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On the fatigue crack growth analysis of spliced aircraft wing panels under sequential axial and shear loads

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ABSTRACT

The spliced wing panels on a surveillance aircraft are subject to sequentially applied axial and shear load cycles. This paper aims to propose an approach to address the fatigue crack growth under this scenario. Current understanding on fatigue crack growth behaviours was reviewed, focusing on crack surface interferences and fatigue crack growth mechanisms under non-proportional mixed-mode loads. A generic spliced plate was analysed using non-linear finite element modelling. The analysis revealed shear-induced-bearing at fastener holes, and predicted both shear-induced-K_I and shear-induced-K_{II} at a 0° crack emanating from the fastener hole edge. When the crack is short relative to the fastener hole radius, the shear-induced-K_I is dominant therefore it has the potential to cause shear-induced mode I overload. As the crack grows longer, the shear-induce-K_{II} increases, and depending on the load level, this may lead to both short-range acceleration and long-range retardation. Through the above analysis, the engineering problem of fatigue crack growth in spliced wing panels under sequential axial and shear loads was converted into a more generally understood problem of fatigue crack growth under cyclic mode I plus intermittent cyclic mixed-mode loads.

1. Introduction

Aircraft structures are subject to spectrum loading from multiple sources. Yet in aircraft structural integrity management, the fatigue crack growth (FCG) is usually predicted assuming a uniaxial load spectrum. This is appropriate in most cases where the multi-axial loads at the global level are transformed by load path constraints into an approximately uniaxial load spectrum at the local fatigue critical area. However, not all the global multi-axial loads can be reduced to a local uniaxial spectrum. For instance, on a surveillance aircraft with a wing mounted power plant, for some areas of the wing, the spliced wing panels as schematically illustrated in Fig. 1 may experience both axial and shear load spectrums. The axial load is caused by the span-wise bending of the wing box, which mainly exists when the aircraft is in air. Meanwhile, the shear load is caused by the wing box torsion due to engine inertia, which is predominant during the landing and dynamic taxiing phases. Notably, the variation of the axial and shear loads occurs almost sequentially, and there are far more axial cycles than shear cycles. This may be viewed as a special case of non-proportional loading.

For the illustrated spliced wing panels, a fatigue crack usually starts from the edge of a fastener hole as indicated in Fig. 1(b). Under the sequential axial and shear loads, the FCG behaviour is affected by a number of extra factors, in addition

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Nomenclature

a	crack length measured from fastener or open hole edge to crack tip
D	diameter of the fastener or open hole
f_b	distributed bearing stress at fastener hole edge
f	contact force vector at asperity facets of a crack surface
K_I, K_{II} and K_{III}	mode I, II and III stress intensity factors
L	distance between fasteners as per definition of Fig. 4
R	radius of the fastener or open hole (=$D/2$)
σ and σ_s	nominal tensile and steady tensile stress applied at a tubular specimen
σ_{bearT}	nominal bearing tensile stress applied at edges of the spliced plate
σ_{byT}	nominal by-pass tensile stress applied at edges of the spliced plate
$\sigma_{x\max}$	maximum value of σ_x at material points within the spliced plate
$\sigma_{y\max}$	maximum value of σ_y at material points within the spliced plate
τ	nominal shear stress, used for multiple cases
θ	orientation angle as defined in Figs 5 and 6

to those that apply to a uniaxial FCG. These extra factors include: (i) load transferring through fastener holes under nominal axial and shear loads, (ii) changes of effective fatigue driving force due to mixed-mode crack surface interference, and (iii) potential alternation of FCG mechanisms under non-proportional axial and shear loads.

At present, the understanding of the above three extra factors is still limited, and no reliable FCG prediction tool is readily available. In the area of multi-axial fatigue analysis, most of the advances are at the forefront of fatigue life predictions as reviewed in [1]. Only a few investigations [2–9] focused on the FCG under non-proportional axial and shear loads, and none of these has considered the load-bearing effects of a fastener hole under nominal shear loads.

The purpose of this paper is therefore to propose an approach to address the engineering problem of FCG in spliced wing panels under sequential axial and shear loads. This will be based on a brief review of the current understanding of FCG under non-proportional mixed-mode loads, and a detailed stress analysis of a generic spliced plate under tension and shear. The brief review is organised to highlight the key aspects from the view point of bridging the engineering problem with the generic scientific understanding, and to reveal the areas that need future investigations. As such, it can be read as a supplementary to the existing reviews of field, for example Refs. [1,8,9], where views from different angles were presented. The need of performing a detailed stress analysis of a spliced plate will be established through the brief review.

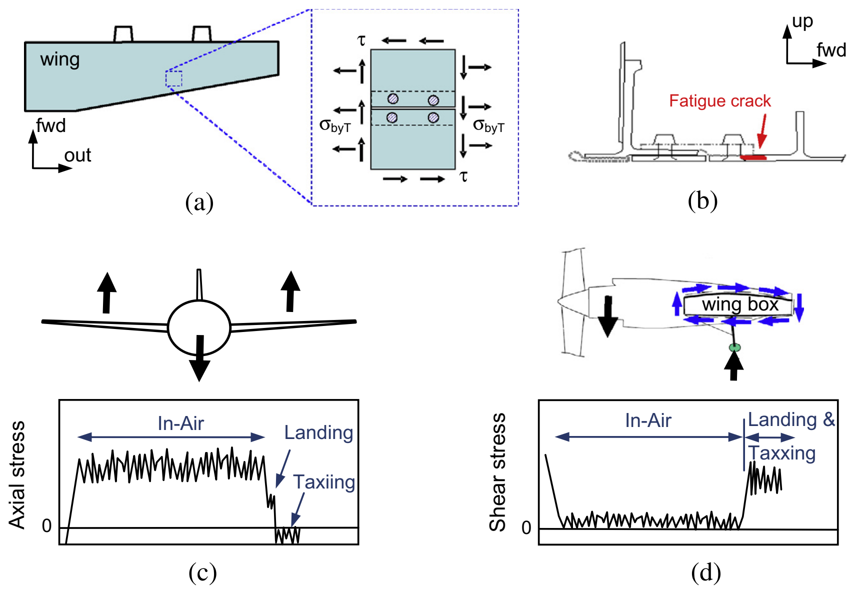

Fig. 1. (a) Spliced wing panels subject to axial and shear loads; (b) cross-sentional view of a representative spliced wing panels [10]; (c) axial load resulted from wing box span-wise bending; and (d) shear load resulted from wing box torsion.