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CERTIFICATION PROGRAMME OF PRIMARY COMPOSITE AIRFRAME STRUCTURE PART WITH ENVIRONMENTAL SIMULATION (DTAS2007)

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Abstract. *The paper presents certification programme of the primary composite airframe structure part (pressurized bulkhead). Within the test the mechanical (static and fatigue) and environmental loading was simulated. The environmental loading represents the 70^o C temperature and 90% humidity. The proposal and realization of whole certification programme in the Aeronautical Research and Test Institute (VZLU) is presented. Designed programme fulfilled the conditions of the FAR-23 (or CS-23) regulations requirements.*
Composite bulkhead was designed and manufactured during the development of a new small Czech air carrier with pressurized fuselage. The bulkhead is designed like honeycomb structure with carbon/epoxy skin. The technical and operational testing conditions, test facility possibilities and follow-up details related to the structure certification are stated. Results from residual strength test and results from advanced non-destructive testing are presented (Shearography method).

1 INTRODUCTION

The relatively substantially part of VZLÚ works was focused to the research and development of the composite materials in former times. Unfortunately all activities in this field were suspended at the turn of the nineties of the last century as a result of well known political changes. Rapid progression in using of composite materials in aeronautical and space applications both in the world and Czech Republic has lead to the prompt work update in the field of composite structures. The main aims of the current research and developing projects are focused to the analytical, numerical and experimental strain and stress analysis, to the design and repair of composite structures and to the development of the test methodologies with regard of airworthiness regulation requirements.

Almost all aeronautical vehicles with composite materials in the primary structure are designed and operated in compliance of Damage Tolerance philosophy. In certain assumptions this approach allows structure operation with allowable size of flaw (damage). Within analyses and certification process of the composite structures, the care has not to be pay only to design and analysis of the undamaged structure, but mainly to assessment of the damage influence to the strength and durability characteristics of the structure.

Through indisputable assets, which have resulted from exploitation of composite materials, there are some existing problems, which must be solved. Without theirs solution there is impossible fully make use of composite structures. One of the fundamental problems is the composite structure certification in compliance with airworthiness regulations (FAR, CS, etc.) – first of all the real environmental account.

This paper presents works regarding both the test methodology development for certification of the structure primary part (pressurized bulkhead) and the test performance in compliance with airworthiness regulations and requirements of Civil Aviation Authority (CAA) of Czech Republic as a support of certification of a new small Czech air carrier with pressurized fuselage.

2 TEST METHODOLOGY WITH RESPECT TO AIRWORTHINESS BASE

The FAR-23 airworthiness regulation was an essential base for the design and realization of the whole presented programme. The next strongly associated documents were taken into the account at proposal: AGATE report (Advanced General Aviation Transport Experiments) - „Material Qualification Methodology for Epoxy-Based Prepreg Composite Material Systems“ and other standards and specifications as MIL-HDBK-17 - Military Handbook for Polymer Matrix Composites, SAE AMS 2980/0-5 - Technical Specification: Carbon Fiber Fabric Epoxy Resin Wet Lay-up Repair, FAA Code of Federal Regulations (CFR): Aeronautics and Space, FAA Advisory Circular 20-107A: Composite Aircraft Structures, FAA Advisory Circular 21-26: Quality Control for the Manufacture of Composite Materials.

Based on analysis of above mentioned documents, two approaches can be applied:

- the proof at room temperature and loads multiplied by knock-down factor,
- the proof under environmental conditions.

The first approach can be used if great number of preliminary material tests and joints specimens was done under higher temperature and humidity. And, of course, evaluated equivalency of knock-down factor (KDF) and environmental effects must be verified by a test at least of one real structural part with environmental simulation. The environmental analysis and proof must take into the consideration also the influence of the other aggressive matters to the structure durability (for example fuel, oils, cleaners, thinning agents, distilled water, etc). Specific problem arises regarding to complex (composite and metal) structures using the KDF: increased loads are applied also on the metal parts, even if a resistance of the metal parts have not to be designed against the increased loads.

The second approach can give the proof under environmental conditions in a single test; nevertheless a proof of the large structures can be very expensive as far as non-acceptable.

It is evident that both approaches are requiring additional costs in comparison with the proof of metal structures. These costs are caused by necessity to perform specimen environmental tests or full scale test in conditioning chamber. If a producer has steady state of composite structures design and when a limited number of composite systems is used, than the first approach can be considered as more effective in long time outlook. Experimental data gathered into material properties database are suitable tool for the proof test at room temperature design, when increased loads are applied.

The design of the composite bulkhead was the first application of composite material for primary airframe structure. Therefore no material characteristic database was available, an appropriate material system was seeking at the time and on the opposite side the term of the production start was fixed.

The structural part load analyses demonstrated that dominant mechanical stresses are caused by cabin pressurization. It is clear that pressurization can be applied if the bulkhead will be installed as part of a pressure chamber.

These factors coincidence represents very favorable circumstances for the test design according the second approach:

- a pressure chamber has to be built for appropriate loading process,
- using a chamber it is very easy to apply conditions for environmental simulation with regard to temperature and humidity effects,
- required proof can be realized by single test.

3 DEFINITION OF TEST STRUCTURE

The pressurized bulkhead was designed as a honeycomb structure with metal core and carbon composite skin. The configuration of the bulkhead structure is shown in the Figure 1 and in the Table 1 respectively.

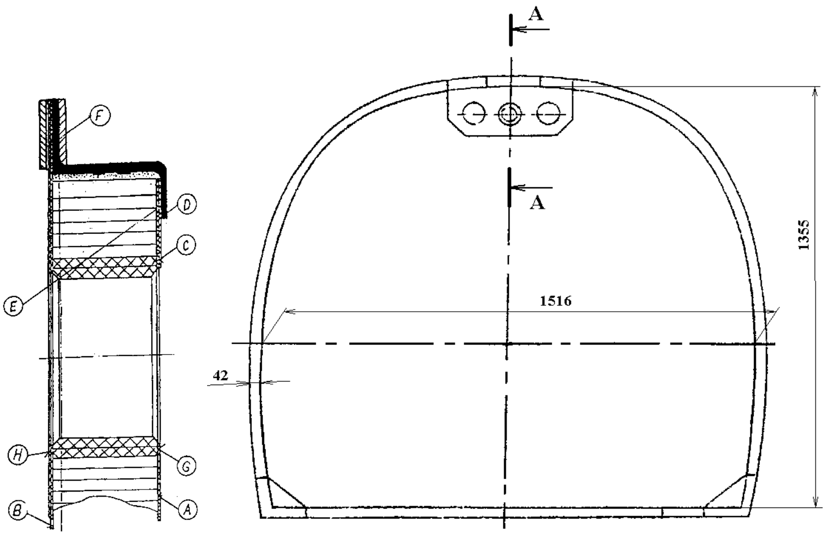

Figure 1: Schematic outline of the pressurized bulkhead structure configuration

The glue joint name	The type of glue joint	Thickness [mm]	Material
A	skin / honeycomb	0,5 / 44	Glue: Letoxid KFL120
B	skin / honeycomb	0,5 / 44	Skin: Fiberdux 913C
C	skin / honeycomb	1.0 / 44	Honeycomb: HEXCEL 1/8-5056-0.0007 Cement: Redux 212 NA Shape : Lepreg NT 2065 1x green paiting
D	shape / skin	2,0 / 0,5	
E	skin / honeycomb	1,0 / 44	
F	shape / skin	2,0 / 0,5	
G	skin / honeycomb	0,5 / 44 (cement)	
H	skin / honeycomb	1,0 / 44 (cement)	

Table 1 : The sense of marks and the list of used materials in Figure 1

3 DEFINITION OF CERTIFICATION PROCEDURE

The certification process of each structure can be divided to the three basic groups:

- ✓ design of the test programme,
- ✓ realization of the test,
- ✓ evaluation of test results.

In generally it can be stated that each design of certification programme must inherently take into account well-balanced both financial and technical aspects. From the view of financial expenses the clear requirement is the lowest price. This requirement is connected with demand on most readily realization of the whole certification procedure. From technical standpoint it is necessary to optimize a real impact of the mechanical and environmental loading to the structure. Therefore all factors, influencing a structure lifetime, must be correctly considered and simulated. Above mentioned each other contending claims are the cause of a great stress to producers and laboratories that have certification tests in own jurisdiction to the time stealing of the tests.

Design of the test programme is possible to divide into the relatively independent areas:

- ➢ mechanical loading,
- ➢ environmental loading,
- ➢ nondestructive inspection,
- ➢ simulation of impact damages,
- ➢ residual static test.

Mechanical loading of each structure must be set on the base of available strain gauge measurements from similar structure in service or from the reliable analytical analysis. In our case the data was available from strain gauge measurement of the airframe full scale test. The data approved that the mechanical loading of the bulkhead is induced only due to inner overpressure of the fuselage. The level of the inside pressure defines only operational flight level or maximum of flight altitude respectively. The initial lifetime of the airplane has been stated to 29270 flights. Because one flight corresponds to one cycle of overpressure, it comes to this that 29270 overpressure cycles represent one lifetime.

One of the important certification requirements is the evaluation of environmental effects on the durability of the structure. The main factors, that have considerable influence on the degradation of composite materials and used technology, are temperature and humidity. For different critical airframe locations it can have a great significance also other matters, as it was discussed above, but for our case there is predominantly influence of temperature and humidity. The essential problems that must be analyzed in connection of the two factors are:

- ✓ absorption and desorption humidity to composite materials and bonded joints depending on temperature,
- ✓ state of stress and strain assessments in structure details that are occurred as a result of temperature and humidity dilatations,
- ✓ elastic and rigidity degradation of materials and structure characteristics.

The problem of environmental spectra determinations can be divided to two parts: 1) assessment of loading spectra, 2) qualification of characteristics of each composite structure elements. These both parts are closely related to each other. One of the input data for loading spectra evaluation is the environmental envelope from the real operational measurements based on similar or identical structures. The second input is the material characteristic. Time of the test should be reduced and the material degradation should be accelerated by increasing of temperature and humidity during the test. However enhanced temperature and humidity in any case must not have any influence on the material characteristics of a composite and the characteristics of bonded joints. It is necessary to take into account also thicknesses of used elements. It is obviously that neither at the end of the structure lifetime (assumption regarding to airplanes lifetime is least 25 years), the heaviest parts don't achieve the equilibrium state in humidity saturation point of view. On the other hand, thinner parts (for example skins) will reach saturation much sooner. For assessment of the saturation time there are a number of theories. Almost all theoretical equations are containing a row of invariables that must be determined by experiment. On the huge literature background research and by other analyses the experimental certification programme was proposed. It represents four design lifetime[1]. It was designed to perform the first fatigue life without temperature and humidity simulation. The aim of this decision was to simulate the successive humidity absorption in the structure. After mechanical loading, which represents the first life, the structure will be loaded for specific time only by enhanced temperature and humidity (conditioning phase). The sense of conditioning period is achieving the saturation state of thinner elements of structure. On the base on performed analyses and own experiences the time of conditioning was set to 120 hours under 70°C and 90% of relative humidity. Both environmental and mechanical loading (70°C and 90% of relative humidity) was applied within next two fatigue life. Within the last, fourth fatigue life the environmental loading was not simulated. In this test phase it was supposed that the damage (either fatigue or impact) is presented. This proposal has been consulted with CAA. The scheme of the whole loading program is shown in the Figure 2.

The nondestructive inspection (NDI) of the structure is the next area which must be ensured and prescheduled. The nondestructive testing (NDT) was performed before the start of experiment, each 2000 mechanical loading cycles and at the end of each life. For the NDT were used:

- o visual method
- o tap test

- ultrasonic method
- shearography method.

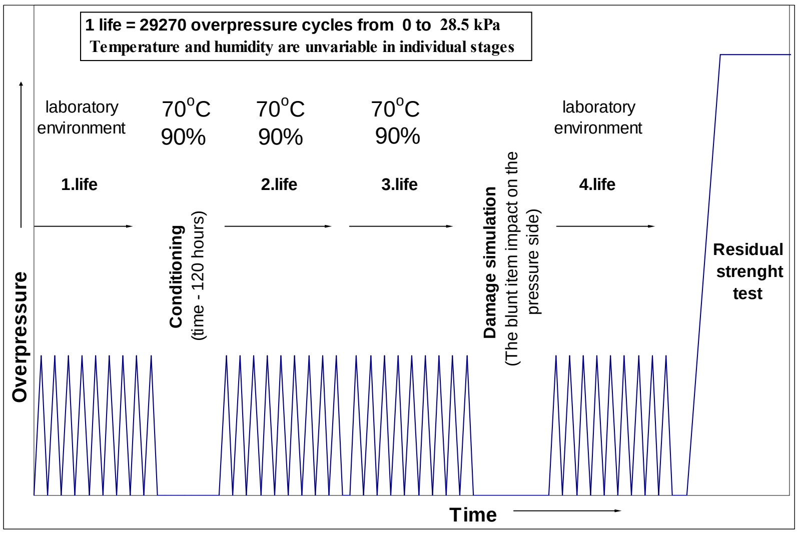

Figure 2: Loading programme for the bulkhead test with environmental simulation

Visual and tap test methodology are well known methods and therefore these methods are not specify in detail in this paper. For ultrasonic inspection BondMaster was used. This device is suitable for composite materials and bonded joints inspection. For measurements are available Pitch/Catch (Swept, Impulse, RF), Resonance and Mechanical Impedance Analysis (MIA) methods. As last but not the least it was used shearography method. The development of this advanced method made possible recent developments of advanced electronics and lasers. The demand for greater product quality in industry has created a need for better and faster techniques for non-destructive testing. The laser shearography is full field method without surface preparation, which removes the main disadvantages of the traditional techniques such as ultrasonic and radiography - that's rather time consuming. The principle of this method is described for example in literature[3,4]. It can be stated, that this method appeared as the best from above mentioned techniques in practice.

The complex inspection of the bulkhead had been made before the test programme was started; all flaws, respectively questionable places were recorded. The small inhomogeneity of bonded joints was identified mostly. An enhanced attention was paid to these places during the test. These places have not caused any damage initiation during the next loading.

The last items, which must be defined before the start of the test, are:

- ✓ establishing of damage critical size, or a moment for test terminate respectively,
- ✓ confirmation of residual static strength, respectively confirmation that also at the end of service life the structure sustain to limit load with relevant safety factors,
- ✓ type and size of impact damage simulation in case that any fatigue damage is not occurred in the structure.

In our case, it means that any pressure leakage of the structure is the moment for test termination. The residual static test is going to be realized after finishing of fatigue test.

4 REALIZATION OF THE TEST PROGRAMME

In compliance with the above mentioned base, the technical specification for the test was issued[1]. The test configuration and special test chamber were designed and manufactured at VZLÚ. The test chamber fulfils all requirements associated with simulation of build in bulkhead to the fuselage. The Figure 3 shows the composite bulkhead location into the test box during the manufacturing. The test was controlled by personal computer with using of FieldPoint modulus and LabView software. The environment requirement was ensured by means of two special climatic chambers called TestAir. Each of them is able to provide demanded parameters (temperature and humidity) for up to three cubic meters capacity in the range of temperature from 0 to 90°C and relative humidity from 0 to 95%. The temperature, humidity and pressure were continuously measured during the test. Figure 4 shows configuration of the test and Figure 5 shows typical curves of recorded values. The stiffness and deflection of the bulkhead in several points were measured before and during the test. Any stiffness changes were not appeared during the test. All conformable documents were submitted to CAA before start of the test.

The disbonding between skin and honeycomb on the left part of the pressurized side in the upper part of bulkhead (near circumferential reinforcement) was detected after realization of third life. Detected disbond size represents area about 20 mm^2. Therefore it was decided that no artificial impact damage will be made. The test continued in according the schedule. After finishing of last fourth life the non destructive measurements was analyzed.

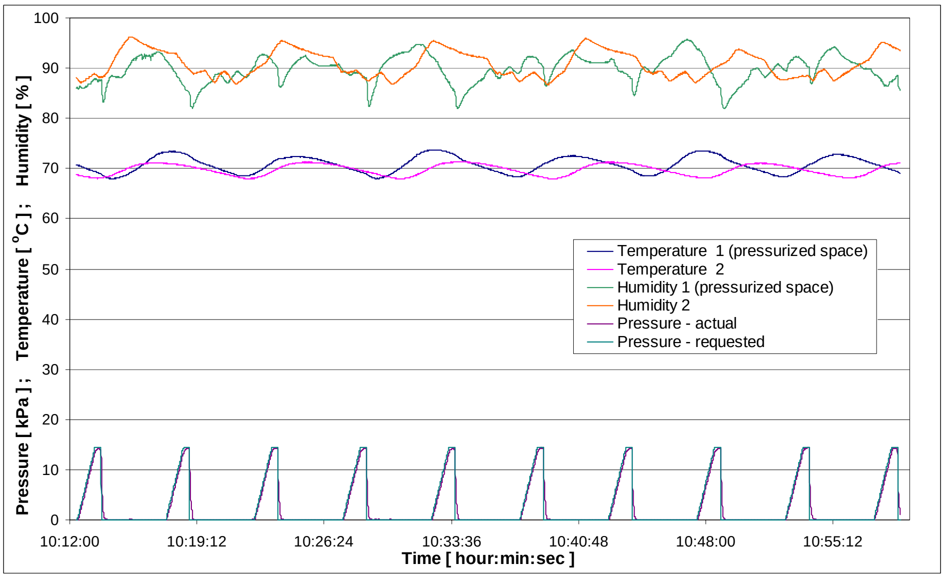

Figure 5: Typical curves of measured values (temperature, humidity and pressure) during the test

Figure 3: Location of the bulkhead inside of the testing box

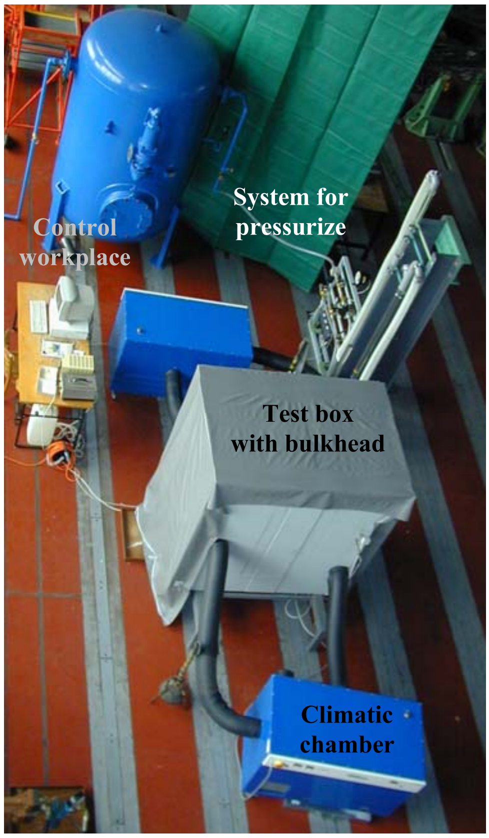

Figure 4: Configuration of the composite bulkhead test

The shearography provided best results in relation to the correct and consistent documentation of damage growth. The result of nondestructive shearography inspection by device Q-800 after finishing of the fatigue test is shown in Figure 6 and Figure 7. Figure 6 shows typical "butterfly" curve (right side) for the defect detection. On the pressurized bulkhead size were detected two flaws. Both flaws were identified as "disbond between skin and honeycomb" on the margin of size (near a circumferential reinforcement). One flaw has 90x40 mm proportion (violet curve in the Figure 7), the second one is continuous around left end of the bulkhead (red curve in the Figure 7) with width from 20 to 45 mm. Typical results from BondMaster "Pitch/Catch Swept" method is shown in Figure 8. Unfortunately during the whole test, the results from this device were not fully consistent. It could be caused by changes in operators. In any case and also from other applications the shearography seems to be very reliable method.

Finally the residual static test was performed. The bulkhead sustains required loading in conformity by airworthiness regulations. Figure 9 shows the measurement of the bulkhead stiffness in three points during the residual static test. Figure 10 shows photos of the bulkhead after residual static test. The honeycomb with bonded skins was tearing out from the frame. Relatively extensive disbond areas between the honeycomb and the skin on the pressurized side of bulkhead were detected.

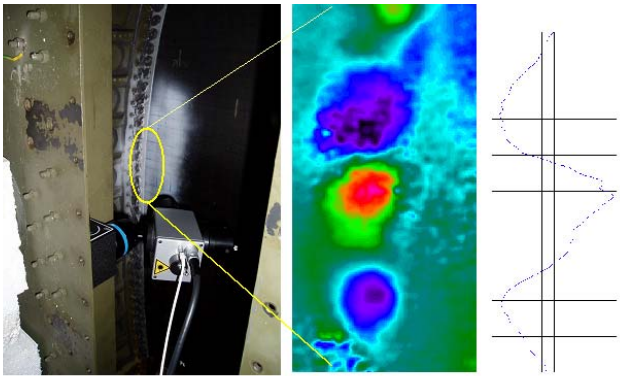

Figure 6: Detail of one full-field measurement (format A4) by shearography system Q-800

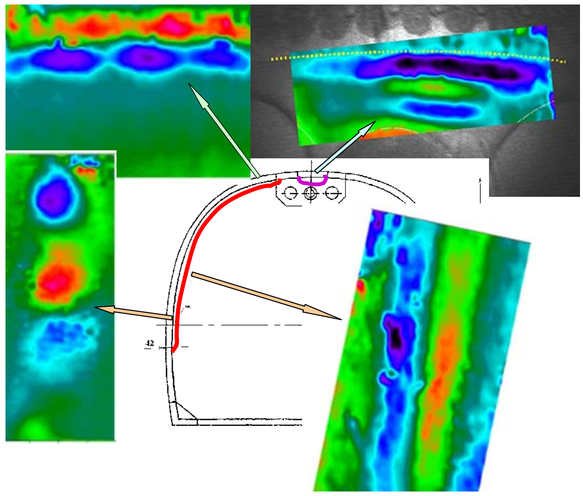

Figure 7: Results from nondestructive shearography inspection whole pressurized sid of the bulkead

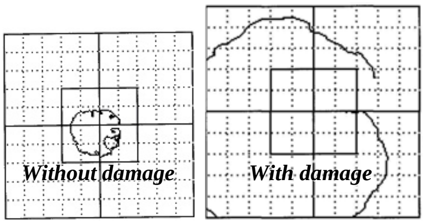

Figure 8: Typical results from measurement by BondMaster device

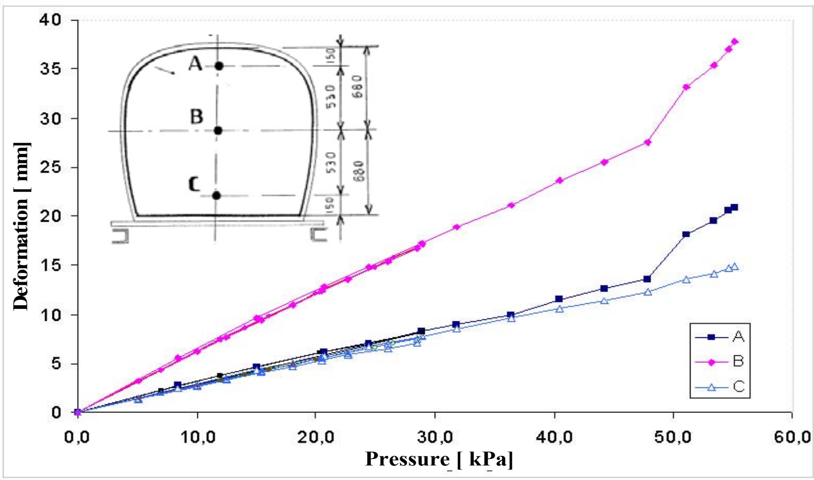

Figure 9: Deformation vs. pressure diagram during the residual static test

Figure 10: General views to the bulkhead after the residual static test

5 CONCLUSIONS

Only the structure which fully fulfilled all requirements of airworthiness regulations can be used in aeronautical operation. Each structure must pass through the certification procedure. On the base of this procedure the aviation authority grand a licence for service. The works performed at VZLÚ in connection with designing, developing and realization of the certification test of primary composite structure are presented in the paper. Methodology was accepted by Civil Aviation Authority of Czech Republic.

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