Non-destructive Inspection of Composite Aileron during Fatigue Test

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Abstract. The operational safety and reliability of an airplane must be an integral part of its design. The use of suitable materials that pass material certification tests is very important for a new aircraft design. The next part is testing specific samples, sub-components, and components such as the aileron. The paper deals with a non-destructive evaluation of composite primary structural part fatigue tests in accordance with damage tolerance philosophy considering impact damage presence. NDT methods such as visual, eddy current, and ultrasonic testing included phased array technique, are used for the inspections. A schedule of inspections was created, and structural durability was verified.

1 Introduction

Certification of any airframe structure can be performed by numerical or experimental methodology in accordance with airworthiness requirements. Although advanced numerical methods are very sophisticated, experimental verification of any primary structure through static and fatigue testing is still necessary [1]. Current airworthiness requirements specify to prove the durability of composite structure based on damage tolerance philosophy [2,3]. These requirements are experimentally discussed in [4] in detail.

The paper deals with a non-destructive evaluation of a primary structure part (aileron) which is manufactured from carbon fibre-reinforced composites using winding technology. The composite aileron is made of carbon filaments (roving) with an epoxy resin in combination with a hardener. It is a thin-walled five-hollow structure.

The key to providing important information on the quality of materials without damage or affecting their structure is non-destructive testing. Non-destructive testing (NDT) is one of the most important testing and analysis tools used in industry to monitor the current condition of equipment or to evaluate the properties of materials, components, and systems. The concept of NDT focuses on the ability to detect all possible damage qualitatively and quantitatively.

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2 Fatigue test of the prototype composite aileron

The main aim of the fatigue test is to determine how the aircraft or its parts are able to withstand the actual conditions that occur during service. The fatigue test is performed to demonstrate the design, to verify the expected or design life, and to detect structural defects that may appear during service. In general, the experimental test is based on simulated flight hours (SFH) which should simulate the real operating conditions according to the relevant standards [5-7].

The aileron fatigue test should demonstrate the "damage tolerance" philosophy and meet the requirements of the No-Growth design philosophy. This means that if there is a defect in the material, the defect should not propagate in the material, which needs to be demonstrated.

The demonstration is performed with defined damage where the aileron structure must withstand repeated loads without damage growth over the life of the structure. Therefore, artificial manufacturing (internal) and operational (impact damage) defects were created in the prototype of the aileron designed for fatigue testing and monitored during fatigue loading. Manufacturing defects were created in the structure of the aileron during production. However, it is important to remember that damage in composite laminates is not initiated only by impacts but also by e.g., stress concentrations or manufacturing flaws [8].

The set-up of the test includes a few hydraulic cylinders, loads were applied into the structure through the MTS system and several strain gauges were installed to the tested aileron.

2.1 Creating operational defects

The operational defects were created as BVID (Barely Visible Impact Damage) after the completion of the second life of fatigue test using an impactor. BVID is barely visible surface damage which is not noticeable at the first glance. These BVID damages represent a high level of risk to the safe operation of composite components. The range of energy used for impacting was from 20 J to 50 J. The process of creating BVID defects on the SUPR system can be seen in Fig. 1.

Fig. 1. Creating artificial (operational) defects (on the left) and the impact damage (on the right)

3 Non-destructive Testing (NDT)

As with any composite structure, various types of defects may occur during manufacture or operation in this aileron. Non-destructive testing is used to detect defects. NDT is a wide group of methods, which are used for testing surface, subsurface and internal material defects without damaging the component [9-11]. Ultrasound (UT) is the main method used for the inspection of the aileron, complemented by visual inspection (VT) and eddy current inspection (ET).

During the fatigue test, it is necessary to monitor whether new damage is initiated or artificially created defects are propagated by NDT inspections. These NDT inspections are performed according to the test plan:

- before the start of the fatigue test,
- after the first life of the fatigue test,
- after the second life of the fatigue test,
- after artificial operational defects have been created,
- periodical inspections,
- after the last life.

An inspection of the internal and external surface of the aileron was performed by visual testing. The method is focused on detection and evaluation of the part surface condition directly by eyes or special equipment (videoscope).

The ultrasonic method makes it possible to detect the presence of internal material defects, even at great depths under the surface. UT was used for an inspection of artificial defects. The defects were monitored due to their possible propagation according to the test plan.

UT inspection using both conventional and immersion phased array techniques (using 3-axis automatic system). The phased array (PA) technique is based on the usage of a probe set, in combination with special electronic circuits, which could shape the beam. PA probes consist of a set of miniature piezoelectric transducers. The setting of output parameters for each transducer separately forms the beam.

For the ultrasonic testing, the ultrasonic device Olympus OmniScan MX2 and the conventional Olympus V 203-RM 5 MHz and phased array Olympus 5L128-I2, 5 MHz probes were used.

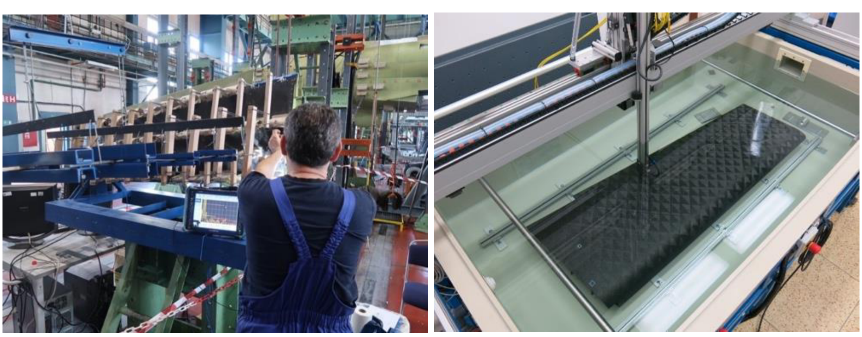

Fig. 2. NDT inspection (UT) during fatigue test of the aileron (on the left) and immersion phased array techniques before the fatigue test started (on the right)

The eddy current testing is one of the most extensively used non-destructive methods for inspecting electrically conductive materials. ET has been used to inspect the surface of the metal parts of the aileron, such as end ribs or the level arm, which is the most critical point of the metal part.

4 Results

The aim of the aileron fatigue test was to prove the no-growth philosophy. For this purpose, the artificial defects were manufactured, and their propagation was monitored using NDT methods. The impact damage was inspected by conventional UT technique during the fatigue testing, and no propagation has been detected.

More advanced view of measured UT data is C-scan. C-scan refers to the image produced when the data collected from an UT inspection is plotted on a plan view of the component. For this purpose, the UT C-scans were created before (Fig. 4) and after (Fig. 5) the fatigue test. Fig. 4 shows C-scan of the aileron and the internal defects in detail (yellow circuits). The artificial operational defects (surface defects) can be seen in Fig. 5 in detail (red circuits). Defects No. 1.-3. are the artificial inserts that simulate delamination. Defects No. 4.-5. are the manufacturing defects as high porosity.

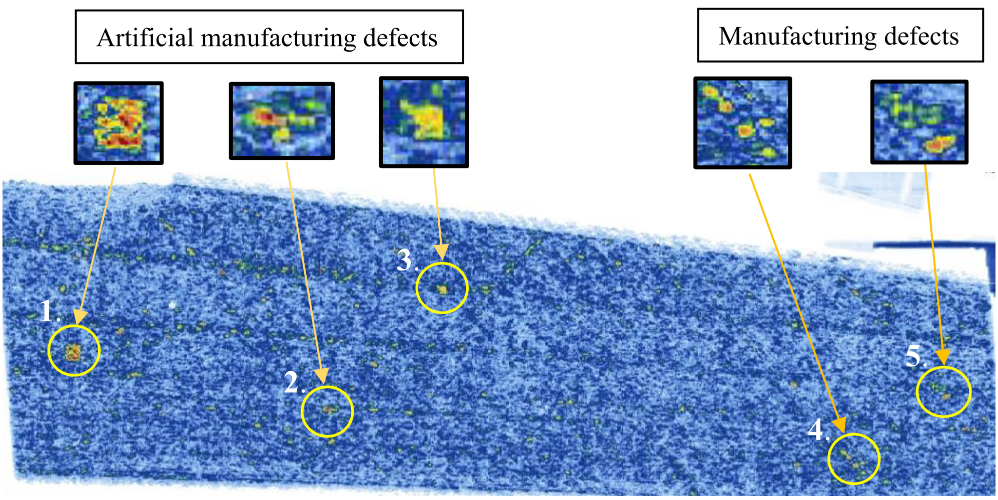

Fig. 4. Ultrasonic testing (C-scan) of the aileron before the fatigue test started

If the two C-scans are compared, it is quite evident that no new damage has been initiated and artificial defects have not propagated in the aileron structure during the fatigue test. The only difference between these pictures is the impact damage, which was created after the second life of the fatigue test (Fig. 5, defects No. 6.-8.).

Impact damage can be seen on the C-scan (Fig. 5) in two types. The first type (No. 6 and 7) is a white circle that is the size of the impact damage created. This is due to the use of more energy during the impacting and the subsequent deformation of the material surface where the UT signal is lost. The second type (No. 8) has a similar shape but is represented by the red colour. This is due to the use of less impact energy, which has not caused significant deformation of the material surface but has resulted in delamination within the material because of the impact.

However, the C-scans show a higher level of noise, which is due to the high porosity and overall structure of the material caused by the winding technology used.

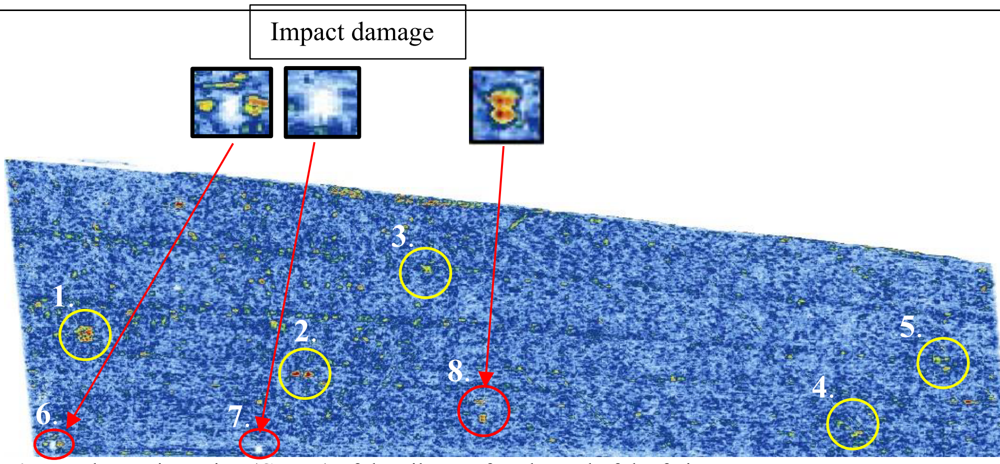

Fig. 5. Ultrasonic testing (C-scan) of the aileron after the end of the fatigue test

5 Conclusion

The prototype of the new aileron was subjected to a fatigue test to obtain airworthiness certification. The aim of the article is to show the process of the fatigue test and NDT inspections during the test. In total, fifteen NDT inspections were performed, and several defects were found including artificial defects. However, one of the artificial (manufacturing) defects was not found. It could be caused by imperfect production.

NDT inspections proved no propagation of the artificial defects and impact damages in the carbon fibre-reinforced composite aileron. The results indicate that the aileron structure is extremely resistant to impact damage as it withstood damages created by impact energies up to 50 J.

The aileron composite structure was verified according to the no-growth philosophy. By contrast, this result leads to the conclusion that the composite structure is too conservative from a strength point of view. Then the next work should be focused to change the philosophy to slow-growth or fail-safe mainly for critical structural parts. The possible procedures for achieving this aim could be the procedure described in [12,13].

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