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Fatigue, residual strength and non-destructive tests of an aging aircraft's wing detail

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ABSTRACT

This study concentrates on fatigue, residual strength and non-destructive tests of an aging aircraft's wing detail of the Finnish Air Force's Hawk Mk.51 jet trainer. The studied detail was the integral stiffener with a drain hole near the wing root. Fatigue tests were deemed necessary to verify experimentally the analytically observed short fatigue life, significant crack growth rates and eventually to re-assess the detail's inspection period for the fleet jets. The results of the study have been utilized e.g. at the complementary type approval accomplished for the Finnish Air Force's Hawk.

1. Introduction

The Finnish Air Force (FIAF) has been operating their Hawk Mk.51/Mk.51A jet trainer fleet since the 1980s/1993s. As the fleet gets older, the fatigue related issues have become more acute. This study concentrates on fatigue, residual strength and non-destructive tests of an aging aircraft's wing detail. The studied detail was the integral stiffener with a drain hole near the wing root of the Hawk Mk.51. The Mk.51A is not considered in this study because it has the modified wing with removed stress raisers (e.g. drain holes), strengthened structural details and changed materials. The results of the analytical life estimation calculations are introduced, too. The results of the study have been utilized e.g. at the complementary type approval accomplished for the FIAF's Hawk.

Fatigue tests were deemed necessary to verify experimentally the analytically observed significant crack growth rate, high stress levels, short total life cycle and eventually to re-assess the detail's inspection period for the fleet jets. Parallel to the above studies, the service inspections of the fleet aircraft resulted in a crack indication within the Mk.51 drain hole region. The crack indication was made before the certified safe life of the wing while no known repair method existed. According to the CSI (company structural instruction issued by the OEM) the wing with crack(s) in this location is not airworthy. Thus, the wing was removed from service.

2. Background and objectives

For fatigue test purposes described above, eight small-scale and six component test specimens were manufactured from a retired wing of a Hawk Mk.51 aircraft.

Small-scale test specimens were primarily used for the purpose of material properties' re-evaluation. To achieve an adequately comprehensive view of the desired material properties, both constant and variable amplitude tests were performed for small-scale specimens. In the presented study, no material tests or comparisons were carried out between aged and virgin aluminium.

Only variable amplitude tests were performed for the component specimens. Component tests were desired to bring light for critical crack size, crack growth rate and eventually non-destructive inspection (NDI) interval. According to the CSI the NDI kick-off point, interval and method are presented in Table 1 (FI = Fatigue Index, FH = Flight Hours). The calculation of the fatigue index is based on the average aircraft mass and the G level exceedances. All Hawk jet trainers have a G-counter which registers the exceedings of the G levels of the flights. 68 FI is the certified safe life for wing of the Hawk Mk.51.

Non-destructive tests were also carried out to evaluate the initial, critical and smallest detected crack size.

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Table 1
Non-destructive inspection program of the studied detail [9]

Kick-off	Interval	Method	NB
[FI]	[FH]		
41	250	Eddy Current	Both rotating and surface probe

3. Specimens

The test specimens were cut from two retired wings. Eight small-scale test specimens were cut from the right wing which had suffered 21.3 FI. One of the component specimens was cut out from the same wing as the small-scale specimens and five component specimens were cut out from another wing which had suffered 60.0 FI.

3.1. Small-scale test specimens

The small-scale specimens were cut out from stringers 1–4 between ribs 1–3 (Figs. 1 and 2). The stringers, ribs and bottom surface of the wing form the integrated structure. The bottom surface side of the specimens was machined to constant dimensions. Finally the machined surfaces were polished. The holes were drilled for the specimens without any finishing treatment, thus corresponding better to real drain holes removed from sealing compound. The width, thickness, length and hole diameter of the specimens were about 20 mm, 6.7 mm, 280 mm and 5.1 mm, respectively.

3.2. Component test specimens

The component specimens represent drain holes where the rib 2 crossed the stingers 3–5 (Fig. 1 and 3a). The nominal main dimensions of the component specimens are presented in Table 2. Fig. 3b reveals the meaning of the different indexes of Table 2. The indexes x_C and y_C specify the location of the center of gravity.

4. Test program and test facility

4.1. Specimen material

The material of the specimens is aluminium in accordance with the British standard BS 2L 93:1971 [2]. The material approximates the aluminium 2014-T6. In a long-transverse direction the material tensile properties are approximately as follows: yield stress 448 MPa, ultimate strength 510 MPa, modulus of elasticity 72,400 MPa and Poisson's ratio 0.33.

4.2. Spectrum

Two FIAF's Hawk jet trainers have the permanent operational measurement loads (OLM) set-up since 2000 [8]. One OLM set-up is in the Hawk Mk.51 and another in the Hawk Mk.51A. The test spectrum was created using six flights of the Hawk Mk.51. The used signal represented the wing root strain on the wing bottom surface. For the selected signals the peak-valley reduction was performed and the cut-off level of low signals was placed into 11.5 MPa based on the material SN-curve. The FIAF's average usage was aspired in the creation of the test spectrum. The prepared test spectrum has 1104 flights corresponding to 1000 flight hours (FH) and 13.2 FI as presented in Table 3. The order of the flights in the spectrum was random. With the proper transfer function (from the OLM strain gauge location to the fatigue critical location of interest) including offset the strains/stresses of the test spectrum corresponded to a load level of the real drain hole.

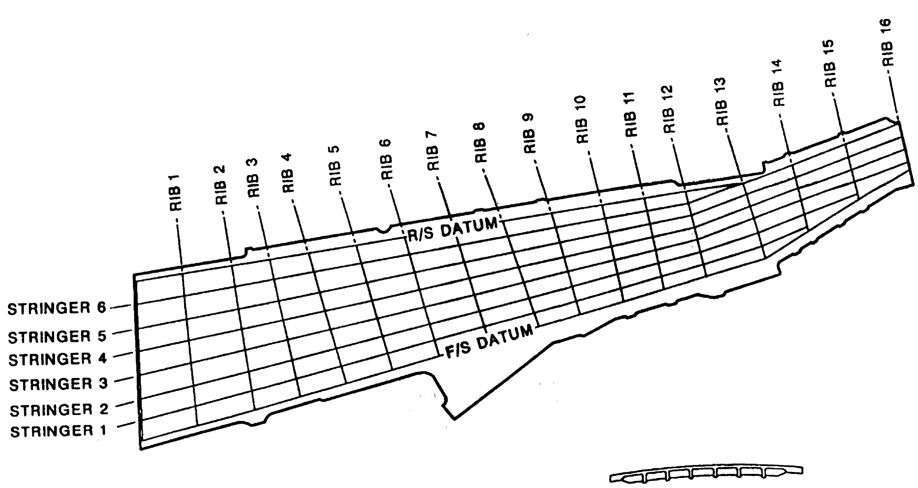

Fig. 1. Numbering of the wing's ribs and stringer [5].

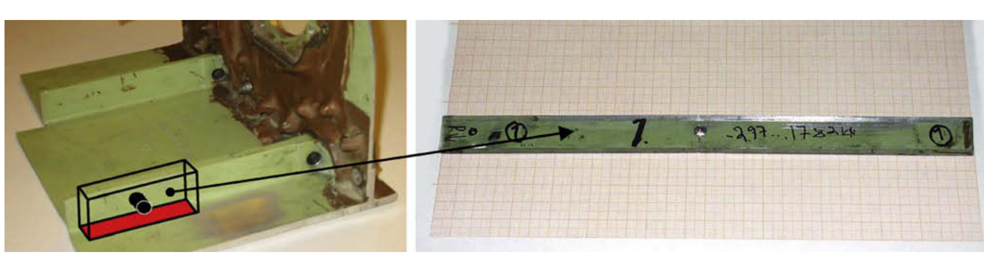

Fig. 2. A small-scale test specimen [3].