig. 2. (a) Disbond at the inboard end of the doubler as indicated by red dashed line. (b) Disbond at the outboard end of the doubler as indicated by red dashed line. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)