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SELECTED ASPECTS RELATED TO PREPARATION OF FATIGUE TESTS OF A METALLIC AIRFRAME

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Abstract

The basis for the computation of the service life of the PZL M28 was the results of the full-scale fatigue tests of the structure [1]. As the PZL M28 is a commuter category airplane according to the 14 CFR Part 23 and CS-23 regulations, the test objects were: (1) wing and wing load carry-through structure, (2) empennage and attached fuselage structure. Additionally, there were fatigue tests carried out for the landing gear and other selected elements including control system elements. The aircraft load carry-through structure is metallic and the cabin is unpressurized. The fatigue tests were conducted stage-by-stage. As the tests progressed, it was possible to extend the aircraft's target service life, applying a safe life philosophy with reference to the primary components of the load carry-through structure.

This paper brings into attention selected issues related to the fatigue tests preparation (the stage following the preparation of the test plan), with focus on the wing and wing load carry-through structure.

Keywords: *metallic airframe structure, full scale fatigue tests*

REMARKS ON THE SCHEME OF LOADS APPLICATION

The cooperation between the author of a fatigue test plan and the team involved in the test preparation should be established as early as possible, long before the test plan has been finished. As shown in [2], the test plan should account for all significant operational loads. In the case of the wing, important loads distributions, especially bending moment for the PZL M28's high aspect ratio wing, should be represented with adequate accuracy. So, during the fatigue test preparation phase, all loads in the test plan should be considered from the point of view of their ability to be simulated in the test. Also, the way in which each load is applied to the test article should be carefully thought out.

Figure 1. presents the PZL M28's wing and wing load carry-through structure fatigue test scheme. There were 12 actuators of MTS Aero system used. Active forces were applied to the wing (6 actuators), main landing gear (2 actuators for vertical forces and one actuator for horizontal force) and the engines frames (2 actuators for applying torque from each engine separately and one actuator for applying the power plant vertical load, LH and RH). Balancing reactions were applied to the fuselage, nose landing gear fitting and engine frames (horizontal force balanced by the engines' thrust). Wing loads were usually applied through clamps – see Fig. 2.

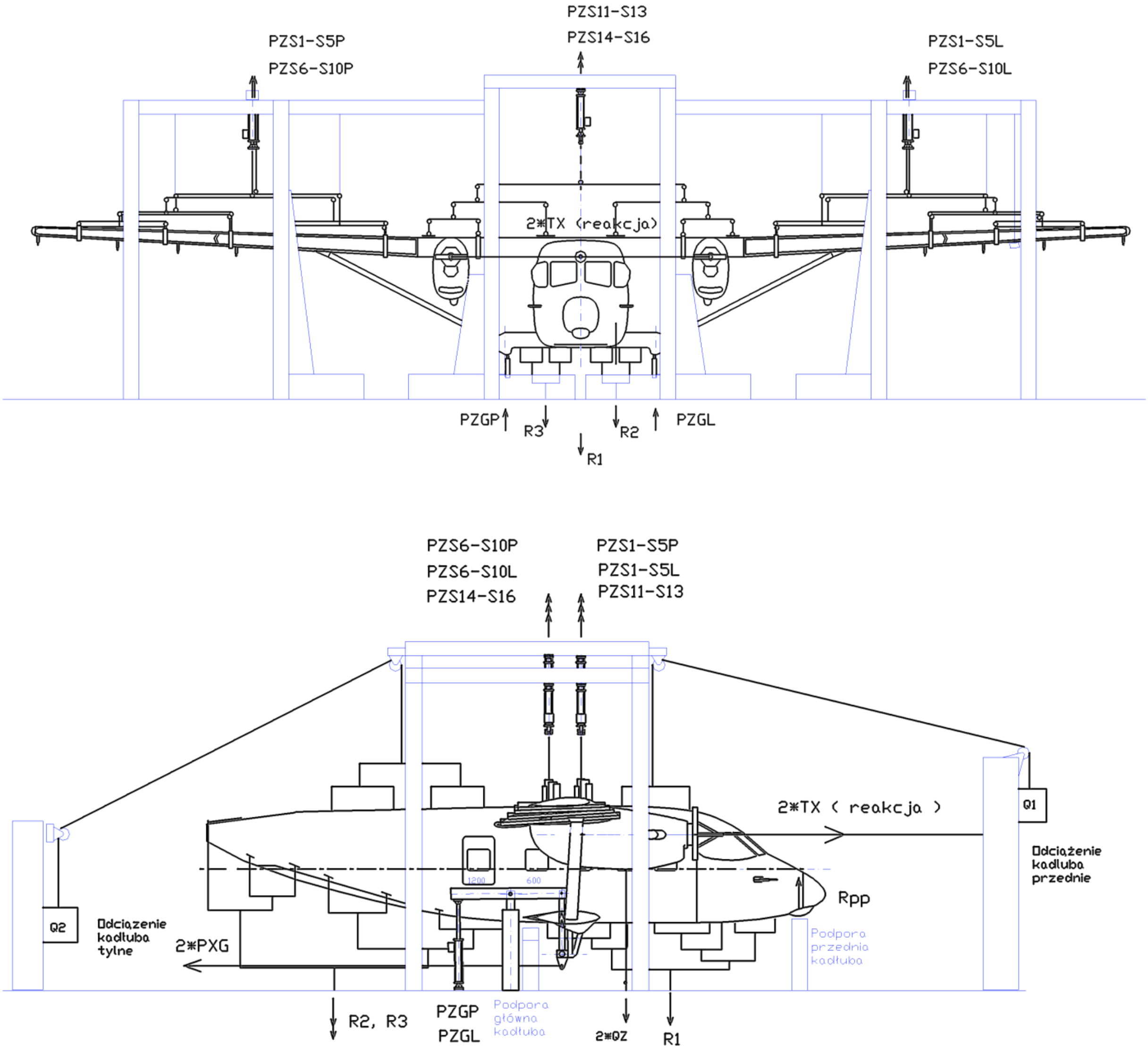

Fig. 1. PZL M28 05 wing and wing load carry-through structure fatigue test scheme. In total 12 actuators were used:

- ***6 for wing loading,***
- ***2 for main landing gear vertical force,***
- ***1 for main landing gear horizontal force (LH and RH summarized),***
- ***2 for engines torque,***
- ***1 for power plant vertical loads (LH and RH summarized) – for clarity not shown on the scheme.***

Balancing reactions are applied to the fuselage, nose landing gear fitting, and engines frames.

Fig. 2. PZL M28 05 wing and wing load carry-through structure fatigue test fixture. Clamps introducing loads to the wing are shown. PZL M28 wing consists of two outer wings and a centerwing. Each outer wing is loaded at 5 spanwise stations by 5 clamps, and the resultant forces are applied by two actuators. The centerwing is loaded at 5 spanwise stations: by 2 clamps at 2 stations and by glued tapes at 3 stations

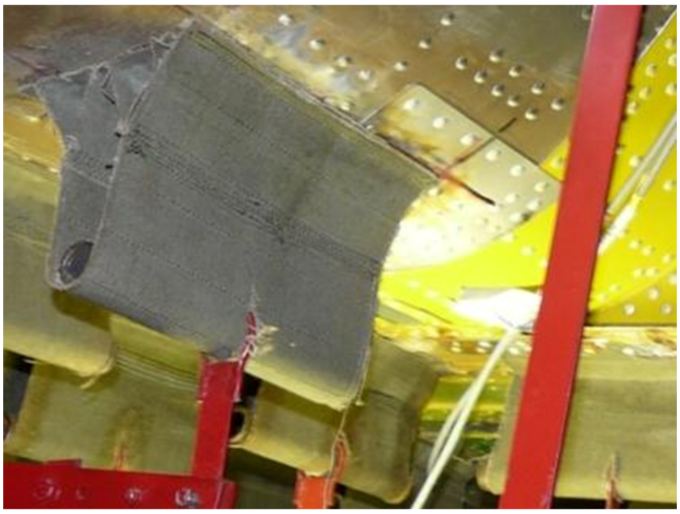

Fig. 3. PZL M28 05 wing and wing load carry-through structure fatigue test fixture. Sample tapes glued on the fuselage are shown

There were 12 clamps in total applied to introduce loads at 12 spanwise stations. At 4 wing stations, loads were applied by glued tapes. Fuselage loads were applied through glued tapes – see Fig. 3. Tapes were arranged in a way which helps avoid excessive load concentration, nonexistent in reality, and likely to introduce damage to the thin-walled fuselage structure. This rule was applied to all the loads introduced. The main landing gear leg is a convenient element to introduce ground loads, of significant effect on fatigue damage of the airframe. Vertical and horizontal loads were applied to each leg – see Fig. 4. Note that horizontal force is shifted from the wheel axle in order to simulate wheel braking effect. The engine frame is a convenient element to introduce engine torque, the vertical force resulting from power plant inertia, and prop thrust force – see Fig. 5.

The overall wing and wing load carry-through structure fatigue test fixture is shown in [1], Fig. 2.

Fig. 4. PZL M28 05's wing and wing load carry-through structure fatigue test fixture. The main landing gear axle is loaded by vertical force, applied through wheel axle axis, and horizontal force, applied at the tire ground contact point (braking moment accounted for)

Fig. 5. PZL M28 05 wing and wing load carry-through structure fatigue test fixture. The engine frame is loaded by vertical power plant inertia force, engine torque and balancing prop thrust force

Remarks on the preparation of the fatigue test of the empennage

In preparing a fatigue test plan a question that needs to be answered is what aircraft elements should be included in tested item. In the case of PZL M28's wing and wing load carry-through structure test, the answer was simple: the test items should include the wing, fuselage and wing struts. The engine frames and main landing gear (without wheels) are added to introduce in a convenient way significant loads that cannot be neglected. In the case of the empennage, the tested item was the empennage and fuselage attached structure. The question arose what part of the fuselage should be in the test fixture. After performing structural analysis, it was decided to cut the fuselage at station two frames before forward stabilizer fittings – see Fig. 6.

Fig. 6. PZL M28 05 empennage fatigue test fixture. The fuselage part used in test is visible on the photo (empennage is dismantled).
***Notice: empennage fatigue test plan was prepared by the Institute of Aviation in Warsaw. Phase one of fatigue test was also performed by the Institute of Aviation in Warsaw* [3]**

REMARKS ON THE ACCURACY ASSURANCE OF APPLIED LOADS AND THE MITIGATION OF RANDOM LOADS

Loads applied during fatigue testing should be as compliant as possible with the test plan loads. The risk of introducing random loads, dynamic loads of unknown value in particular, should be minimized.

Current quality check hardware and software provisions of the MTS Aero system (control and safety modules) are:
limits – multilevel (4 or 8) limits of set up forces;
errors - two-level error limits (in %) of applied forces shape (static, dynamic);

A/B compare – two-level continuous comparison of two independent measurements;
null-pacing - test slow-down module in order to achieve accuracy;
persistence – diminishing of safety modules sensitivity to short-time impulses;
shutdown, shutdown recorder - for emergency test shut-down with recording;
proportional, integral, rate gain, feed forward, dynamic P gain, piston ratio - optimization of servo-valves amplifier control parameters;
independent, fast, two-sided excessive hydraulic valves.

As regards the applied loads accuracy, as a rule, all possible compromises are used at PZL (particularly those related to test speed). PZL takes all possible steps to assure that errors of forces introduced into the test stand do not exceed 2 %. In practice, the following rule definitely finds its justification: the slower the execution of the tests – the smaller the error of loads representation.

As regards random loads mitigation, the MTS Aero control system makes it possible to apply the automatically maintained limit values to the actually executed loads. In the event of the quality of the applied forces being threatened, the system's null-pacing program module slows down the rate of test execution in a self-acting way. If keeping the limits is still not possible, the system generates written warning messages for the operator, and in extreme cases it automatically stops the test execution in a „shutdown" mode, generating a message giving the reason for the emergency shutdown. The limit values individually concern the values of executed force extremes and their momentary and maximum values. Moreover, these limits are of two-level: warning, failure.

The system prevents an accidental actuation of protective measures e.g. when short-term dynamic loads associated with the loading system operation, but not of a fatigue hazard nature, may apply on the measuring system of the actual fatigue loads introduced into the object. The application of the MTS Aero „persistence" program module makes it possible to determine time frames for each individual channel, where exceeding the programmed limits of forces measured not resulting in unjustified operation of the protections are possible.

Should any of the automatic test-measuring system force measuring channel fails, the MTS Aero System still allows the quality of the test and test object to be protected. Every generated force is double-measured, and the „A/B compare" system module compares both measured values on an on-going basis. If, for any reason, these values begin to differ, the system reacts automatically and depending on a size of the measured error selects one of the available options, including stopping the test in a "shutdown" mode. Despite high accuracy achieved in the phases of design and preparation of the test stand as well as correct control of the test execution, some unpredictable occurrences and failures of the test object or the test stand are possible, resulting in the emergency shutdown of the executed fatigue test.

The „shutdown" program module allows the process of emergency shutdown to be optimized in such a way that dynamic loads of the stand (generally heavy loaded) remain under control and do not cause additional damages. Briefly, the operation of this module consists in a very quick (in less than 0.01 sec.!) shutting off the stand hydraulic system from the hydraulic supply and arresting hydraulic liquid in actuators to prevent sudden pistons' movement. The test object and the loading systems become motionless and then slowly, at an adjustable speed, move towards decreasing all force values loading the test object.

Every self-acting actuation of the Aero 90 system emergency shutdown automatically starts recording of values of all test parameters measured in the system. The „shutdown recorder" continuously measures all parameters of the executed tests at a rate of 100 measurements per second and records values measured in the last 20-second interval. If the system emergency shutdown module actuates, the „shutdown recorder” will permanently save the measured values, and the 20-second interval may be divided into two intervals: before the occurrence and after the occurrence (post shutdown recorder).

A post-test analysis of those automatically recorded values of the test parameters will allow to evaluate reasons of the occurrence that resulted in emergency shutdown of the test execution. Even more importantly it will enable the evaluation of its effects. This is particularly important since it will allow to evaluate loads of the object in a view of their conformity to the allowable values that do not endanger its representational nature.

The authors have discussed only some aspects and possibilities of providing the quality of fatigue test executed in the MTS Aero System.

FINAL REMARKS

The above described provisions were checked in long-running fatigue tests of PZL M28 05’s airframe. No comments to their functioning arose during tests conduction, i.e. day-by day tests progress and test events. Some details will be presented in a subsequent paper.

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