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INVESTIGATION OF AN IN-SERVICE CRACK SUBJECTED TO AERODYNAMIC BUFFET AND MANOEUVRE LOADS AND EXPOSED TO A CORROSIVE ENVIRONMENT

S.A. Barter and L. Molent
Air Vehicles Division, Defence Science and Technology Organisation, 506 Lorimer Street,
Fishermans Bend 3207, Australia, *Simon.Barter@DSTO.Defence.gov.au*; *Lorrie.Molent@DSTO.Defece.gov.au*

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Abstract

During routine inspection of a vertical tail attachment stub former from a combat aircraft, cracking was found about an attachment bolt. This former was replaced and was made available for examination. The cause of the cracking was found to be fatigue. The stub had experienced both aerodynamic buffeting and manoeuvre loads (often in combination) and these had produced many prominent fatigue progression markings on the crack surface, and by assuming that these marks were caused by similar events evenly distributed across the service life of the stub a crack growth curve was derived. During the life of the aircraft, significant down-time periods for maintenance had occurred and evidence of corrosion was found in discrete areas of the fatigue crack's surface that suggested that they were the result of these periods of inactivity. By assuming that the corrosion occurred whilst the aircraft was on the ground it was possible to correlate the crack growth curve to known flight hours.

1 Introduction

The F/A-18 Hornet is an extremely manoeuvrable, versatile, high performance fighter/attack aircraft. The inner wing Leading Edge Extension (LEX) provides fuselage and inner wing lift enabling it to achieve angles of attack (AOA) in excess of 60 degrees. The twin vertical tails canted slightly outward exploit the high-energy vortices generated by each LEX to provide good directional stability at these high AOA conditions. Unfortunately, these vortices break down at AOA>10 degrees, buffeting the structure and exciting the resonant frequencies of the empennage, producing high acceleration levels (Ref [1]) that result in high stress levels in key structural components. There is a synergistic interaction between the quasi-static manoeuvre loading and the higher frequency buffet loading with respect to fatigue damage. The general effect is that the buffet load cycles are applied at high mean loads, which increases their contribution to fatigue damage. The problem was so severe that the manufacturer retroactively strengthened the vertical tail (VT) attachments (Fig. 1), by fitting cleats to the inboard sides of the base of the tails to increase the tail attachment strength, and fitted aerodynamic fences (known as "LEX fences") to the LEX to reduce buffet severity. However, cracking of the VT continues to be found in service, mostly in the outboard flanges of the VT attachment stubs.

Fig. 1 A view of starboard attachment stubs after removal of vertical tail. The Y598 stub is marked with an arrow (aft is to the left).

Fatigue cracks have been found by the Royal Australian Air Force (RAAF) in the outboard flange of the attachment stub former using an ultrasonic inspection technique. These cracks are usually adjacent to the aft lower VT attachment fastener holes in one of the aft two stub formers. In one aircraft, at 3088 airframe hours, cracking was found in both aft stubs (the most structurally important) and this led to the stubs being replaced at 3850 airframe hours. As a result, a stub former was sent to DSTO for examination of the cracking. The location of the cracking found by the in-service inspection is shown in *Fig. 2*.

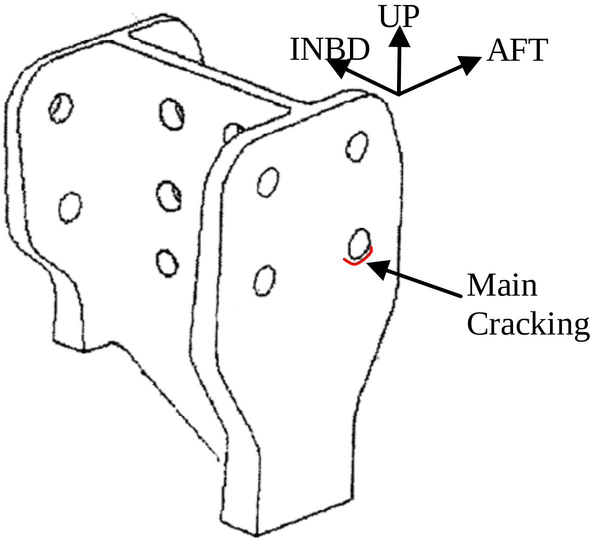

Fig. 2 The position of the detected cracking in the starboard Y598 stub frame, stub attachment.

It is often a difficult task to determine the age and the rate of in-service crack growth. This paper demonstrates that through the application of quantitative fractography, an understanding of how lead [2] cracks grow in typical materials used in agile aircraft, along with some knowledge about the usage and maintenance periods of the aircraft, can result in useful fleet lifing information being derived. In this instance corrosion markings on the fracture surface helped to define the derived crack growth data.

2 Detailed Description of Damage

The stub was forged from aluminium alloy 7050-T7452 and was 11.35mm thick at the location of interest. The cracking in the outboard flange near the lower aft fastener hole (diameter of about 10mm) originated from just below the hole in an arc of about 110^o starting at about the 4 o'clock position and ending at about the 8 o'clock position (where 12 o'clock is up). *Fig.* **3** shows the location of these cracks. The cracks included many small cracks, some of which had joined to form larger cracks. The largest of these was 6.8 mm long on the surface of the flange. Several of the other cracks were about 1-2 mm long on the surface, and some of these overlapped each other and were in the process of joining. No evidence of fretting adjacent to the cracking could be found, and the Ion Vapour Deposited (IVD) corrosion protective coating remained intact over the cracked surface.

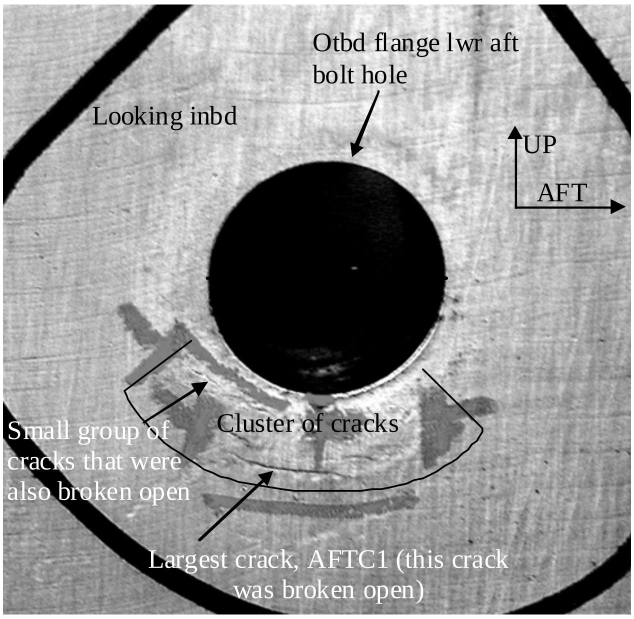

Fig. **3** The outboard surface of the stub outboard flange showing the aft lower fastener hole and the cracking about the lower side of this hole. The two sections of cracking that were broken open are marked.

After breaking open the main crack, hereafter designated as AFTC1 as noted in *Fig.* **3**, and some of the other cracks, hereafter designated as AFTC2, AFTC3 and AFTC4 (the cluster shown in *Fig.* **3**), it was possible to measure their crack depths. At its deepest point from the surface of the flange AFTC1 was about 2.05mm deep. At this section, the flange thickness was measured as 11.35mm. The AFTC1 crack was the product of several cracks that had joined which accounts for its shallow depth in comparison to it surface length, although an examination of the crack's surface did suggest that it was growing faster at the sides than at its deepest region. A view of the surface of AFTC1 is shown in Fig. **4** (after cleaning the crack's surface).

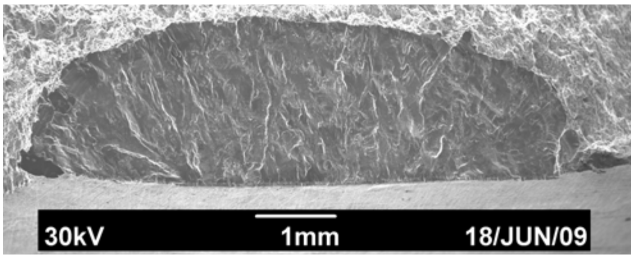

Fig. **4** View of the surface of AFTC1.

Three other significant cracks AFTC2, AFTC3 and AFTC4 were also broken open and these are shown in Fig. **5**. Each of these cracks was the product of several smaller cracks that had joined. The positions of some of the more significant origins are indicated in Fig. 5. AFTC2 was about 1.25 long by 0.84mm deep, AFTC3 was about 1.63 long by 0.67mm deep and AFTC4 was 1.75 long by 0.65mm deep.

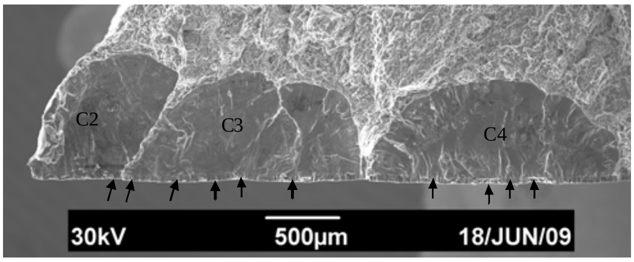

Fig. **5** View of the surfaces of AFTC2, AFTC3 and AFTC4. Although each crack was treated separately here, the arrows that mark the more prominent origins indicate that each crack was made up of several small cracks that had joined.

3 General fractography

A scanning electron microscope montage of a section of the centre of crack AFTC1, from the surface of the flange to the end of the cracking is shown in Fig. **6**. In this Figure it can be seen in the region encircled by the white dashed line that the crack progression marks appear to be spreading out as the crack gets deeper indicating crack growth rate acceleration. Whereas the areas encircled with black dashed lines appear to be growing at about the same rate.

The multiple initiation sources from which this crack and cracks AFTC2, AFTC3 and AFTC4 started were all etch pits beneath the IVD coating. Before breaking the crack open, it was thought that these types of cracks were initiated from fretting damage to the surface, but clearly this is not correct and the discontinuities from which these cracks grew had been present since the former entered service. For this reason, it is most likely that the cracking initiated at the commencement of service (see [2]) and this fact was used in the next section to help develop the crack growth curve.

Away from the origins, the surface of each of the cracks displayed well-defined fatigue progression markings. An examination of these markings on AFTC1 with the optical microscope revealed that there were many dark and light bands that were similar in appearance, and that these bands grew steadily further apart initially and, as indicated in Fig. **6** were more evenly spaced towards the end of the cracking. Although the dark bands were randomly distributed in terms of the distance between each other, they were reasonably consistently spaced over the depth of the cracking, although some damage in the form of light corrosion (see below) to the crack surface up to about half the depth, see Fig. **6** and Fig. ***7*** did make the banding just before the end of this area more difficult to discern. The positions of the bands were measured to allow an indication of the crack growth against an unknown time base since the key events that caused them were not clear. The measurement results are presented in the next section.

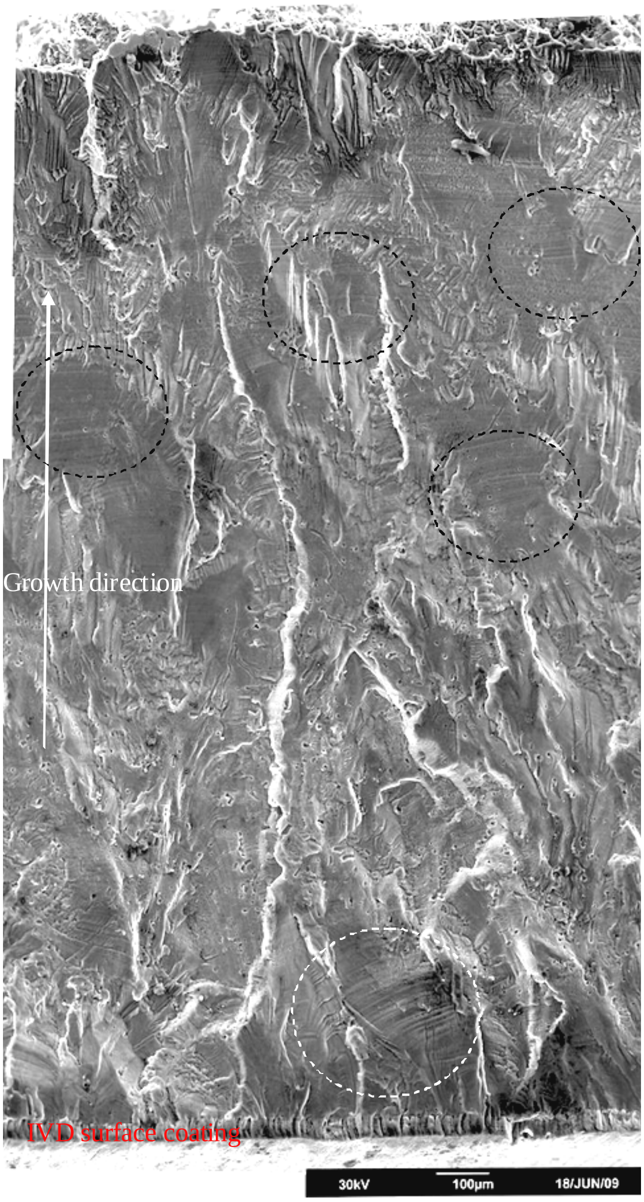

Fig. **6** A montage of a section of the centre of the AFTC1 crack, from the surface of the flange to the end of the cracking. In the region encircled by the white dashed line, the crack marks appear to be spreading out indicating acceleration, whereas in the areas encircled with black dashed lines, the crack appears to be growing at about the same rate.

Information about the long maintenance down times that this aircraft was subjected to was provided by the RAAF in order to see if these times could be matched to some of the more obvious corrosion markings. An inspection of AFTC1 revealed that there were a few prominent features that was thought to be related to down times rather than flight loading. It was hoped that these would help in pegging the crack growth curve to a time scale. The features are marked on Fig. *7* and they were more evident prior to cleaning the fracture surface. The features consisted of a region of light corrosion attack marks (up to the white dashed line on the Figure), an apparent boundary where the crack is deflected (black dashed line) and a clean band of growth at the end of the crack. The deflection is difficult to observe in a 2D representation so a topographical representation of a section of the crack is shown in Fig. ***8***. At the start of the crack's plane deflection, there was a narrow dark band of growth that appeared to have been darkened by environmental factors rather than the loading. It is postulated that this region may have been the result of a considerable period of down time since this is when these cracks would have been subjected to a humid hot environment (RAAF base Williamtown) for the longest uninterrupted period.

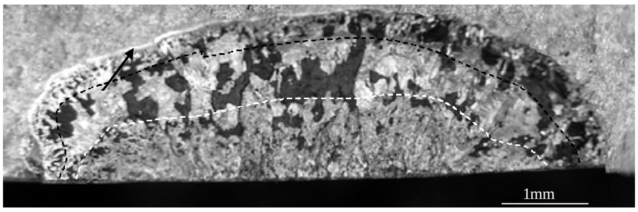

Fig. *7* A view of AFTC1 prior to cleaning showing an approximate boundary of light corrosion attack (white dashed line), the approximate boundary where the crack is deflected (black dashed line), see Fig. 8, and a clean band of growth at the end of the crack that appears in this picture as a thin bright line at the end of the fatigue crack.

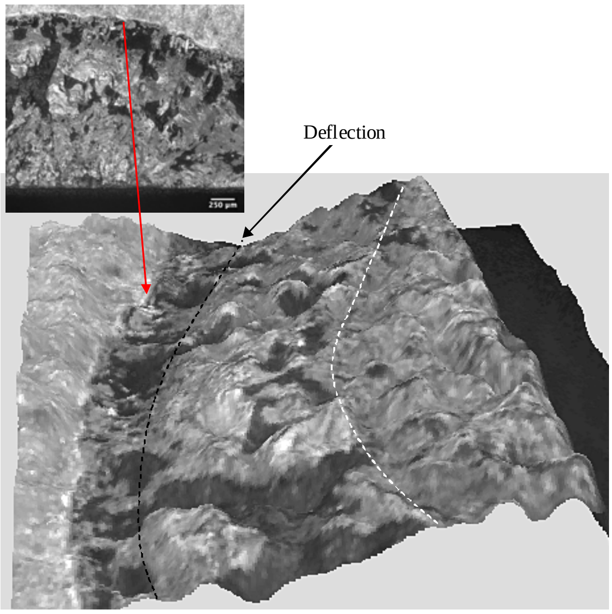

Fig. **8** A view of a section of AFTC1 prior to cleaning. The view is a topographical representation of the area of the crack's surface shown in the insert. The boundary of the extent of the light corrosion attack (white dashed line), the approximate boundary where the crack is deflected, proceeded by a dark band (black dashed line) and a clean band of growth at the end of the crack (arrow) are marked.

4 Quantitative Fractography

Quantitative fractography was performed for AFTC1 only. The crack's surface displayed well defined fatigue progression markings. An examination of these markings revealed that there were many dark and light bands that were similar in appearance, and that these bands initially grew steadily further apart, and as the crack grew larger they seemed to become more consistently spaced. These distinct groups of progression markings were measured, although the appearance of these markings did change as the crack grew deeper. Nevertheless, it was thought that the marks measured were made by similar loading events in service and were therefore representative of the growth rate of the cracking over time. The markings measured are plotted on both a linear and log crack depth versus 'events' plots in Fig. 9, using an initial measured discontinuity depth (etch pit from the IVD application process) and assuming that cracking commenced when the stub entered service. The events have been scaled assuming a constant application of these events over the entire life of the stub against the reported flight hours (i.e. a repeated syllabus of mission types).

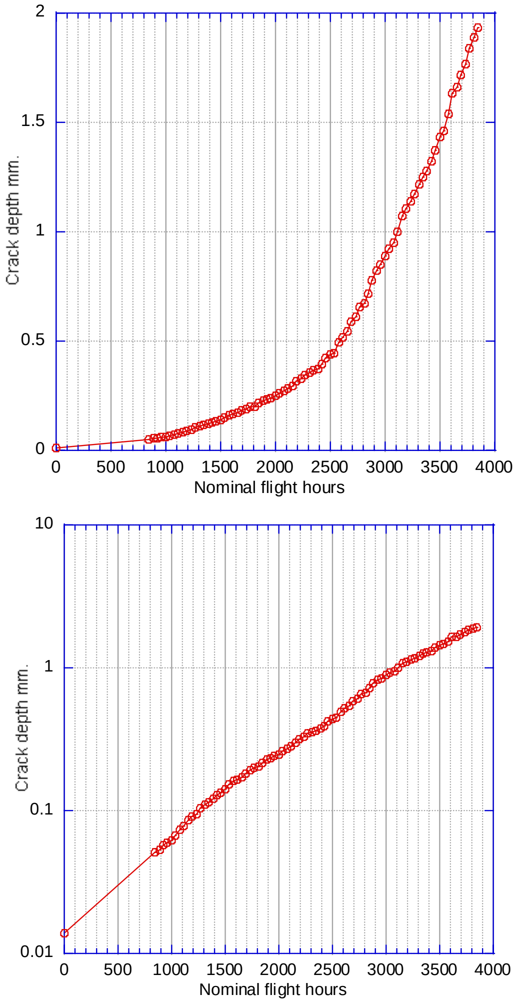

Fig. **9** The derived crack growth curves for the markings noted. These plots show the linear crack depth verses linear life and the log crack depth verses linear life.

The flight hours subsequent to which the aircraft spent the longest down times during the life of the stub former were available. It is thought that during these periods moisture entered the cracks and caused corrosion or darkening of the crack's surfaces. Since these environmental effects appear to have caused some major marks on the crack surface (two of which are identified in Fig. 7) these were aligned to the longest down times: a 291 day down-time and a 748 day down-time. Finally, a 62 day down time was noted not long before the removal of the Y598 former. It was most probable that the period following this down time accounts for the bright band of growth at the end of the crack. Placing these points on the crack growth curve gave the results shown in *Fig.* 10. An examination of these curves shows that the major marks when aligned to the major down times gave a good agreement with the proposed crack growth curve.

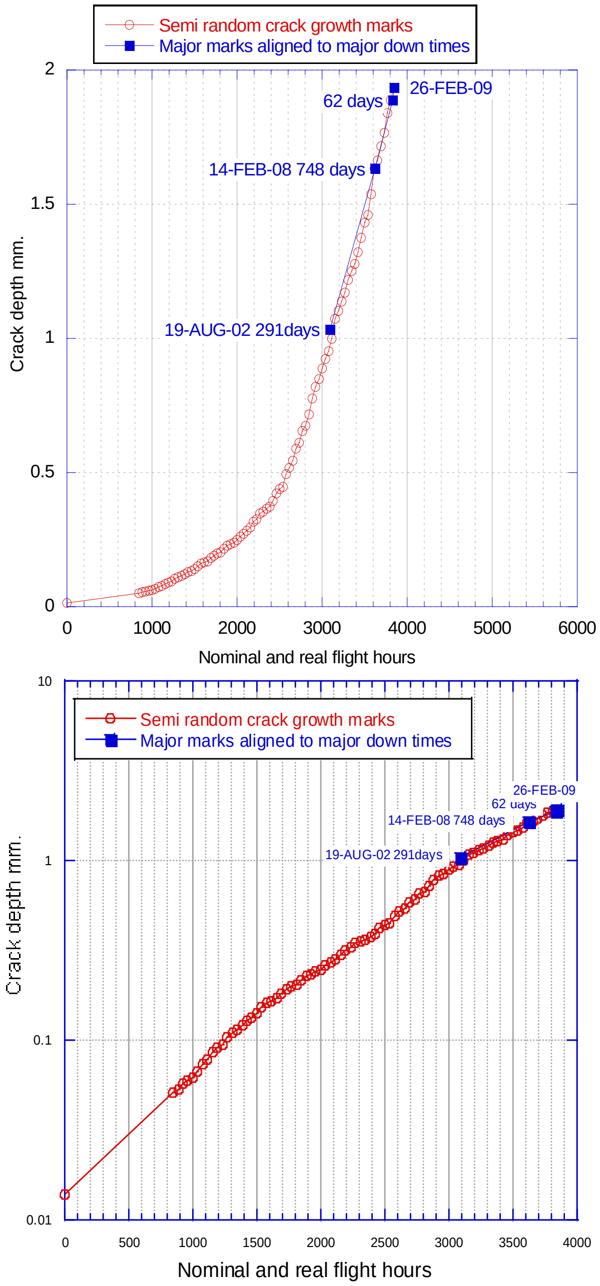

Fig. **10** The crack growth curve for the markings noted and the major marks aligned to the major down times. The agreement is good on both the linear and log representations.

5 Loading Mechanism

It appears that the early growth of the stub cracking associated with the fastener hole accelerated a little faster over the first few thousand hours of life and then almost stopped accelerating i.e. grew at a constant rate. It is consistent with loading that appears to be driving this cracking that is partially due to local bending via single shear transfer through the fastener: the schematic shown in Fig. 11 shows how the load travels through the fastener from the titanium VT fitting to the stub. A “button-shim” exists between the VT fitting and the stub and the thickness of the shim has a significant influence on the amount of bending that occurs, given that the interference fit fastener is correctly installed through the titanium and the aluminium parts. This loading along with the beneficial effect of the interference fit would explain why the cracking occurs away from the hole near the base of the shim.

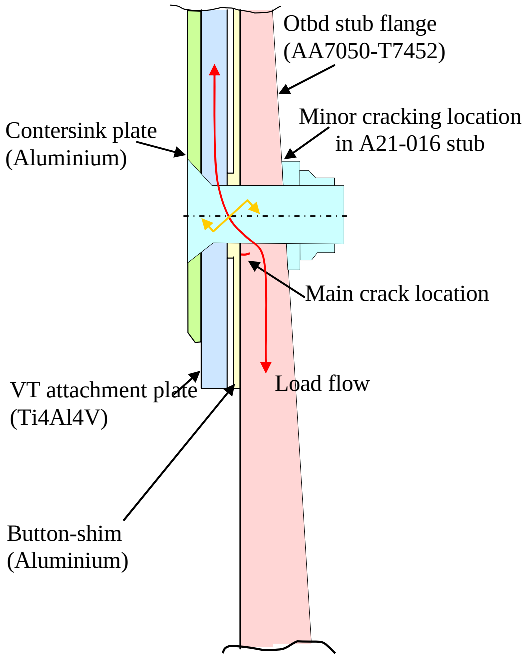

Fig. **11** A schematic of the VT fitting to stub attachment at the lower fastener hole.

6 Conclusions

A quantitative fractography examination of a crack in a vertical stub of a combat aircraft was conducted.

The stub had experienced both aerodynamic buffeting and manoeuvre loads (often in combination) and these had produced many prominent fatigue progression markings on the crack surface. By assuming that these marks were caused by similar events evenly distributed across the service life of the stub, a crack growth curve was derived. During the life of the aircraft, significant down-time periods for maintenance had occurred and evidence of corrosion was found in discrete areas of the fatigue crack’s surface that suggested that they were the result of these periods of inactivity. By assuming that the corrosion occurred whilst the aircraft was on the ground, it was possible to correlate the crack growth curve to known flight hours. From knowledge of when these down-times occurred, the crack growth curve was calibrated to actual flight hours. This investigation provided useful data for lifing of other stubs and for setting inspection intervals.

References

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[2] Molent L, Barter SA and Wanhill RJH. The Lead Crack Fatigue Lifing Framework, Int Fatigue; 33 (2011) 323–331.

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