Abstract. The concept of the non-destructive testing of materials (NDT) is focused on the ability of how all the possible damages can quantitatively be detected according to the test pyramid. When NDT is accomplished during full scale test (FST) for establishing a fatigue life of aircraft structures, damage tolerance approach (DTA) must be considered. It can be defined as the ability of the 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. Introduction

The implementation of new materials and design concepts for new types of aircraft structures requires a significant large number of material tests starting from coupon tests through different levels of component tests (shell, barrel) up to full scale testing of complete aircraft structures accompanied by measurements and non-destructive inspections.

As one of the most important engineering service providers for the aerospace industry in Europe and an expert for outstanding engineering services, IMA Dresden offers complex services for development, qualification and certification testing. This includes the development of new test concepts and the acceptance of the responsibility for design and procurement of the test equipment.

As an example, IMA Dresden has been involved in many structural tests of development and certification programs of the international aerospace industry during the past years. The test activities cover all mechanical structural tests along the so called test pyramid. IMA Dresden has long time experience in inspection of aircraft components.

Tests of all levels of complexity require a wide spectrum of NDT inspections. Furthermore, this provides the opportunity of developing and testing the required NDT methods and instrumentations for new designed components that are made from innovative materials.

2. Test philosophy

The test pyramid for all mechanical structural tests (static and fatigue) consider material tests at coupon level, different levels of structural and component testing up to testing of complete aircraft structures (major tests), fig. 1.
For the fulfilment of rigorous requirements for aerospace NDT have been applied to aerospace material. The concept of the NDT is focused on the ability of how quantitatively all the possible damages can be detected according to the test pyramid. When NDT is accomplished during FST for establishing a fatigue life of aircraft structures, DTA must be considered. It can be defined as the ability of the aircraft structure to sustain expected limit loads in the presence of fatigue, corrosion or accidental damage until such damage is detected during inspections and is afterwards repaired [1]. DTA requires that all the possible damages must be detected before they reach at critical status under maintenance inspection schedule. Such work will be a criterion for establishing NDT inspection interval required for the maintenance inspection schedule.

The procedure includes the necessary certification process to ensure the provision of data for aerospace industries for a reliable material selection and detailed design. Being able to perform wide-spread testing requires a lot more than just being able to perform certain tests. This became apparent in a lot of certification and accreditation processes in the past. On the one hand there is the diversity of materials to test, e.g. metallic or non-metallic, and the complexity of the combination of different material types. On the other hand there is the necessity of the right test type considering every demand. This leads to numerous options in performing destructive tests with static and fatigue loading as well as non-destructive tests.

3. Technology development

The implementation of new materials for fuselages requires a large number of tests and validations. The spectrum of investigations reaches from a simple material specimen over coupons up to a complete fuselage. With all of the tests static and dynamic properties are studied. Important for the security is the damage tolerance behaviour of the fuselage structures. The design of further fuselages is strongly influenced by new innovative materials and joining technologies.

New aluminum alloys with lower density and welding suitability are developed. Alloy systems Al-Mg-Si-Cu (AA6013), Al-Mg-Li und Al-Mg-Sc, the extension of the application of titanium alloys and the development of high-strength magnesium alloys as well as the application of carbon fiber reinforced plastic materials are important aspects for new design, inspection and testing demands [7].
Joining technologies for the fuselages:
- The actual design of fuselages is characterized by the fastener and the adhesive technologies.
- Alternatively the laser beam welding for the skin-stringer joining is applied.
- First studies to the friction stir welding (FSW) were implemented.
- An other direction for development is the extrusion of fuselage skin shells with integrated stiffener elements.

New laser welding machines were developed at Fraunhofer IWS Dresden. The so improved and new welding technologies for stringer-skin-joints and clip-skin-joints are possible, fig. 2. New welding adapted construction principles now exist.

![Fig.2: Laser beam welded integral fuselage structure](image)

For carbon fibre reinforced polymer (CFRP) material riveting is not the only way to combine structure parts. The behaviour of bonded structure parts and the material properties after impact damage or under cyclic conditions are of important interest. Starting with simple structure part up to whole CFRP panel with complex joining between several materials and structure parts are to be inspected, fig. 3.

![Fig. 3: Design of CFRP structure parts](image)

At flat and curved panel testing the following conditions were studied, fig. 4+5:
- Stress distribution of skin and stringer for an intact structure (normal and bending load)
- Load redistribution within the stringers for a cracked skin
- Load redistribution within the stringers for cracked skin and cracked stiffener
- Estimation of crack growing rates in relation to materials and structures
- Influence of the stiffener design
- Influence of joining technology

Fig. 4: Panel test device, crack propagation investigation [6]

The idea of “IMA Panels” means a special test concept: Curved sections were inspected while creating the basic conditions, which are required for these. The multi-axial and continually applied cyclical loads on the load bearing structures sufficiently reflect the practice [2, 3, 4, 6], fig. 5.

One way of carrying theory into practice is to perform tests of relevant aircraft structures by representing real life conditions. One key structure of modern civil aircraft is the fuselage. Tests of the fuselage can be done by testing a barrel or just a curved panel, fig. 5+6. The latter variant is more flexible, faster and cheaper.

These new developed curved fuselage panel test rigs were engineered with special focus on test series for new generations of aircraft structures and fuselage of CFRP, respectively [5].

Fig. 5: Curved fuselage testing devices for side and upper panel
728 JET-Barrel as development test
Basis is the fuselage of the 728JET (Ø 3470 x 4090 mm)
The fuselage consists of 10 shells over 7 frame distances.
Verification of the damage tolerance concept
Validation and adjustment of the test results with the design goal and the calculation
The test consists of 2 phases:
Phase I: Fatigue 100,000 simulated flights
Phase II: Damage Tolerance 110,000 simulated flights.
Study of the failure propagation for different crack configurations and estimation of the residual stress

4. Inspection demands
The concept of the NDT is focused on the ability of how quantitatively they can detect all the possible damages according to the test pyramid. It is necessary to determine the monitoring period for the structure, that means the criterion for detectable damages, fig. 7.

Several aspects are essential for determination: the inspection starting point (initial inspection), the inspection time and the repeat inspection interval [1].

Therefore several inspection methods need to be applied for special materials and areas of interest (impacted skin areas, fig. 8; bonded stiffener elements, fig. 9; structure cuts; joining areas) under testing conditions:

- Manual pulse-echo-technique
- Ultrasonic phased array technique, e.g. fig. 8+9
- Ultrasonic through transmission
- Ultrasonic immersion technique
- Eddy current inspection with one or multiple frequencies, fig. 10+11
- Optical methods (e.g. ARAMIS), fig. 12
The bore hole inspection with multiple frequency technique will be used for determining the damage location, the damage depth into the bore hole and the length into the material up to 2 mm. It is qualified for aluminium and will reduce the repair effort for the in-service, fig. 10.

For inspection on welded stringer NDT methods like eddy current (fig. 11), dye penetrant testing or ultrasonic phased array testing are possible.
An inspection based on ARAMIS method can detect the maximum buckling of outer skin under internal pressure and longitudinal load. The principle is:

- 3-D displacement of the surface
- deformation of the surface (out of plane)
- strains in X,Y direction
- shear strain angle
- 3D - surface
- information about single points and lines
- cuts in several lines and different steps
- diagrams, overlay pictures, data export

References


