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MSD crack propagation by DBEM on a repaired aeronautic panel

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ABSTRACT

This paper focuses on the use of the Dual Boundary Element Method (DBEM), as implemented in a commercial code (BEASY), to investigate the damage tolerance performance of a riveted repair flat aeronautic panel, realised and tested in the context of the European project "IARCAS" (VI framework). Such panel is assembled in such a way to simulate the in service repairs, with doublers riveted over corresponding cut-out. The panels, repair patches and rivets are modelled in a two-dimensional analysis with no allowance for out-of-plane bending, with edge-cracks initiated from some skin rivet holes and growing due to fatigue load. In the model, the layers representative of each component are overlapped but distinct, providing no allowance for the existing offset. The two-dimensional approximation for this problem is not detrimental to the accuracy of numerical-experimental correlation, so it turn out to be useful to study varying repair configurations, where reduced run times and a lean pre-processing phase are prerequisites.

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1. Introduction

The ability to determine the fatigue life for a damaged structure has become increasingly important with the advent of the damage tolerance criteria mandated by Federal Aviation Administration (FAA) regulations for ageing transport aircraft; consequently, the repair techniques have been compared on the basis of their fatigue behaviour performances [1,2]. In order to develop an effective riveted repair methodology, it is important to be able to accurately determine the complex stress field created by the repair, as well as the resulting reduction in the stress intensity factor (SIF) for a possible new crack affecting the repaired portion of the panel. Numerical simulations are useful to identify the most fatigue critical locations where to check the effects of a possible crack, growing under a given spectrum load.

During the past decade, extensive research has been developed in the area of the riveted patch repair performance, also in comparison with the bonded patch repair (more recently adopted): most of the numerical analyses have been performed by using the finite element method (FEM) [3–5], but some works have also been done by using the boundary element method (BEM) [6–11].

This paper focuses on the use of Dual Boundary Element Method (DBEM) [12,13], as implemented in a commercial code (BEASY), to investigate the riveted repair damage tolerance performance of a fatigue flat panel, realised and tested by, respectively, the aircraft companies AIRBUS FRANCE and EADS CCR, in the context of a European project named IARCAS (VI framework).

2. Problem description and DBEM numerical model

A repaired aeronautic panel, undergoing a uni-axial fatigue remote load, is designed in such a way to simulate in service repairs, with doublers applied over corresponding cut-out and edge-cracks initiated from some rivet holes, belonging to the repaired part of the main panel (Fig. 1a).

Different configurations of mechanically fastened doublers for a damaged aircraft skin (Fig. 1b) are analysed by DBEM in order to compare their fatigue performance, and the corresponding results are validated by comparison with experimental outcomes.

Panel, patch, and rivets have been modelled in a two-dimensional DBEM analysis (Fig. 2) so that out-of-plane bending is not considered, but this is acceptable for the low thickness values involved [9–11,14,15]. The two-dimensional approximation is useful to study varying repair configurations (different patch thicknesses, rivet diameters, number of repair patches…), where reduced run times and a lean pre-processing phase are prerequisites. Plate thickness and rivet stiffness are illustrated in Table 1, with reference to the repairs analysed (Fig. 1b).

The DBEM analyses are fully linear because, due to the relevant length of the initial considered cracks, the non-linearity coming from the pin-hole contact can be neglected; anyway the implementation of a non-linear contact analysis would be straightforward even if run time consuming.

Skin and doubler have the material properties of Al 2024 T3: Young modulus $E = 69{,}000$ MPa, yielding stress $\sigma_y = 365$ MPa and Poisson ratio $\nu = 0.33$; whereas the stiffeners and rivets are respectively made of Al 7349 ($E = 71{,}000$ MPa) and Al 2017-NAS 1097 ($E = 72{,}400$ MPa).

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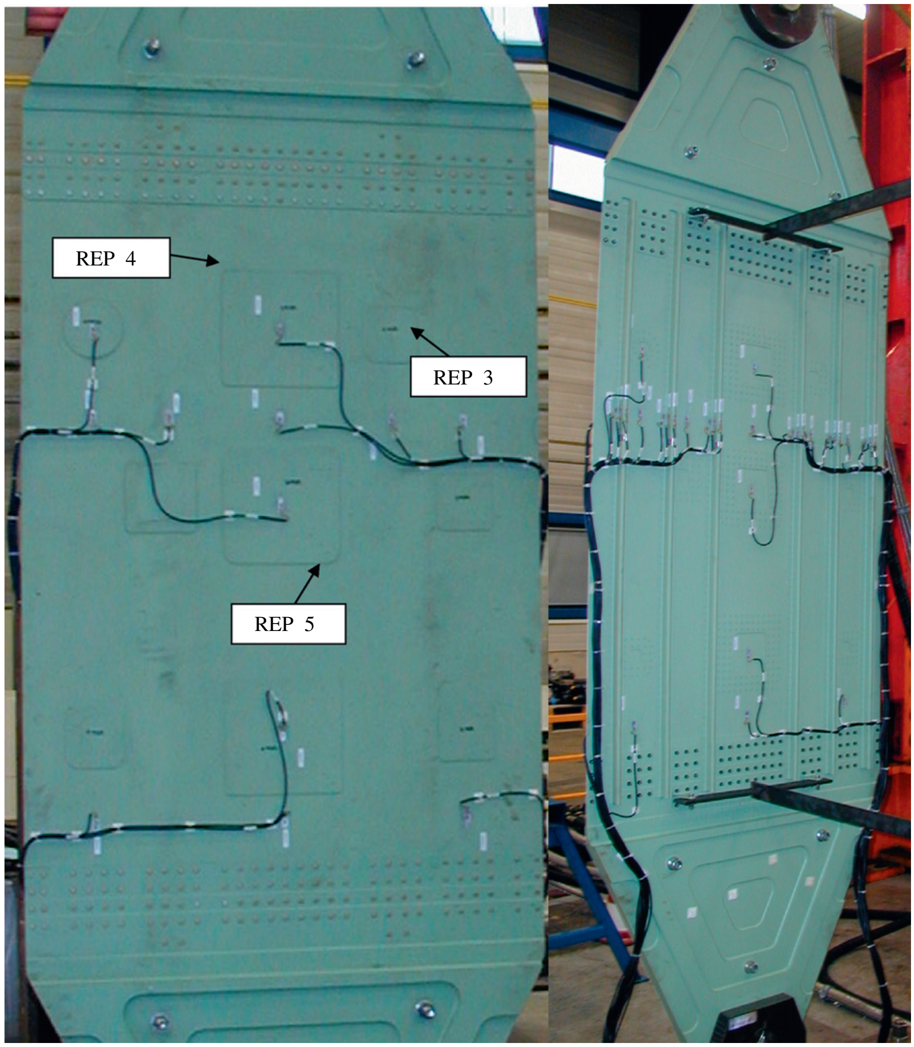

Fig. 1a. Panel in testing configuration: front view (left) and backward view (right), with highlight of the repairs analysed: REP 3–5.

In the numerical model, the skin and the repairs in the cracked area, are modelled by different patches, and the rivet connection between them is modelled by two circles, representative of the two halves in which the rivet is divided, respectively engaged with the two corresponding skin and doubler holes [16] (Fig. 3).

Such circles are connected each other by "internal springs" having a stiffness ($K_x = K_y$) corresponding to the rivet shear stiffness (Table 1). The same approach is adopted to connect the stiffeners to the skin.

The repairs in the noncracked areas are modelled as they were bonded to the skin, considering a local increase in the skin thickness corresponding to the repair thickness.

In conclusion, doublers, skin and stiffeners, where necessary, are modelled as different zones with different thickness and material properties, and the rivet connection between them is explicitly modelled only in the critical area affected by the crack propagation; in the remaining areas, the skin and the corresponding repairs are connected by a continuous attachment as if they were bonded. In particular, only the rivets corresponding to repairs Nos. 3–5 and that part of the stiffener located between REP 3 and REP 4 are explicitly modelled. The different layers representative of each component (skin, repair, rivet half, stiffener) are overlapped but distinct so that there is no allowance for the existing offset: all the different component medium planes are coincident [16]. The aforementioned approach enables the modelling of the real membrane stiffness of each single component.

The modelling accuracy can be assessed also taking advantage of the strain gauges outcomes (Fig. 1a and 1b): monitoring internal points (providing the numerical strains) are introduced in the DBEM area in correspondence of the experimental strain gauge locations. This facilitate the DBEM model calibration.

The crack edges are discretized with discontinuous quadratic boundary elements and the stress intensity factors (SIFs) are calculated using the J-integral technique, with 33 integration points on the J-path [12]. The crack propagation direction is derived by the Erdogan and Sih criteria (maximum principal stress criteria) [17].

The propagation analysis is based on the NASGRO3 formula (Eq. (1)), where the fatigue material properties, reported in Table 2, are obtained from the NASGRO database correspondingly to the Al 2024 T3 (all the analysed cracks will affect the only skin).

The maximum remote fatigue load applied is $P_{\max} = 28{,}405$ N (Fig. 2) with a stress ratio $R = 0.1$.

$$\frac{da}{dN} = \frac{C(1-f)^n \Delta K^n \left(1-\frac{\Delta Kth}{\Delta K}\right)^p}{(1-R)^n \left(1-\frac{\Delta K}{(1-R)K_c}\right)^q} \tag{1}$$

3. Experimental outcomes and numerical approach

Considering that part of the skin connected to repair No. 4, two cracks are detected in the skin after 95,445 fatigue cycles (Fig. 4a).

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