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THE CRACKS PROPAGATION CALCULATIONS IN THE PZL-130 ORLIK STRUCTURE

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Abstract

The article presents the results of research carried out under a research project on the evaluation of fatigue life. The subject of the analysis was the critical elements of the PZL-130 Orlik. The numerical crack growth analyses were performed using the NASGRO equation. The Orlik aircraft are mainly used for the basic pilot training in the Polish Air Force. Each airplane is equipped with a digital flight data recorder. The record of more than 36000 flight hours is the basis for numerical analysis of fatigue life.

1. INTRODUCTION

In the Polish Air Force, the PZL-130 Orlik is used mainly during the basic training of military pilots. Currently, there are two versions of the aircraft: TC-I and TC-II, operating in the Polish Air Force. The design is based on the Fail Safe concept. It means that the design provides for adequate ways and means of conducting inspection of the technical condition of the structure. The airplane was given 6000 hours service life, with the overhaul executed every 1000 flight hours. More often periodic inspection of the structure are carried out, the scope of which is governed by the relevant documents. Currently, the average flying time for the operated population is approximately 800 hours. Each airplane is equipped with a digital flight data recorder. Now, the record of more than 36000 flight hours is the basis for numerical analysis of fatigue life.

The estimation of fatigue life relies on the durability test of critical airframe components. The critical elements are designated by the designer during the designing process, for example, by selecting the most intense regions. In the case of the Orlik plane, the critical components have been selected based on the finite element analysis. For the purposes of critical elements designation and the experimental determination of their fatigue life, the full scale fatigue test is performed. For the PZL-130 Orlik, the full scale fatigue test has not been carried out.

2. MATERIAL TESTING

The knowledge about the properties of materials used in the design, in particular information on the fatigue life of materials, is an important source of information for those responsible for designing and operating machinery. The phenomenon of fatigue of materials is particularly important in aviation. The aircraft are designed so as to optimize their weight. It has a significant impact on fatigue design. Nowadays, more and more planes and helicopters are being used far beyond their design life. Given the enormous cost, it is not possible to immediately replace aging aircraft with the new ones. Therefore, worldwide research is conducted to enable a longer service life. In particular, the studies relate to properties of materials. In the case of aircraft, such as the PZL-130 Orlik, a major difficulty is the insufficient information about the materials.

Material tests as well as collection and validation of data are the activities that research centers focus on. The Air Force Institute of Technology offers a Certified Strength of Materials Laboratory and access to the aviation technology withdrawn from operation. As part of a research project carried out at AFIT, some preliminary studies on static stretching of the material and the fatigue crack growth tests are also performed. The analysis of this study was based on a few selected elements of the PZL-130 TC-I wing.

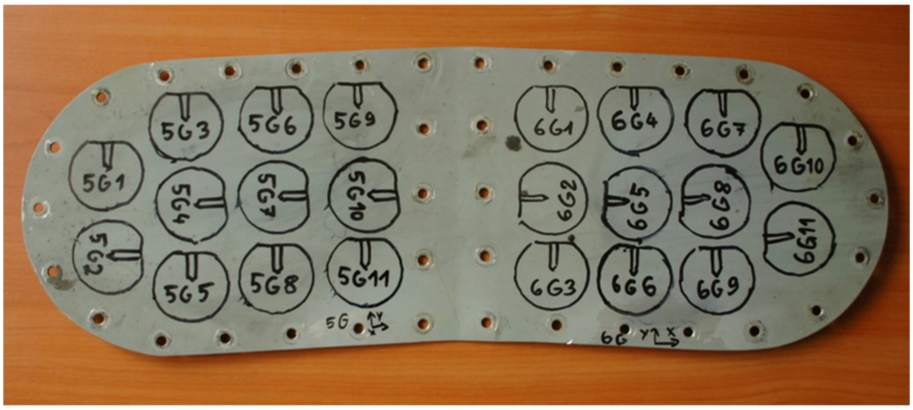

Fig. 1. Location of samples for fatigue tests

Studies of crack growth rate were performed using sixteen specimens of round compact type (RCT). They were prepared using material taken from withdrawn aircraft. The specimens were taken from the cover, which was originally located in the central part of the wing of the PZL-130 Orlik. The test was carried out according to the Strength of Materials Laboratory test procedures.

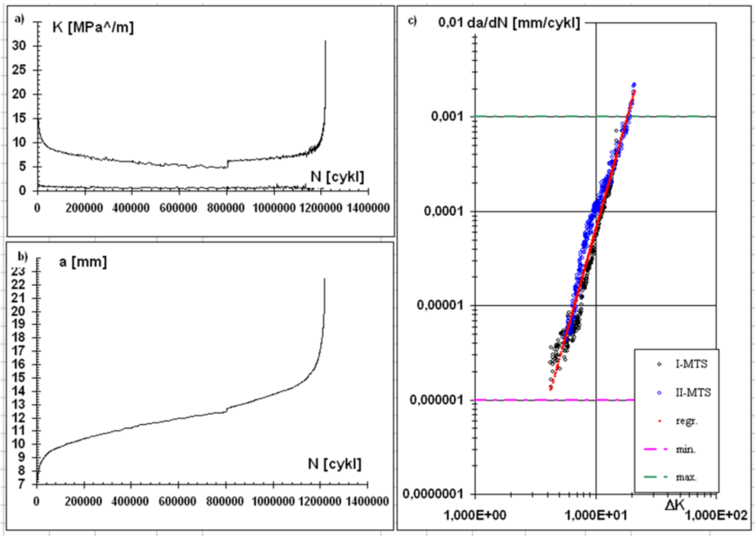

Fig. 2. Test result for RCT sample

A detailed and verified database of material properties is required to carry out reliable fatigue analysis. The implementation of fatigue tests of materials is time consuming and very expensive. Only the largest scientific centers in the world can afford to launch extensive test programs and collect all useful material parameters in a proper data base. Such programs are expensive so access to their results is usually limited. Organizations such as Federal Aviation Administration support the design and operation of aircraft. They provide information about the properties of the most popular materials used in aviation To perform the numerical analysis of fatigue crack growth, the software such as NASGRO or AFGROW is used. This software includes in its resource material data provided by the world-renowned research centers. NASGRO contains a set of results for approximately 3000 samples. Samples are classified by category of materials, their heat treatment, orientation, environmental conditions, and temperature. This gives the user great possibilities for calculation, especially for items made from standardized materials.

A significant problem is that Russian or Polish material types do not fully correspond to materials produced according to U.S. or European standards. NASGRO allows you to enter new data into the base of materials. Entering your own material data can increase the usefulness of this software. The user is responsible for the quality of data provided. Unreliable data or incorrectly entered data can cause significant errors in analysis results.

The NASGRO materials database was used to perform the analysis. It was assumed that 2024-T3 is the equivalent to the materials used for the airframe of the PZL-130 Orlik.

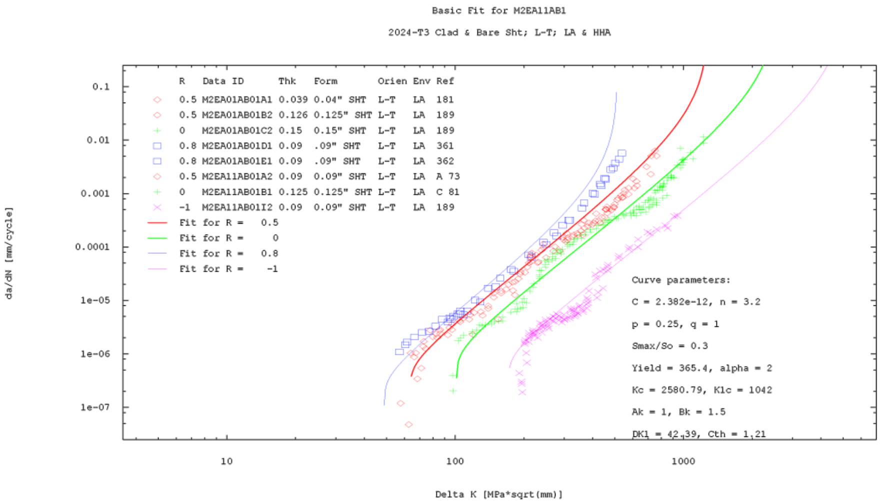

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Fig. 3. Crack growth rate diagram for the 2024-T3 alloy (NASGRO data base)

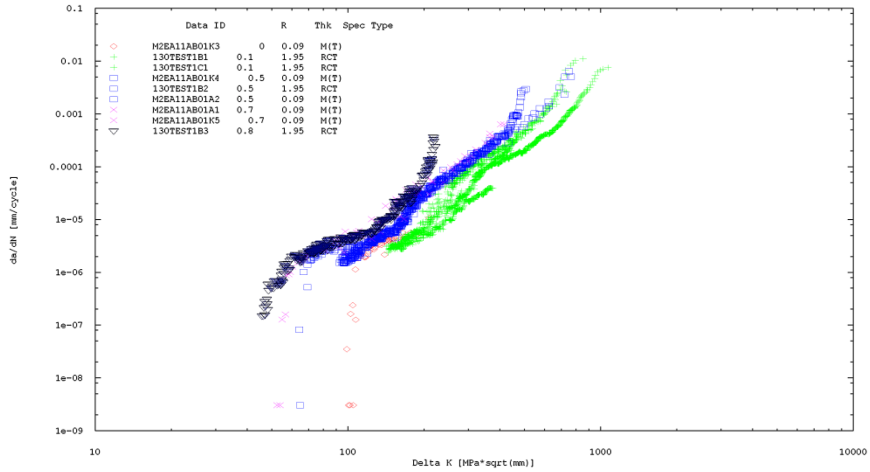

Fig. 4. Sample comparison of properties of alloy 2024-T3 with the results

3. CRITICAL ELEMENTS

Operation of the aircraft according to the damage tolerance philosophy requires the determination of critical elements in its structure. Designation of critical components should be carried out during the design of the aircraft, and reviewed and modified during the tests carried out on the manufactured structure and, if necessary, also during operation. Despite conducting full scale fatigue tests it is hardly possible to find all critical elements.

Given the current lack of full scale fatigue test of the PZL-130 Orlik airframe, to designate the critical elements of its structure, the finite element analysis was used. The elements of high positive stress level were selected. Only one load case (vertical acceleration – g load) was taken into account during the FE analysis. The consequences of this simplification were accepted.

The crack growth analysis was performed for some critical components Their shape was determined based on measurements of real structure (in possession of AFIT).

The critical elements used in the numerical analysis were made of aluminum alloy. The exception is the wing-to-fuselage connection rod made of steel. For the purpose of the analysis, the original materials were replaced with the data collected in the NASGRO material base.

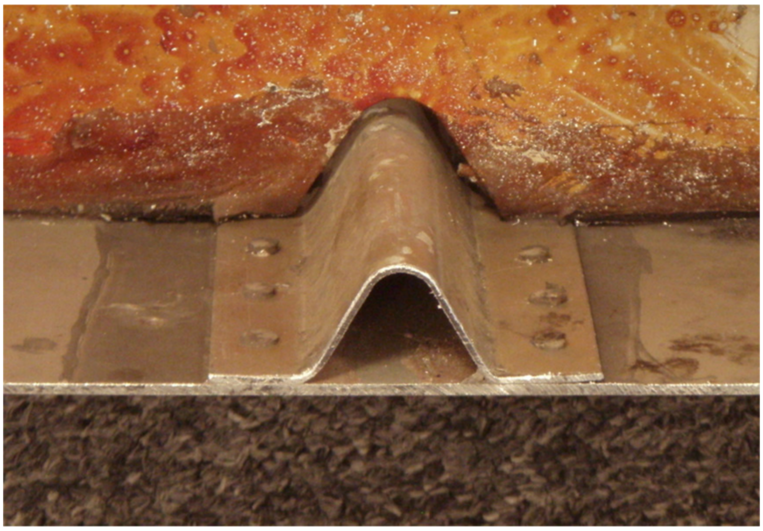

Fig. 5. Longeron (internal view)

4. ASSUMED MODELS OF CRACKS

Figure 6 shows crack cases selected for the purposes of the analysis. Following the recommendations of the research methodologies and the NASGRO software instructions, crack models were selected according to the geometry of the critical element. The initial crack length applied in the calculation was 1.27 mm. Other dimensions were selected according to the measurements. When the element thickness was smaller than the initial value of the parameter a, the calculation was performed only for through crack cases.

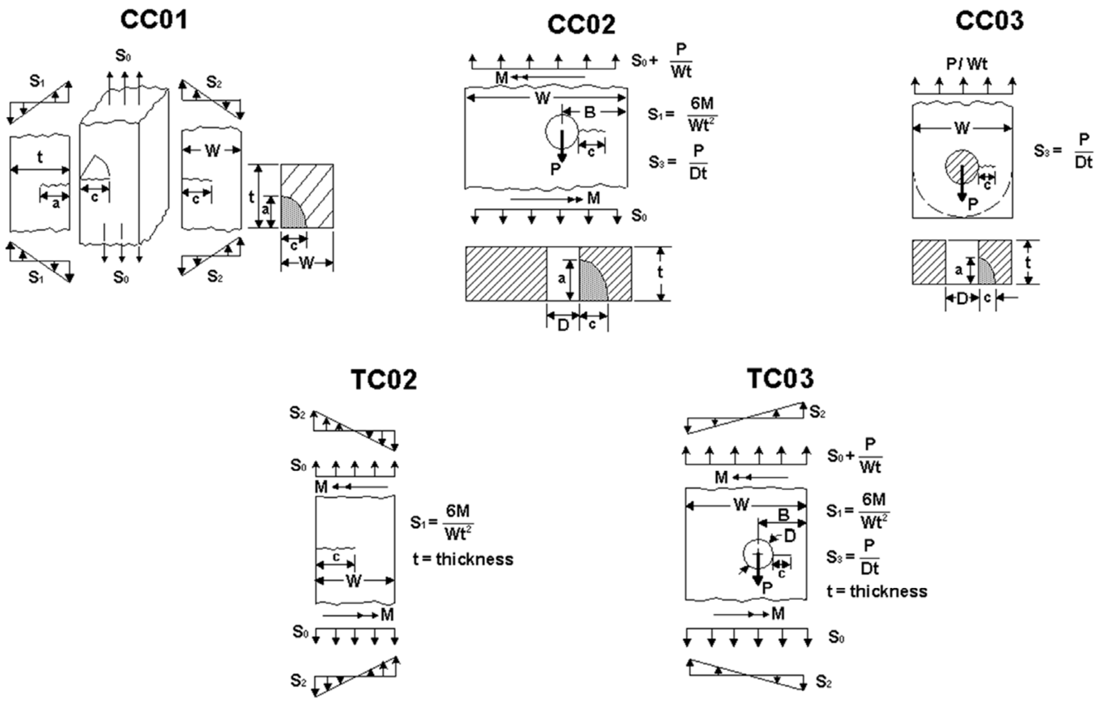

Fig. 6. Crack cases selected for calculations

5. LOADS SEQUENCES

The NASGRO software is able to use different load sequences. The basic representation of the spectrum is the NASGRO long block format. With the recorder on board of all aircraft, a real load sequence can be assumed. This is usually a time history of the recorded nz-signal. The system automatically converts the records to the NASGRO long block. In addition, at the stage of processing the spectrum to the NASGRO format, it is possible to declare the required level of filtration. This operation eliminates small range cycles and reduces the size of the final file.

The problem of selecting the suitable spectrum for fatigue test is complex. It must take into account the usage profile of the aircraft. The best solution is individual tracking for each airplane. This data set allows analyzing the individual usage and individual fatigue management. But this is very expensive and often not feasible.

There are many different solutions to the fatigue life analysis in aviation. One of them is to use the standard spectra created and developed by the research centers. Examples of such spectra are FALSTAFF, HELIX or TWIST. Due to the significant differences in aircraft usage in different parts of the world, the standard spectrum need not provide adequate accuracy of the fatigue analysis.

The Representative Loads Sequence (RLS) was developed for the trainer PZL-130 Orlik. Recorded real flights were taken into consideration. The aim of developing representative load sequence (RLS) for the PZL-130 Orlik was to obtain a load time history which was the best approximation of loads acting an aircraft structure during average flight. This load time history should be short enough to be used for numerical calculation or laboratory tests.

The single block of the RLS spectrum consists of 55 flight hours. The load values correspond to the recorded g load.

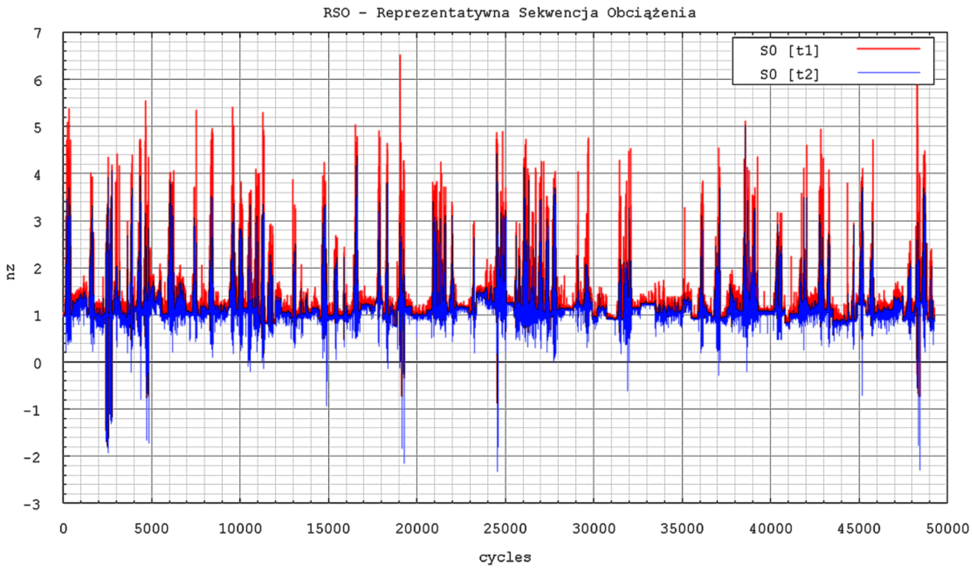

Fig. 7. RLS loads sequence

The load spectra can be edited (e.g. scaled, added, filtrated, randomized, transitioned) using the NASGRO software before they are used to calculate the fatigue life with the crack growth method. Each transformation of a source spectrum gives a new load spectrum as its result. This capability of the software was used for testing how the load spectrum affects the calculated fatigue life. The truncation of the spectrum significantly affects the size of the file that contains the record file. In the case of 10% truncation, the number of cycles was reduced 25 times but only a 1% change in the fatigue life was observed.

6. CRACK GROWTH RATE ANALYSIS

Based on information gathered on the critical location, spectrum and material properties fatigue life analysis was performed for twelve computational models. For all models, different spectra as well as crack cases were investigated. The first two calculation models were used to determine the fatigue effect of spectrum loads. The rest correspond to the critical elements selected for the analysis. To calculate the fatigue life of crack growth method, the following load sequences were used:

- RLS Truncation 10%;
- FALSTAFF;
- RLS Truncation 10% (generalized Willenborg model).

The RLS spectrum is a representation of operation of the PZL-130 Orlik. To shorten the calculation time, a 10% truncation level was used. That level of filtering does not result in significant changes in the estimated life.

An alternative to the RSO is the Falstaff spectrum. It was prepared as a standardized spectrum for the jet fighter aircraft. It is not a fully suitable representation of the PZL-130 usage, but may provide a basis for comparative analysis.

In addition, calculations were performed with the retardation model. The generalized Willenborg model was selected. It seems most appropriate to show the potential impact of the retardation phenomenon on the fatigue life. The analysis of the retardation and the choice of its models was not the subject of this work and it was not examined in detail. The properties of the retardation model were chosen according to software manual.

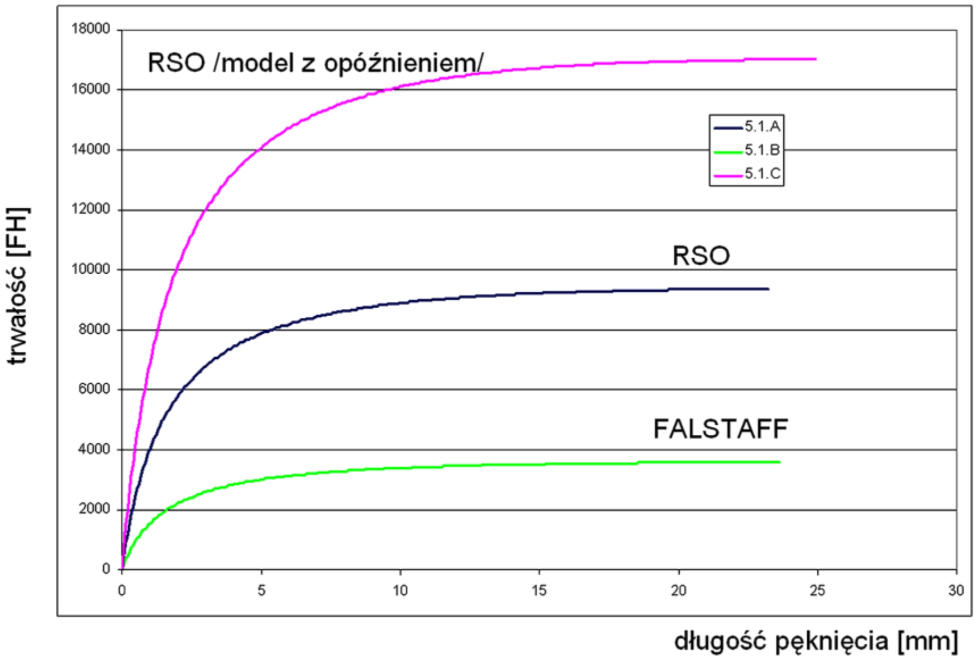

Fig. 8. Summary of crack growth rate curves for different load spectra

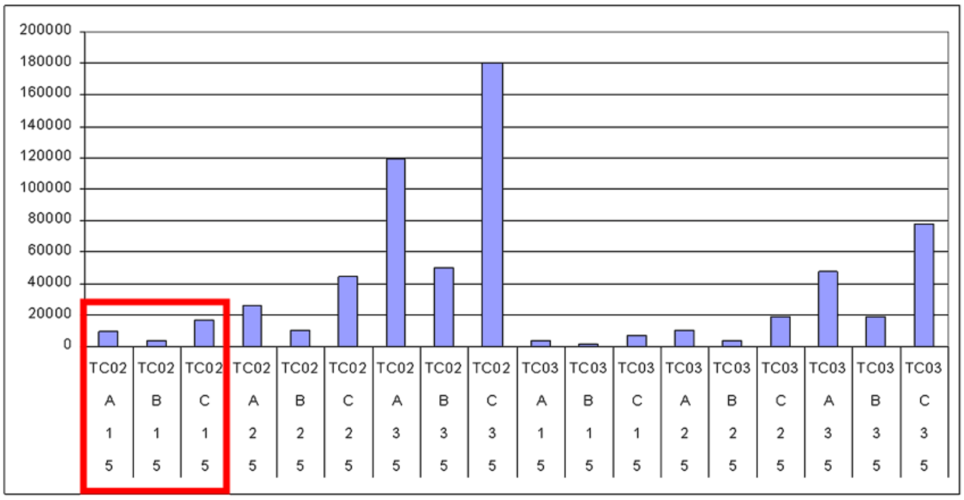

Fig. 9. Graphical representation of durability for the selected critical element

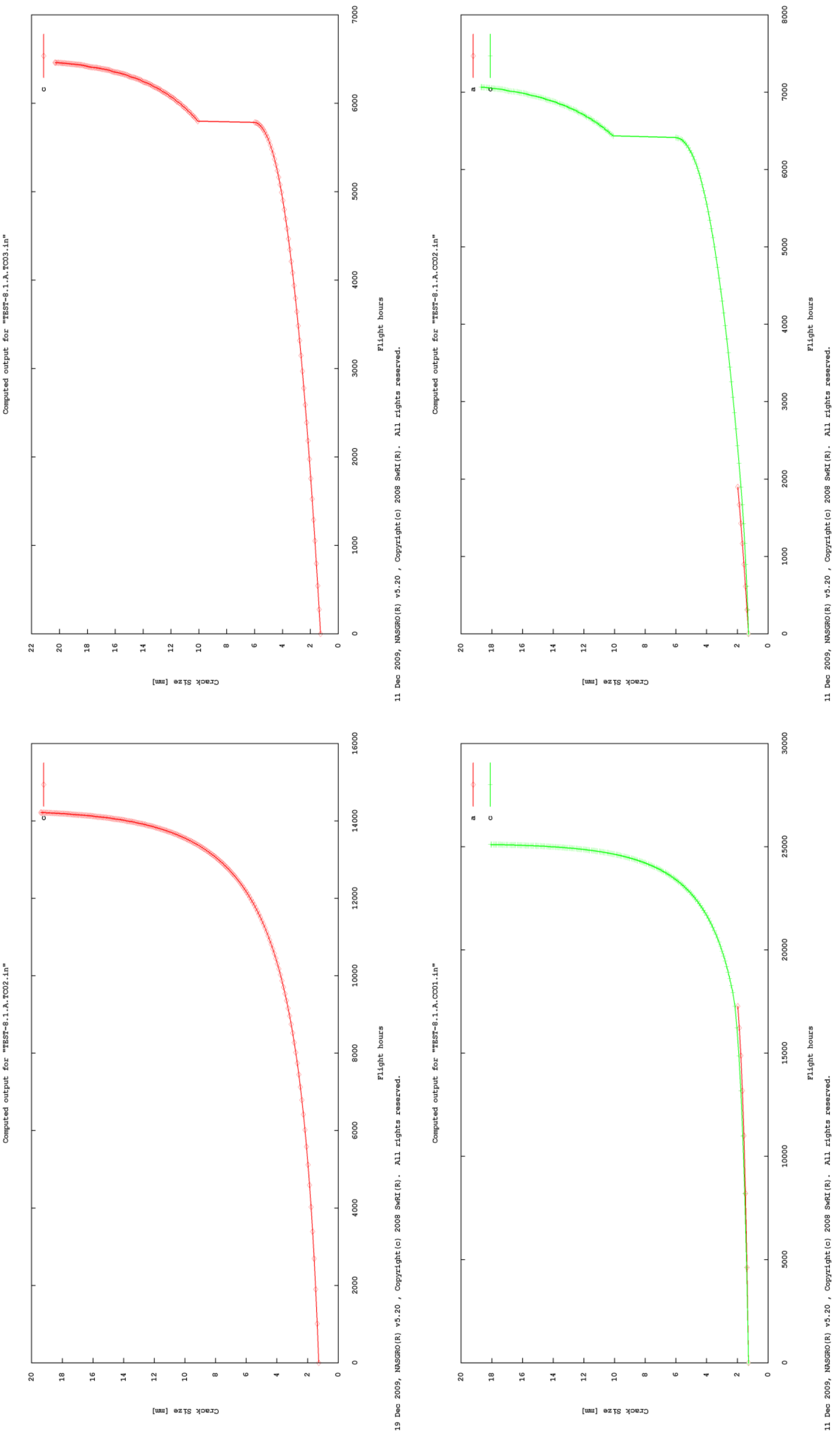

Fig. 10. Crack growth rate curves for the longeron doubler – different crack cases

7. SUMMARY

It should be noted that the analysis of fatigue life using crack growth has to be used in close cooperation with non-destructive testing of the structure. In addition, throughout the total time of the operation, the history of flying should be collected and next the loads sequence should be updated periodically. Only such a combination enables managing the operation effectively and safely. Shown in Figure 8 and Figure 9, the results of the analysis of the total durability of critical elements are not in accordance with the concept of damage tolerance. Proper management of the operation and selection of test methods for non-destructive testing as well as operation profile changes can affect the durability.

Depending on the loads spectrum chosen to analyze and crack case (Figure 9), different results were obtained. So far, the operation of aircraft PZL-130 in Poland is less aggressive than the application of standard spectra would indicate. A more detailed analysis of sustainability requires a loads sequence better representing the local impact. Critical elements defined using the global FEA model should be verified on the basis of the full scale fatigue test.

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