Advanced Integration of Non-Destructive Testing during Laboratory Fatigue Test of Airframe Metal Parts

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Abstract. Aircraft structure of a new design or significantly changed structure is subjected to experimental fatigue test due to safety assurance. Structural parts of aircraft frame are loaded in the laboratory, where the service conditions are simulated. According to airworthiness authorities, multiple time of design life is established. Because of fatigue behaviour of structure material, some damage occurs and crack growth is studied. For crack detection during fatigue test, the methods of non-destructive testing are used. Research and development projects, related to inspection of specimen by modern methods, improve the quality level of strength testing. The experiments were finished by teardown inspection and results of previous non-destructive inspections are validated by fractography.

Introduction

Non-Destructive Testing (NDT) is an integral part of modern industry. The safe-life philosophy secures aircraft safety in service by a scatter factor related to experimental strength test. NDT is required in the course of full-scale fatigue test for establishing the fatigue life of the structure. Much more attention has been focused on NDT through damage tolerance approach. It can be define as the ability of aircraft structure to sustain expected limit loads in the presence of fatigue, corrosion or accidental damage until such damage is detected through inspections and repaired [1]. The damage tolerance approach requires that damage should be detected before reaching critical size under maintenance inspection schedule, so this approach forces periodic NDT inspection of structural significant items in service.

Aeronautical Research and Test Institute is the major centre for aeronautic research, development and testing in the Czech Republic. The Institute successfully fulfils orders from the Czech as well as foreign industries comprising both civil and military sectors. The Experimental Strength Department performs experimental task connected with certification strength tests of primary aircraft structure, their components and models. In order to meet present and future requirements for fatigue related NDT, the following aims are to be dealt with:

- Choise of appropriate inspection method and technique
- Inspection reliability is investigated in research tasks
- The laboratory involvement in development projects

Inspection Methods

1.1 Full-scale Fatigue Test

To ensure airframe integrity in service, full-scale fatigue test is an indispensable part of structure certification for service operation. The fatigue test is a long-term task. It usually takes several weeks till many months. The frame of aircraft structure with implemented and bonded sensors is surrounded by fix structure of a stand and hydraulic actuators are attached through the rigs, see Figure 1. Access into critical points should be made possible through periodic inspections. For inspection efficiency it is important to meet reliability with minimum disassembly.

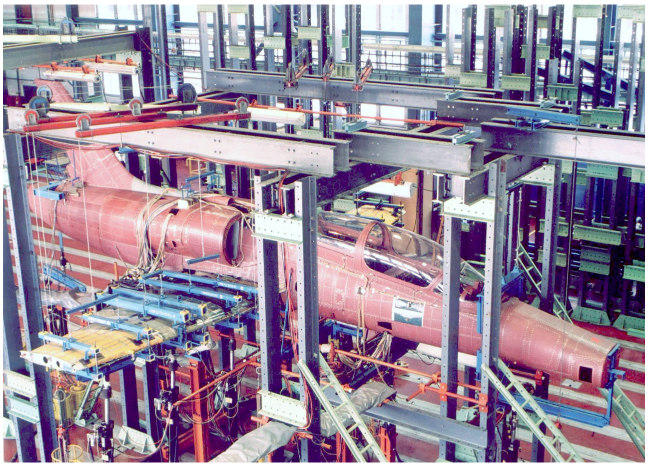

Figure 1. Full-scale fatigue test

1.2 Critical Points

Due to service efficiency, airframes are designed to carry maximum loads with minimum weight. Resulted high level of operating stresses makes significant accumulation of fatigue damage inevitable. The most critical points are known from design, but the well designed frame may crack anywhere. The whole structure should be inspected with the emphasis on the expected critical points, see Figure 2.

Figure 2. Critical points of aircraft structure

The cracked elements can be generally categorized, see Table 1. The spar flanges and stringers have a relatively low percentage of damage occurrences, because these elements, as non-exchangeable part of primary structure, are designed carefully. However, these cracks are usually the most critical.

Table 1. Damaged elements

skin	47.5 %
rivet body	27.5 %
bolt	16.0 %
spar flange	2.7 %
bonded joint	2.0 %
stringer	1.8 %
other	2.5 %

1.3 Methods of Non-destructive Testing

Visual inspection is the common NDT method used extensively to evaluate the condition or the quality of structure elements. It eases to carry out, inexpensive and usually doesn't require special equipment. It should be noted that the role of visual inspection is very important for maintaining and improving aircraft structural integrity to the present. It is used most effectively for the general inspection of whole structure where the time results in significant cost savings. Surface preparation can range from wiping with a cloth to treating with chemicals to show the surface details. It can identify where a failure is most likely to occur and identify when failure has commenced. Visual inspection is often enhanced by other surface methods of inspection, which can identify defects that are not easily seen by the eye.

For sophisticated inspections the laboratory is equipped with manual eddy-current and ultrasound systems. Because the airframe is a complex structure and each type is unique, it is not effective to design full-automated inspections. Acoustic emission monitoring is used for preliminary warning about failure progression. Smaller parts like subassemblies and models are inspected through similar ways as full-scale with advantage of more simplicity.

Inspection Reliability

2.1 Probability of Detection

The inspection reliability is generally associated with the ability of a technician to detect cracks in the inspected structural significant item. The probability of detection (PoD) for the specific crack length is then usually taken as a measure of the inspection performance, see Figure 3. The initial crack length is small and generally assumed not detectable by current inspection technique. After a certain propagation time in service the crack grows and becomes reliably detectable with given NDT technique. For inspectable structures, the initial cracks must grow slowly and not reach a critical length in some predetermined inspection interval. Critical length is usually defined as the crack length for which the structure can just sustain a limit load.

For aircraft maintenance it is important to select appropriate NDT techniques and inspection period in terms of initial inspection and inspection interval. In [2], there are investigated crack detection capability of visual and eddy current methods.

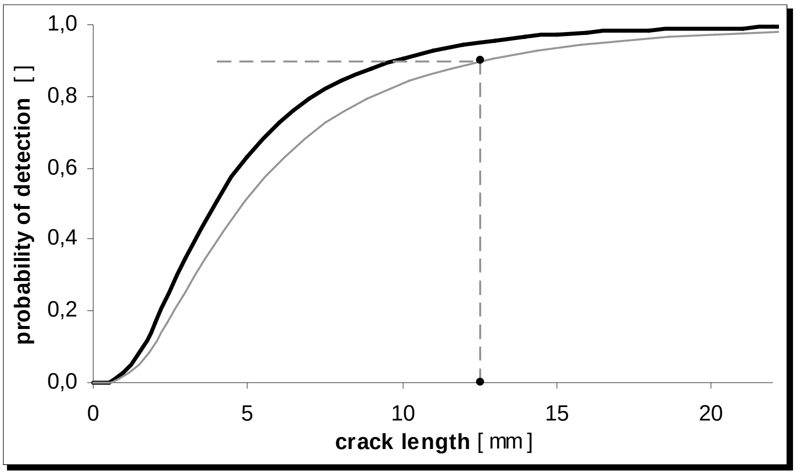

Figure 3. Estimation of reliably detectable crack length

2.2 Data Processing

One of the most important fields of research is experimental data processing. Manufacturers and users of industry structures are interested in failure prediction and maintenance under conditions. According to damage tolerance approach, methodology studies solve:

- Probability of crack detection
- Inspection reliability and confidence level
- Scheduling of maintenance system

Huge packages of experimental data are statistically analysed and studied, resulting in assessment of inspection reliability. An economical optimisation leads to schedule an inspection strategy to provide acceptable safety at minimal costs. The detectable crack length may assess the quality of considered NDT method.

Although often the crack detection during certificate fatigue test is not concerning on primary, the data are accessible through periodic inspection. Extension of the structure life, which became actual with the end of the safe life, is the task of these experimental data processing. We know the detected length of cracks appeared during the whole fatigue test. The structure was inspected periodically and we must quantify the detectable crack length, independent of inspection interval preliminary estimated without optimization. Because generally there are a lot of fatigue cracks on the structure for similar critical points, we cannot analyse each one in detail. We use simplified estimation of missed lengths. The couple of the length we missed and the length we consequently detected forms the boundary of the detectable length. Quantification of the detectable length is then possible by statistic tools with related levels of reliability and confidence, see Figure 3.

Knowledge of quantified detectable length of the crack, reliability and confidence level allow us to optimise inspection scheduling in service applications. It is necessary to hold the safety guarantee of the whole life extension process and to have a possibility of safety level presentation.

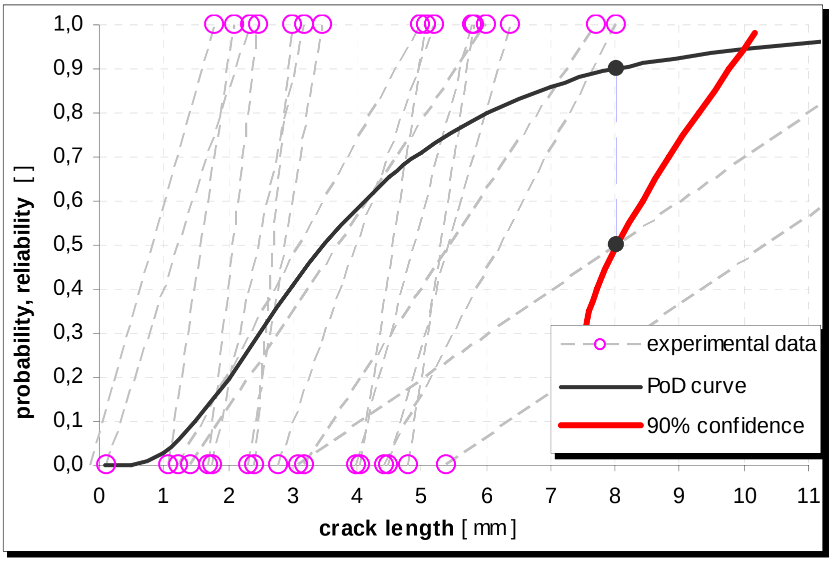

Figure 3. Reliability through inspection interval

Development Project

3.1 Techniques of Traditional Method

Airframe inspections are applied under difficult conditions, e.g., composites, steel/al-alloy boundary, large curved surfaces, complex and unknown structures. Visual method, especially remote techniques, is most common one, but its reliability is limited by human factor and surface conditions. Sophisticated instruments give better results and are used in selected points. Acoustic emission, see Figure 4, is permanently monitored and signs of fatigue cracking are checked in frequency domain. One of the advantages compared to other NDT methods is the possibility of monitoring to observe damage processes during the entire load history without any disturbance to the specimen. Common problem for every method is to recognize fatigue cracking and background noise, e.g. scratches for visual, geometric shape for ultrasound, material imperfection for eddy current, friction for acoustic emission.

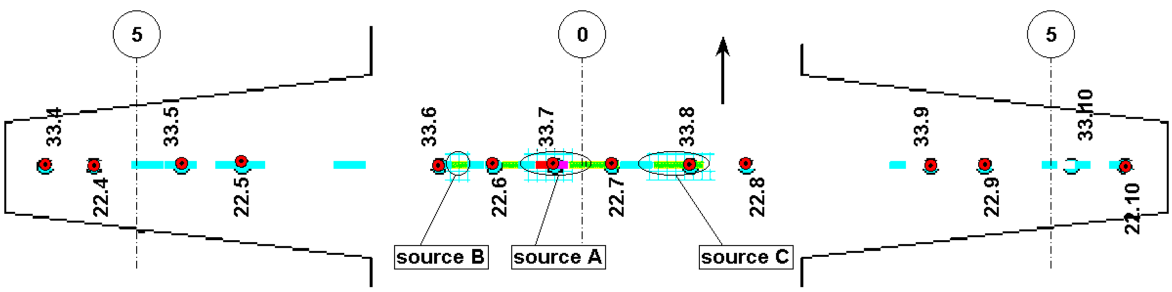

Figure 4. Acoustic emission monitoring

A traditional approach is to combine statistical and empirical methods, thereby establishing a statistical correlation between measurements and the required properties of hardness and case depth. An alternative scheme is to train a neural network to extract the required material properties using a reference set of specimens and measurements. However, both of these approaches depend on acquiring a specific set of test data under controlled conditions. The data is then useful for estimating the properties of new samples

3.2 Non-linear Methods

All of traditional non-destructive testing and monitoring methods have specific drawbacks when applied to complex structures. However, non-linear methods have great detection potential and are more sensitive to common and hidden defects.

The outcome of the feasibility tests looks promising. The non-linear method may be implemented for detecting flaws in local, relatively simple elements, because structure behaviour must be understood for right signal interpretation. The Aeronautical Research and Test Institute is involved in national research programs, e.g. STRATECH, PROGRES and TANDEM, and European “Health Monitoring of Aircraft by Nonlinear Elastic Wave Spectroscopy“, where completely new system for non-linear NDT is being developed.

Maintenance Scheduling

4.1 Laboratory Environment

In parallel to loading in the course of fatigue test, a health monitoring system suitable for service maintenance is composed. Methods of non-destructive testing are used through crack detection and documentation of test specimen continuous degradation. Experience and validated practice are transferred from laboratory environment to service condition. Final surface treatment and outfit installation should be reflected for operation usage. The different reliability and capability movement under the field conditions are established by experimental test of full-equipped critical point model.

4.2 Service Inspection

The NDT scheduling for the damage tolerance approach is illustrated in Figure 5. The beginning of periodic inspection is established according to experimental fatigue life. The scatter factor of crack initiation is taken into account. Inspection interval depends on distance between detectable and critical crack length on the growth curve. The crack should be detected with desired reliability to meet safety requirement. System of repeated inspections is usually less cost-expensive than achieving the final reliability in the first inspection only. The operate level of PoD should be optimised from the economical point of view, because scheduled number of inspections is related to each inspection reliability.

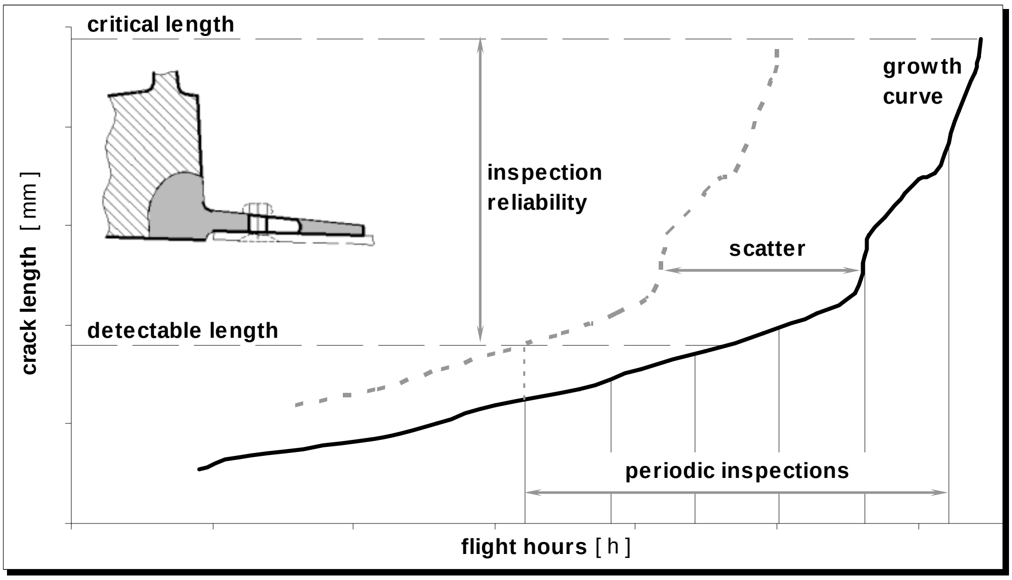

Figure 5. Scheduling of service inspections

Conclusion

Aerospace industry is one of the most advanced and important fields of NDT applications. Except quality inspection of structural part production, non-destructive testing is widely used in the case of fatigue evaluation of aircraft structure. Classic non-destructive inspection for structural defects is a vital component of testing and maintenance. Non-destructive evaluation is opening the door to precise presentation of fatigue test results.

The effort to increase fatigue life of aircraft structures leads to an advanced design philosophy, which permits a fatigue crack being initiated during service. With aging aircraft the increase in damage detection is an important and difficult task. Also new is the issue of crack growth management. A schedule of structure inspections is established for aircraft in service and critical points are checked by NDT during maintenance.

Acknowledgements

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