FATIGUE INITIATION AND CRACK GROWTH BEHAVIOUR IN GLARE FROM THE AIRBUS MEGALINER BARREL TEST

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Abstract

The MegaLiner Barrel (MLB) pressure cabin test was part of the Airbus 380 structural fatigue evaluation programme. The test was discontinued after 45,402 simulated flights. Samples were designated for teardown, and the NLR is carrying out teardowns of some GLARE (GLAss REinforced aluminium laminate) panels. The teardowns include Non-Destructive Inspection (NDI), and some fractographic analyses of detected fatigue cracks. This paper presents fractographic results for a GLARE window area.

1 Introduction

The MegaLiner Barrel (MLB) test was initiated by Airbus Deutschland in the mid-1990's to study the fatigue behaviour of a double-deck fuselage configuration. Several design solutions, structural materials and joining methods were investigated, and the applied fatigue load spectrum was set at a level high enough to obtain fatigue damage. The results contributed to the subsequent robust design of the Airbus 380.

The test was discontinued after 45,402 simulated flights. Stork/Fokker Aerospace then specified a programme of teardown and additional fatigue testing for GLARE (GLAss REinforced aluminium laminate) panels from several key locations of the MLB. This programme is being done by the NLR, and includes several Non-Destructive Inspection (NDI) techniques and some fractographic analyses of detected fatigue cracks.

This paper presents fractographic results for a GLARE window area. The fractographic analysis had the following objectives:

- Verification of NDI techniques.
- Establishing fatigue cracking patterns.
- Determining fatigue initiation locations.
- Estimating fatigue "initiation" lives and crack growth behaviour for *lead cracks*.
- Providing data to verify and improve fatigue crack growth models for GLARE.

2 The GLARE Window Area

Figure 1 shows the GLARE window area after its removal from the MLB. The windows are A340 shape rather than the A380 elliptical ones. This difference is unimportant for the present work. This window area was in the lower row of

Fig.1. GLARE window area cut from the MLB

starboard windows, midway along the MLB. The basic structure is a GLARE 3-7/6-0.3/0.4 skin fastened to die forged 7175-T73 aluminium window frames by press fit 3/16" (4.76mm) Hi-Loks. The GLARE code means seven 2024-T3 aluminium layers 0.3mm thick (five inner layers) or 0.4mm thick (two outer layers), interleaved with six glass fibre layers.

3 NDI Summary

Figure 2 gives an overview of the NDI results after fastener removal and separation of the GLARE skin and aluminium window frame. These results were obtained from eddy current pencil probe rotor inspections of the fastener hole bores. The GLARE contained many more

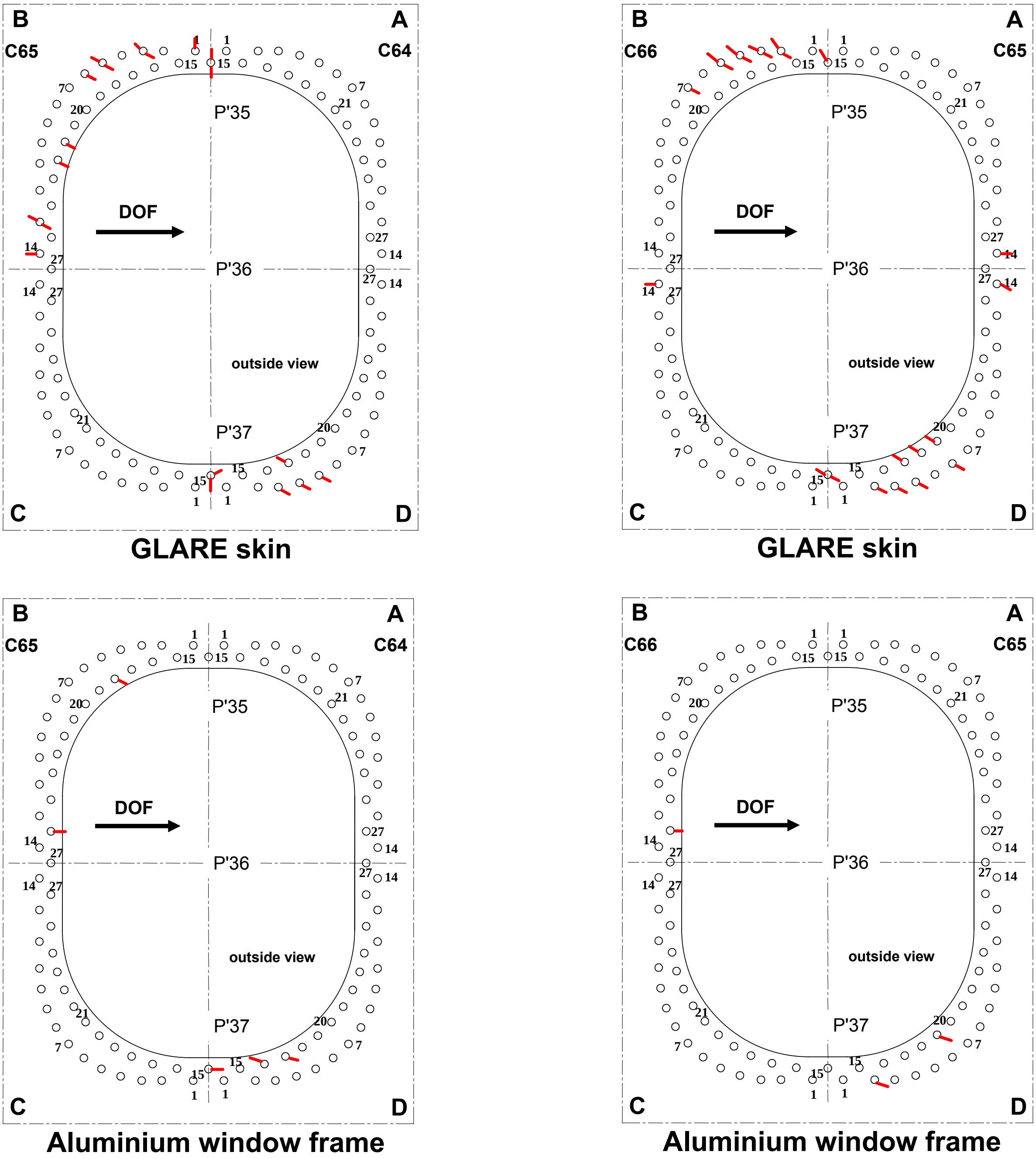


Fig.2. Overviews of the crack indications from NDI of the fully disassembled GLARE skin and aluminium window frames. **DOF** = Direction Of (simulated) Flight

crack indications than the window frames, mostly in the **B** and **D** quadrants. These were the quadrants largely subjected to shear loads during the MLB fatigue test.

4 Low magnification fractography

4.1 NDI Verification

The NDI-indicated fastener holes were opened up for optical fractography using the procedure shown in figure 3. This verified the NDI for all GLARE fastener holes with maximum crack lengths ≥ 0.24mm. Also, there were only 4 false calls for a total number of 216 inspected fastener holes. These results demonstrate that our NDI capability will detect most cracks in GLARE during teardown.

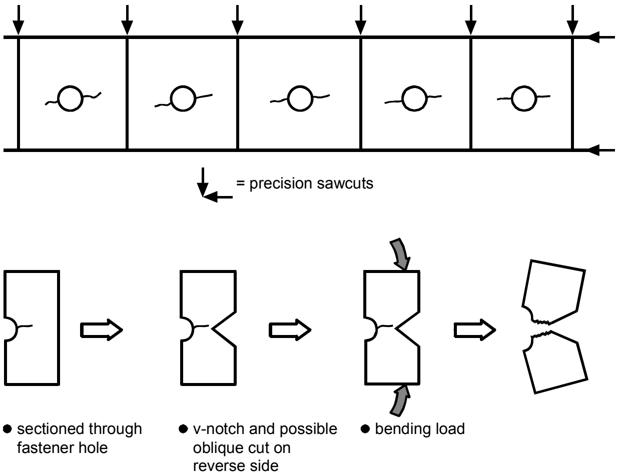


Fig.3. Procedure for opening up cracks.

4.2 GLARE Cracking Patterns

Figure 4 gives representative examples of the cracking patterns in the aluminium layers of the GLARE skin. Most cracks were in the fastener hole bores, the largest mainly in layer 5. Only a few cracks grew from the countersinks, and only in layer 3.

The R.H. example in figure 4 shows the fastener hole (B4, C65-C66) with the largest GLARE cracks. These were 0.91 and 0.95mm long. The crack in layer 6 was selected for detailed fractography.

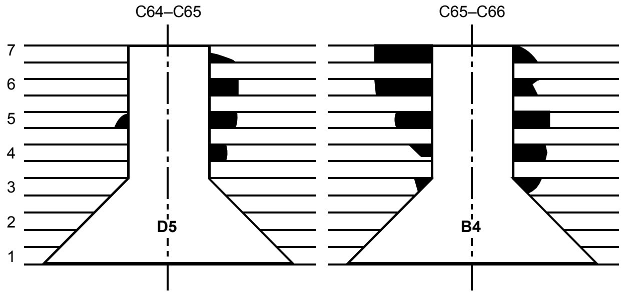


Fig.4. Examples of GLARE cracking

The R.H. example in figure 4 shows the fastener hole (B4, C65-C66) with the largest GLARE cracks. These were 0.91 and 0.95mm long. The crack in layer 6 was selected for detailed fractography.

4.3 GLARE Fatigue Initiation

The smaller cracks in figure 4 show that they began from one or both corners of an aluminium layer. This was also the case for all the other cracked fastener holes in the GLARE skin. Thus the most likely causes of fatigue crack initiation, besides the severity of the applied fatigue load spectrum, are the stress concentrations provided by these corners.

However, this does not explain why many more cracks began in the fastener hole bores (layers 4 – 7) rather than in the countersinks (layers 1 – 3), where there are so-called “knife edges”. It is possible that local secondary bending favoured fatigue initiation in the fastener hole bores.

Support for this possibility comes from the window frame cracks. These were all corner cracks with maximum dimensions along the fastener hole bores.

5 Detailed Fractography

5.1 Approach and objectives

- Use the largest window frame crack to check the “readability” of the MLB fatigue load spectrum.
- Estimate and compare the fatigue “initiation” life and crack growth behaviour for this *lead crack* and the largest

“readable” crack in the GLARE aluminium layers. This “readable” crack was slightly shorter than the GLARE *lead crack*: 0.91mm compared to 0.95mm, see figure 4 and the accompanying text.

- Provide data to verify and possibly improve fatigue crack growth models for GLARE.

5.2 Practical details

The GLARE fracture surfaces were exposed to a low-temperature oxygen plasma for 30 – 45 minutes. The adhesive degraded completely, enabling separation of the aluminium and glass fibre layers. However, the sample temperature remained below 60 – 80°C, thereby avoiding heat damage (oxidation) of the aluminium fatigue fracture surfaces.

Fractography was done using a Field Emission Gun Scanning Electron Microscope (FEG-SEM). The FEG-SEM’s high resolution is essential for studying fatigue at low growth rates.

5.3 MLB Fatigue Load Spectrum

The MLB test spectrum was defined by Wagner [1]. There are eight basic flight types, occurring with different frequencies in a block of 2150 flights, which was repeated until the end of testing.

The spectrum is complex in detail, but for the present purpose it can be regarded simply in terms of the maximum load in the window area during each simulated flight. The maximum loads represent internal pressure + shear loads that are mainly due to the maximum vertical gust loads in each flight.

Table 1 gives the positions of the severest flight types A – C in each flight block. The fractographic analyses in subsections **5.4** – **5.6** relied almost entirely on crack front markings due to these flight types.

Table 1 Severest flights in the MLB spectrum

A	B	C
1379	58,127, 196,1094	139,148,366,494,671,956,1026, 1392,1549,1785,1854,1928

5.4 Spectrum Fractographic “Readability”

The largest crack in the aluminium window frames was at fastener hole D19 in window area C65-C66, see figure 2. This crack was quarter-elliptical with length 1.68mm normal to the fastener hole bore. This direction was selected for fractographic analysis.

FEG-SEM fractography showed that fatigue fracture was a mixture of faceted and mainly continuum-mode areas. The latter contained evident crack front markings due to the peak loads in severe simulated. flights.

Figure 5 gives an example of identifying the severe simulated flights, notably flight types **A**, **B** and **C**. The crack front markings from these flights were mostly sufficient for tracing fatigue crack growth back to a small crack length. However, the fainter crack front markings from **D** type flights helped in checking the numbering of **B** and **C** type flights. In general, the fractographic “readability” was excellent.

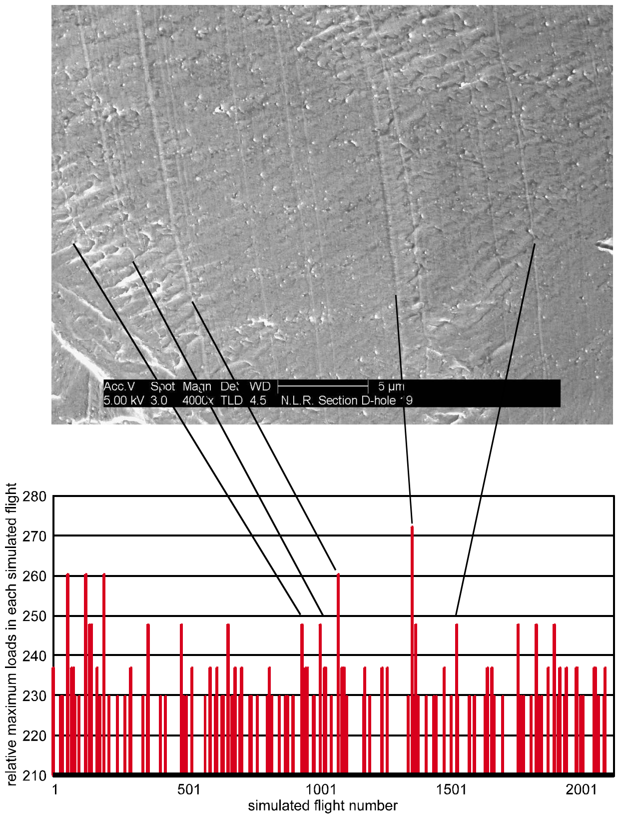


Fig.5. Example identification of severe flights from crack front markings by peak loads

5.5 Window Frame Crack Analysis

The excellent fractographic "readability" of the largest window frame crack enabled tracing crack growth back from the end of the MLB test to a crack length of 0.15mm. This was necessary to obtain the following information:

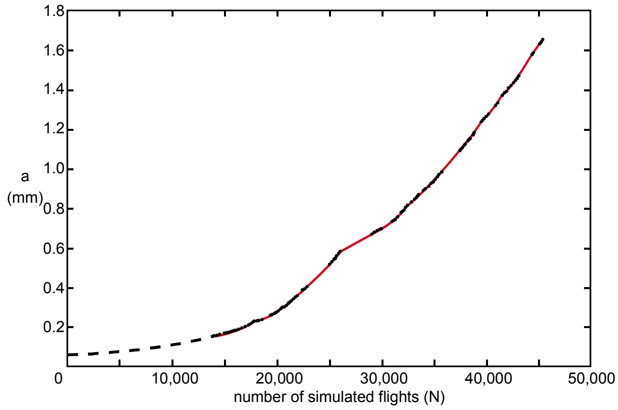
- Fatigue crack growth curves.
    - a *versus* N
    - da/dN *versus* a*
- An estimate of fatigue "initiation" life.

where a is the crack length in the selected direction, N is the number of simulated flights, da/dN is the fatigue crack growth rate, and a* is the mean crack length for the crack growth interval used to calculate da/dN.

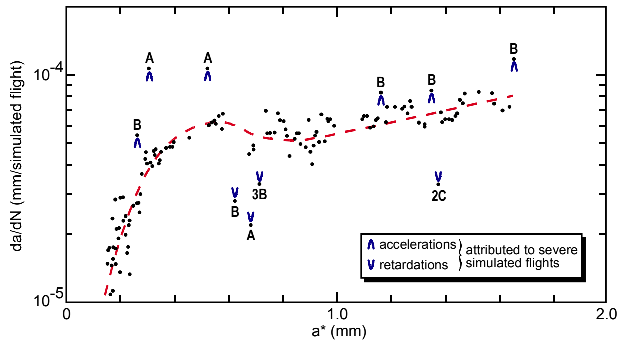
Figures 6a and 6b show the curves of a *versus* N and da/dN *versus* a*, respectively. Both show the effects of severe simulated flights, pointed out explicitly in figure 6b. Most of these effects appeared to be transient.

However, beginning at a crack length of about 0.6mm there was a persistent retardation of fatigue crack growth. This could be due to termination of the "short crack effect". This effect is well known, and is generally attributed to no fatigue crack closure in cracks smaller than about 0.5mm. Thus once the window frame crack grew beyond 0.5mm, closure-induced retardation due to peak loads in severe simulated flights would have become possible.

The a *versus* N curve in figure 6a suggests that the fatigue "initiation" life was zero, and that there was an initial crack size of about 0.06mm. In fact, the crack initiated from a fretting scar due to fastener movement against the bore of the fastener hole [2]. This explains the effectively zero fatigue "initiation" life [3] and also the indication of an initial crack size, which was most likely due to the fretting scar.



(a) Crack length *versus* number of simulated flights

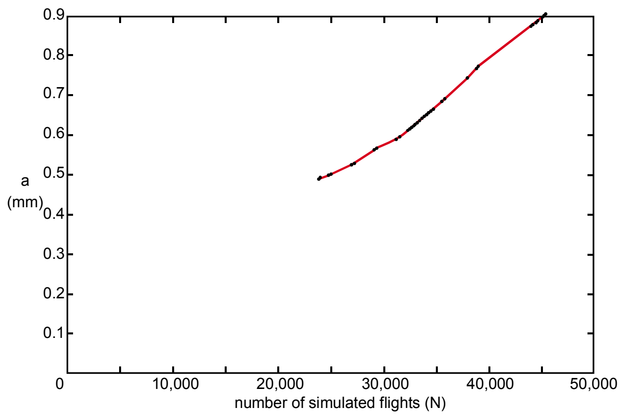


(b) Crack growth rates *versus* mean crack lengths

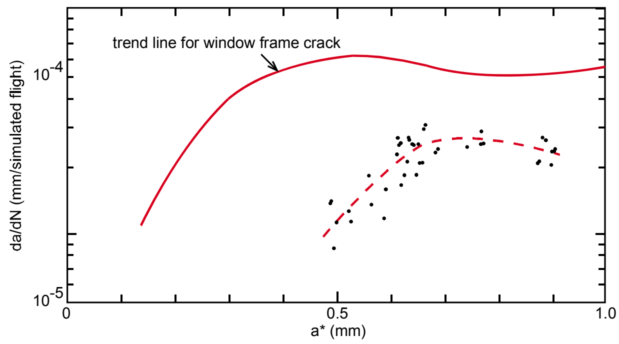
Fig.6. Window frame crack analysis

5.6 GLARE Crack Analysis

As stated in subsection 4.2, the selected crack was in aluminium layer 6 of fastener hole B4 in window area C65-C66. Figure 7 presents the same types of crack growth curves as those for the window frame crack. The data are limited, but enough to show a growth rate "plateau" at



(a) Crack length *versus* number of simulated flights



(b) Crack growth rates *versus* mean crack lengths

Fig.7. GLARE crack analysis

about 50% of that for the aluminium window frame.

Back-extrapolation of the a *versus* N curve in figure 7a is unfeasible, owing to the limited data. The crack could not be traced back to less than 0.45mm, owing to too closely-spaced crack front markers. Hence an estimation of the fatigue "initiation" life is not possible.

5.7 GLARE Crack Growth Models

One of the main objectives of this investigation was to provide data to verify and possibly improve current fatigue crack growth models for GLARE. However, all the GLARE aluminium layer cracks were much too small to contribute to this objective: see, for example, the models proposed by Toi [4], Wu and Guo [5], and De Koning [6].

On the positive side, these teardown results demonstrate the high fatigue damage tolerance capability of the MLB GLARE skin. This is supported by the fact that the applied fatigue load spectrum was set at a level high enough to obtain fatigue damage during the MLB test.

6 Conclusions

A GLARE window area from the MegaLiner Barrel (MLB) pressure cabin test was subjected to Non-Destructive Inspection (NDI) and teardown. The window area consisted basically of a GLARE skin fastened by press fit Hi-Loks to die forged aluminium alloy window frames.

Fractographic investigation of the NDI-indicated fastener holes gave the following results:

- Low-magnification fractography verified the NDI for all GLARE fastener holes with maximum crack lengths $\geq$ 0.24mm. Also, there were only 4 false calls out of a total of 216 inspected holes. These are excellent results, demonstrating high NDI capability.
- Most of the cracks in the GLARE skin were in the fastener hole bores rather than the countersinks. The cracks began from one or both corners of an aluminium layer, whether in the bores or countersinks.
- The preference for GLARE cracking in the fastener hole bores is possibly due to local secondary bending. The window frame cracks support this, since their maximum dimensions were along the hole bores.
- The fractographic "readability" of the MLB fatigue load spectrum was excellent for the largest window frame crack, but less so for the largest readable crack in the GLARE aluminium layers. The crack growth rates for the aluminium layer crack were much lower, making resolution of the crack front markings more difficult.
- The largest window frame crack was traced back to 0.15mm. The fatigue "initiation" life appeared to be zero, with an initial crack size of about 0.06mm. These results are best explained by the fact that the crack initiated from a fretting scar.
- The largest "readable" GLARE aluminium layer crack could not be traced back to less than 0.45mm. This made it unfeasible to estimate a fatigue "initiation" life. Nevertheless, it was evident that this crack grew significantly slower than the largest window frame crack.

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