SIMULATION TOOLS APPLICATION
IN ITALIAN AIR FORCE FACILITIES: AN EXAMPLE

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ABSTRACT

Besides usually performed experimental activities, such as SEM and metallographic analysis, the Chemistry Department of Flight Test Center has reached a know-how on Failure Investigation Analysis (FIA). Italian Air Force is growing in carrying out post-project's evaluations on structural parts just in service. The Finite Element Analysis (FEA) is a helpful tool used to understand the structure's behaviour and their breakages.

In this paper, the failure occurred on the bottom side of a main landing gear swinging lever showing a typical fatigue morphology.

During this FIA, an ALGOR FEA has been carried out to confirm the origin of the fracture near the most stressed area and to determine the stress value on that location zone.

Further more, by the direct measuring of spaces between two following beach marks located on the fractured surface (SEM observation), it has been possible to simulate the mechanic fracture propagation, by means of AFGROW analysis, using a load spectrum that fits observed spaces.

These experiments and simulations allowed to understand the way because the part didn't comply the original safe life evaluation requirements, demonstrating the need to improve the actual procedures with a damage tolerance philosophy.

1. INTRODUCTION

Since more than 20 years ago, the Chemistry Department of Italian Air Force Flight Testing Centre has been working on the theoretical and experimental analysis of structures and materials used by Italian Defence Organization, studying in depth aeronautical components.

One of the most important part of this activity has been focused on failure analysis, in order to investigate failures and inconveniences, and to avoid that they could repeat again.

This kind of activity requires many instruments that allow a lot of exams, such as fractography, hardness evaluation and metallographic analysis.

Besides these tecnological determinations, in the last years, because of the diffusion of structural analysis software, Chemistry Department activities have grown up enhancing personnel skill by means of numerical simulation competences.

This engineering specific staff is an helpful aid for the failure analysis and, generally speaking, is an useful tool in understanding materials' behaviour.

In this paper, some structural numerical simulations have been exposed; they allowed us to give an interpretation on crack phenomenology, suggesting the need of changes in design philosophy, getting over safe life criterion and highlighting the damage tolerance strategy.

2. FAILURE INVESTIGATION ON MAIN LANDING GEAR SWINGING LEVER

This failure investigation on the main landing gear swinging lever has been commissioned to the Chemistry Department by A.N.S.V. (Agenzia Nazionale per la Sicurezza del Volo).

The swinging lever has been kept on service 17 years, totalizing 26139 Flight Cycles (CSN), 7177 less than the its original fatigue life of 33316 cycles fixed on a safe-life criterion.

Since last overhaul inspection, 8 years before failure, the part has been flying 12765 cycles (CSO).

The swinging lever (red part in figure 1) is a hallow forged component of the main landing gear, connecting the wheel axle with the leg structure (yellow part in figure 1) and the shock absorber (green part in figure 1).

The fracture lies on a plane, which is transversal to the longitudinal swinging lever axle, near the shock absorber lug (figure 2).

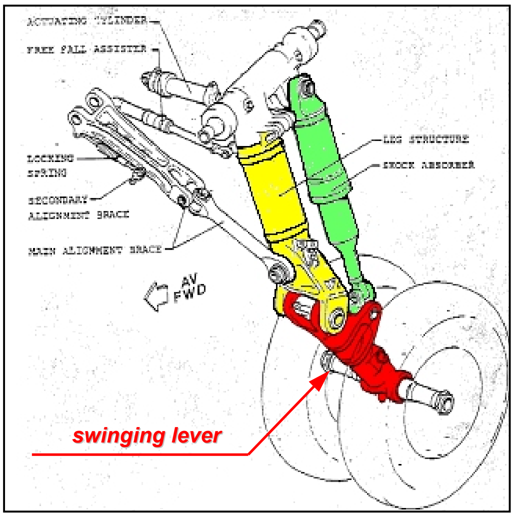

figure 0

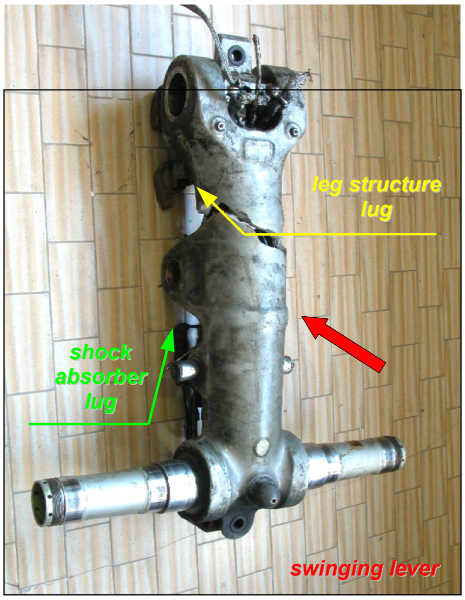

figure 2

2.1 Visual exams

On the fracture surface three different zones have been found (figure 3):

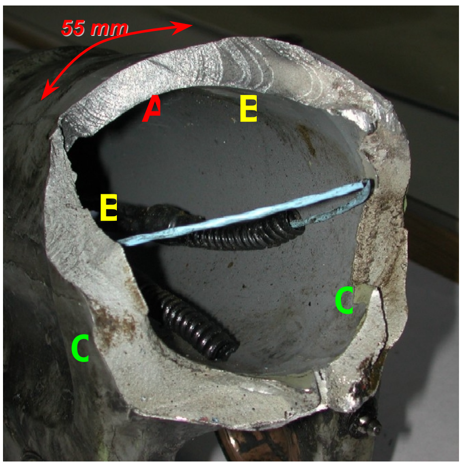

figure 3

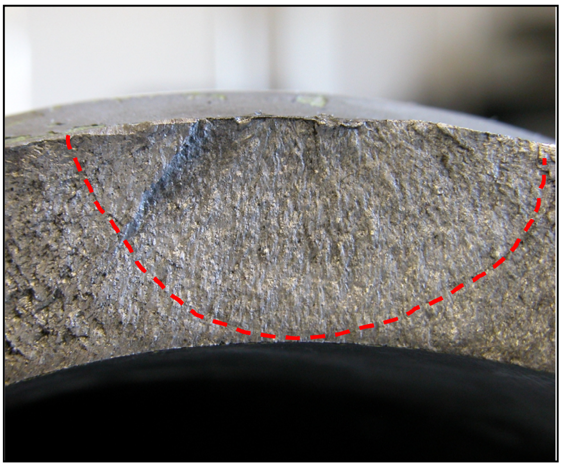

figure 4

- **Zone A**: length about 55 mm and depth as the thickness of the part, 13 mm (figure 4). On the lucid and fine grained surface it has been observed semi-elliptical lines as beachmarks typical of a fatigue propagation (fi

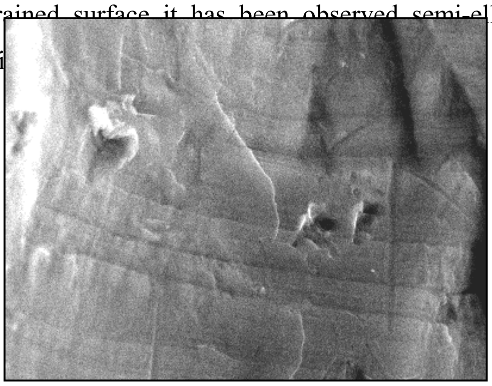

figure 5: 1.5 mm from onset (2000X)

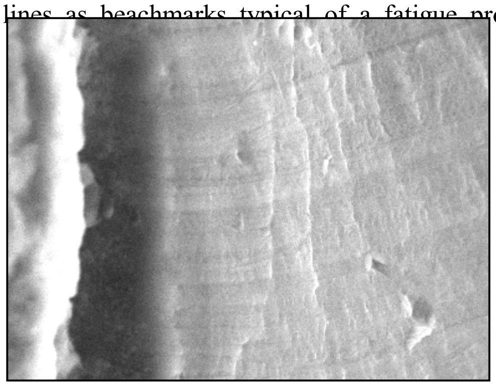

figure 6: 4 mm from onset (2000X)

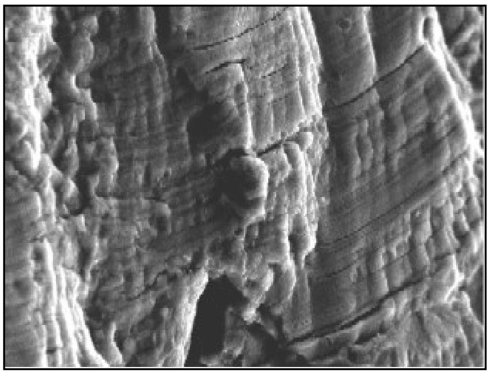

figure 7: 8 mm from onset (1000X)

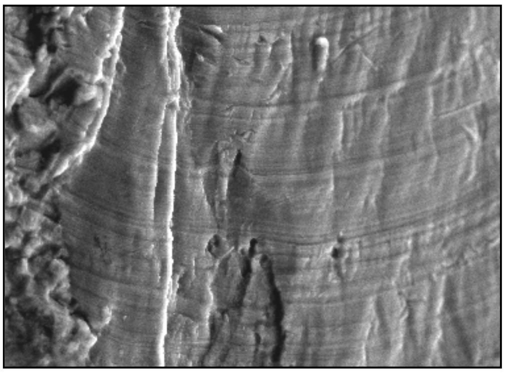

figure 8: 10 mm from onset (500X)

By the beachmarks, it is possible to point out the onset on two defects on the external surface, one each other far 2 mm and near the vertical symmetry axle of swinging lever (figure 9) [3].
Metallographic exams on the radial section of the fracture surface, showed a typical forged part microstructure, containing second phase precipitates at the grain boundaries. Furthermore, there are some defects near the onset with a maximum depth of 600 μm (figure 10).

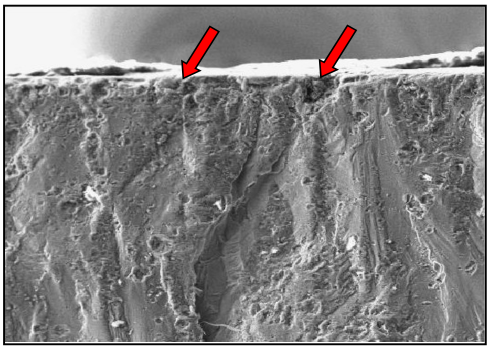

figure 9

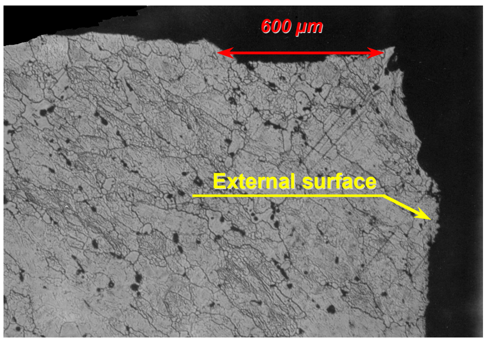

figure 10

- **Zone B**: it is a multi-facial zone with bright and dark areas alternation, due to fatigue and overload; this area represents the instable propagation region and begins when the crack depth reaches the internal side.

- **Zone C**: gross grained, it shows only dimples and represents the final overload zone.

2.2 Chemical and hardness analysis

The typology of the lever's alloy has been determined by emission's spectrometry. It is an Aluminium Alloy AA 7010 whose hardness, calculated by Rockwell method (indenter with a steel sphere 1/16'' of diameter, applied load 30 Kg), is about HR30T 74.

2.3 EDS exam

It has been conducted near the onset, where the deepest defect has been observed (figure 11a). The analysis showed an anomalous Silicon concentration depth about 300 µm (red zone in figure 11b) [4] [5].

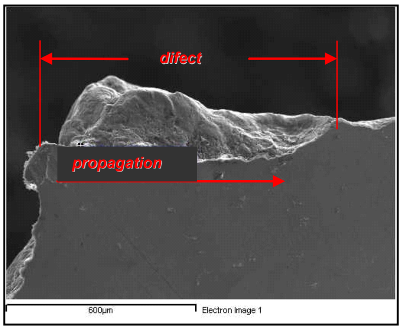

figure 11a

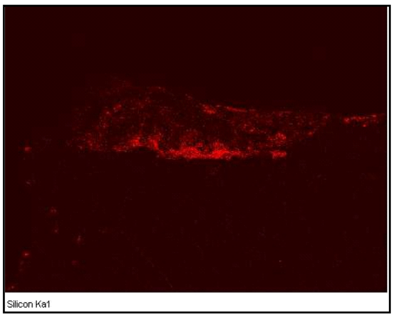

figure 11b

2.4 Finite Element Analysis

The goal of this simulation has been to find the more stressed zone in the swinging lever. Stress analysis has been carried out by an ALGOR FEA, assuming the leg structure (A) and the shock absorber (B) lugs as hinge points and the weight static load as applied on the axle lug (C); the results confirmed that the origin of the fracture effectively found overlays on the most stressed area. The stress value is around 140 MPa.

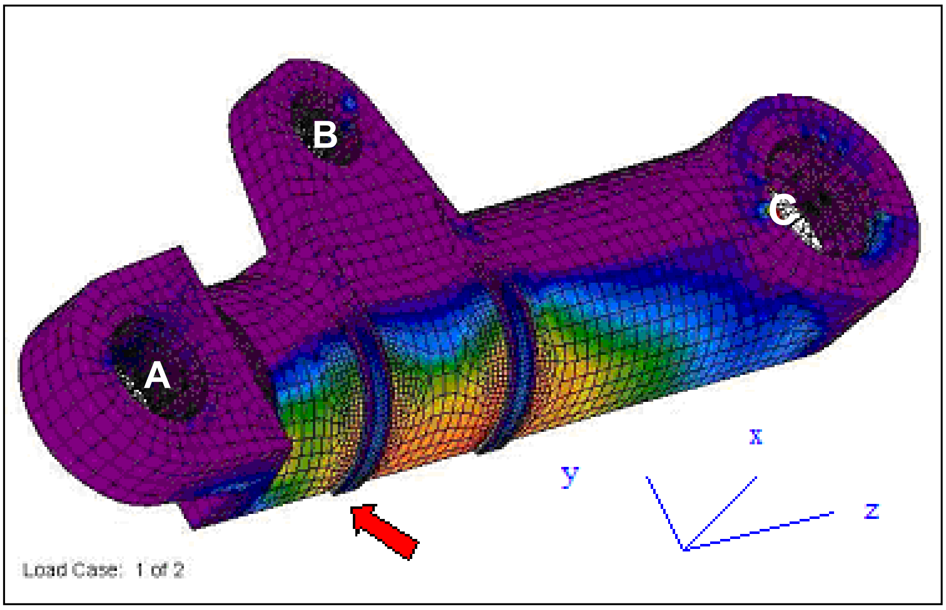

figure 12

2.5 Mechanic fracture propagation simulation

The distances measured between two following beachmarks (figure 5 to 8) were plotted vs. the crack depth, figure 13 [6] [7]. The point distribution was fitted by an exponential curve, whose integral, calculated between 1.5 and 12.5 mm, measured about 3500 flight cycles as critical value to produce a catastrophic failure. The cycles needed to propagate the crack till the catastrophic failure were much more than 3500 because of the non-linear trend on the semi-log curve in early stage of propagation, figure 14.

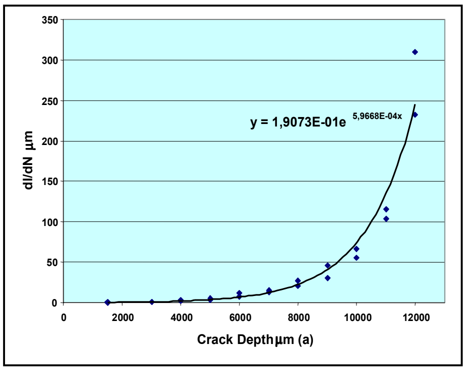

figure 13

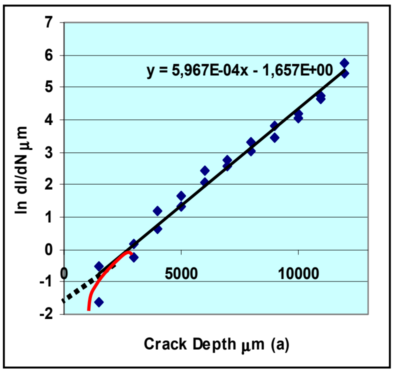

figure 14

The flight cycles has been calcutated by an AFGROW analysis, simulating the crack propagation. It was found a load spectrum (S_{mean}=140 MPa by ALGOR FEA) that could fit the measured exponential curve, figures 15 and 16: according to this simulation, assuming a starting defect in the range of 200-300 µm, the flight cycles number was estimated of 20000, in the same order of magnitude shown by the real flight cycles totalized on the swinging lever.

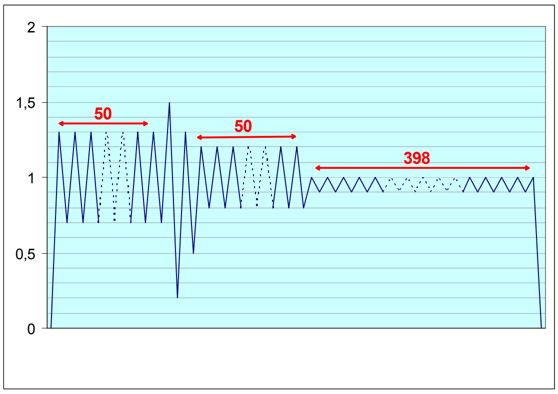

figure 15

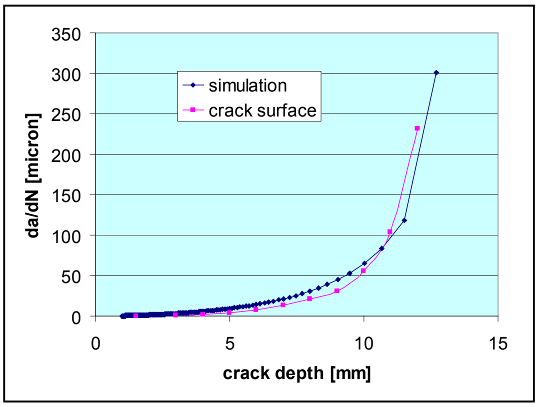

figure 15

By this simulation has been clarified that this crack has grown prevalently in a *propagation stage* (LCF), with a *nucleation stage* very short or absent, in spite of the quite low loads (HCF) acting on the swinging lever [8].

2.6 Final considerations

Chemical and microstructural characteristics have been resulted as project's specifications require; in addition, the absence of corrosion phenomena, allow us to assert that the crack's cause does not lie in the swinging lever's alloy selection.

No geometric stress concentration factors, neither pit corrosion on the lever, neither superficial damage able to cause the only propagation stage have been observed on the crack surface; the anomalous Silicon concentration seemed to be the only factor able to push the system to get over the nucleation stage. This is confirmed by the AFGROW simulation, which assuming a defect of 300 µm (see the size of the Silicon concentration), gives a number cycles result that is compatible with the counted flight cycles.

Afterwards, considering that defects were probably generated in the swinging lever's production stage, it was stated that the part did not comply the original safe life evaluation requirements, demonstrating the need to improve the actual procedures with a damage tolerance philosophy [9].

3. CONCLUSION

By the example exposed above, the need of improving more and more simulation analysis in running procedures has been demonstrated. The Chemistry Department is extending its own capabilities toward the numerical structural analysis, in order to enrich as well as possible the failure analysis resources in a wide range.

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