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EXEMPLARY APPLICATIONS OF THE REVERSE-ENGINEERING METHOD IN THE PROCESS OF EXTENDING SERVICE LIVES OF AIRCRAFT IN OPERATION IN THE POLISH AIR FORCES

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1. Introduction

Aircraft production plants set up service lives of aircraft. After the service life has expired, a question arises whether the aircraft should be taken out of service while it still shows good health/maintenance status and capability enough for being operated further on. The aircraft's health/maintenance status is affected by many and various factors, e.g. environment within which it is operated, tasks/missions performed, materials used, and manufacturing processes applied. All actions aimed at extending the service lives of individual aircraft should be preceded with analysis of criteria according to which this should be done, with the actual health/maintenance status of the aircraft serving as the basis for steps to follow. Knowledge of the history of operation of individual aircraft gives grounds for carefully approaching the problem of extending their service lives. If the history remains unknown, the principles set by the manufacturer(s) will be in force. The already gained operational experience proves that the actual service life of an aircraft is practically longer. The Air Force Institute of Technology with the seat in Warsaw, Poland, has been engaged for many years in the problems of controlling utilisation of service lives of aircraft operated by the Polish Air Force. In the course of all these years, our own research and test methods have been worked up and are continuously developed and improved.

The Polish Air Force operates mainly the Soviet-made aircraft. Therefore, the original documentation and/or results of experimental work remain either difficult of access or unavailable at all. Such situation requires reverse-engineering method to be widely used. One of the procedures which falls within the scope of this method consists in constructing computer models of parts of or whole aircraft structures. After having generated a computer model one can pass to numerical computations usually used to attain at least one of the following objectives:

- evaluation of stress in the structure after modification(s),
- estimation of how failures (corrosion) affect the stress distribution,
- estimation of fatigue life.

2. Exemplary applications of the reverse-engineering method

2.1 Reduction in stresses within the wing-root joint

The first example refers to the spar-flange eye at the wing root of a jet trainer. After some time of operational use, some microcracks in the regions close to the eyes of wing-spar flanges could be found in several aircraft. There is a plann to design a new wing root. Untill the new wing root has been finished old roots are used. A decision was made to remove microcracks by grinding them off.

Maintenance, in particular, repair experience gave grounds to determine a maximum radius of a microsection to be r=3.5 mm. This, in turn, gave rise to a question whether the selection made was the optimum value in respect of the level of material effort and degree to what the material effort was affected by both the depth and shape of a microsection. It was also decided to make numerical computations with the finite element method (FEM) to determine relationships between the shape of the microsection and the level of the material effort.The 3DX Microscribe scanner (Fig. 2) was used to construct the model shown in Fig. 1.

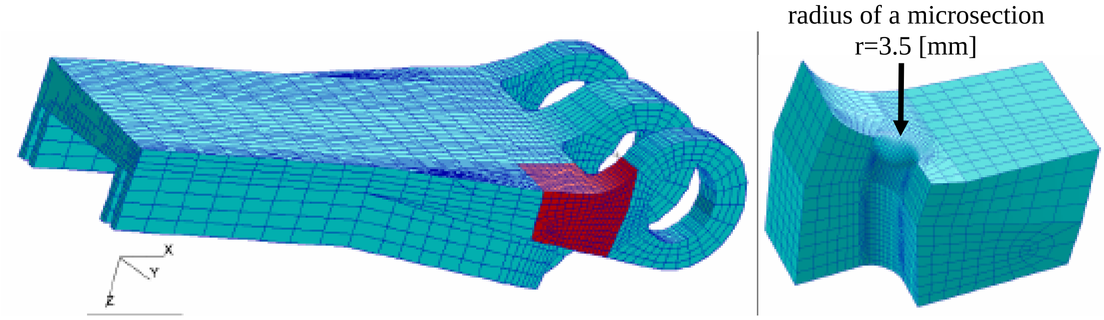

Figure 1. FEM model of the wing-root joint

Figure 2. The Microscribe scanners

The scanner was used to read out co-ordinates of points on the real object's surface, which gave grounds to construct a geometrical model with the MSC.Patran program engaged.
Numerical computations with the finite element method (FEM) were applied to determine the optimal shape of the microsection to reduce then stress concentrations. The percentage values are to be referred to a model without a microsection (r=0) [Niezgoda 2000].

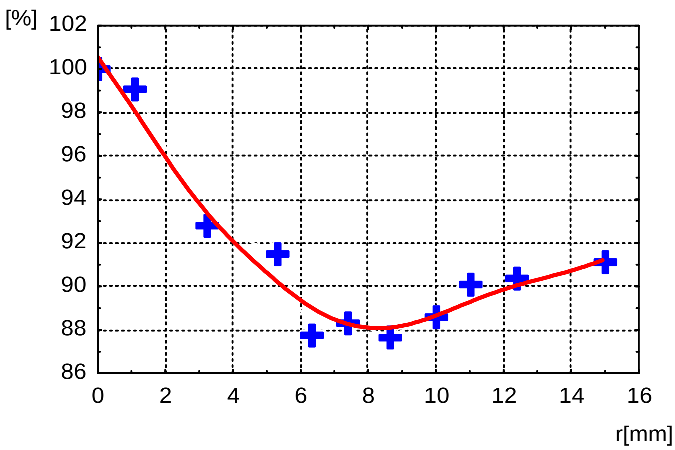

Figure 3. Dependence of the maximum material effort within the examined component on the radius of a microsection

The conducted analysis confirmed attempts to reduce material effort within a critical component by selecting a suitable grinding technique to be really effective. Each modification of the microsection's shape given consideration reduces the maximum material effort. The location of the maximum effort doesn't change, which means that the changes of shape haven't significantly changed operation of the considered element. Reduction in the material effort gained is still larger than 10% of the material effort at r=0.

2.2 Interlayer corrosion

Another example illustrates the problem of estimating the interlayer corrosion in riveted joints, which results in the so-called pillowing effect. The riveted joints find many applications in aircraft industry. Corrosion remains unavoidable throughout the process of operating aircraft. Corrosion of material within a lap joint leads to the pillowing effect which occurs in sheet-fixing riveted joints. The riveted joints are typified with the two elements to be joined, e.g. two sheets of metal or a sheet and an angle bar, contacting each other with their surfaces to build the so-called overlaps, with rivets fastening them. The riveting technique requires many rivets to be arranged, depending on real needs and conditions, in one or several rows within the area of a joint. Released products of corrosion (hydrated aluminium oxides) are of volume greater than that of the corroding material. Since corrosion occurs inside the joint, the products of corrosion cannot escape from the joint. As the volume of corrosion products increases, the joint expands. The elements that build up the joint change their shapes, the change being proportional to the joint's rigidity. The greatest changes in shape are to be found between the rivets, whereas the smallest ones - close to zero - in the areas of contact with rivet heads.
The resulting deformation shows on the surface as sheet folds within the area of the joint, its shape depending - among other things - on the rivets distribution. Corrosion within a riveted joint is a real hazard, in particular to aeronautical structures. A fuselage skin plays its role in the transmission of loads affecting the aircraft in flight. Corrosion within a riveted joint is a real disadvantage for at least two reasons: first, thickness of sheets of fuselage skin is reduced, and second, some extra stress occurs where rivets contact the skin sheet due to pressure of corrosion products. Since corrosion remains unavoidable, some methods of investigating into the problem of how the interlayer corrosion affects the aircraft's operational safety need to be evolved. Amount of the pillowing-effected deformation can be a measure helpful in non-destructive testing to determine degree of corrosion inside the riveted joint. Optical measurement of the pillowing volume is feasible with the DSIGHT Aircraft Inspection System (DAIS). The DAIS system supplies information on the pillowing volume by means of indirect measurement of the deformation amplitude.

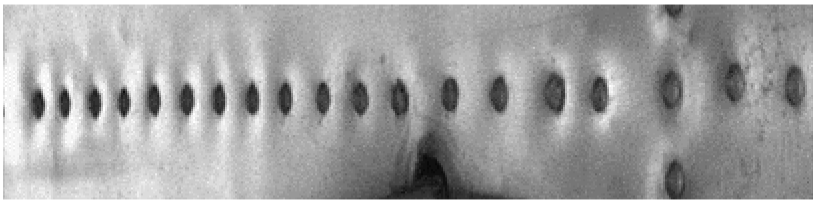

Figure 4. Graphically represented measurements taken with the DAIS

Such information is however insufficient to properly assess whether the joint is safe or not, because any deformation depends on many and different influences of at least some effect, e.g.:

- the arrangement of rivets in the joint,
- thickness of sheets,
- intensity of corrosion.

The numerical-modelling technique can be additionally engaged to analyse whether the riveted joint is safe, with the pillowing effect taken into consideration. The interlayer-corrosion-effected stress within the riveted joint can be determined by means of numerical simulation with the (FEM), engaged [Bellinger 1997]. With the numerical model engaged, the effects of microcracks initiated in the area of rivets can be modelled [Bellinger 1999]. Analysis of how the location of rivets affects the pillowing intensity is also possible. The findings of such analysis are expected to deliver some clues on designing and developing riveted joints of such a kind as to minimise the effects of interlayer corrosion.

Evaluation of pressure exerted by the products of corrosion is probably the most fundamental difficulty in the field. However, it is possible after accepting several additional assumptions. These are as follows:

- corrosion throughout the area under analysis is of equal intensity,
- products of corrosion gain volume proportionally to that of the corroded material,
- products of corrosion exert pressure of exactly the same value throughout the corroded area.

Application of the above-suggested approach enables evaluation of pressure (the so-called ‘equivalent pressure’) exerted by the products of corrosion for a pre-set level of corrosion in the riveted joint given consideration. Evaluation of the equivalent pressure consists in finding such a value of pressure at which deformation of skin sheets allows the products of corrosion remain contained inside the joint. Knowledge of the non-linear relationship between the amount of equivalent pressure and the level of corrosion is of key significance to the process of modelling the pillowing effect. Finding this relationship proves an uphill task and consists in function sampling, i.e. in evaluating equivalent pressure for the assumed level of corrosion. The relationship found proves to be true solely for the considered type of a joint featured with geometrical arrangement of rivets, skin-sheet thickness, and the material used.

The assumption on the level of corrosion intensity (corrosion density) has become a starting point to evaluate the pressure. Knowing both the depth x_k to which the corrosion has penetrated and the area s_k over which it takes place enables the volume occupied by the products of corrosion V_k to be determined:

$$V_k = s_k x_k \left(\frac{V_{mr}}{2} - 1 \right) \tag{1}$$

where: V_{mr} - coefficient of gain in the products-of-corrosion volume [Bellinger 1994]. For the hydrated aluminium oxide $Al_2O_3 3H_2O$, the V_{mr} coefficient takes value 5.454. The algorithm to evaluate the equivalent pressure follows the steps as mentioned below [Baraniecki 2000]:

1. A simplified FEM model of the skin (flat elements only, with no rivets) is constructed,
2. The model is loaded with pressure of any value, e.g. 1MPa,
3. Deformation of the skin is determined,
4. Volume of space effected by loading the skin with pressure V_n,
5. Two values, V_n and V_k, are compared,
6. If the compared values differ, the value of pressure is to be changed and steps 3 through 5 repeated.

The usage of a simplified model to evaluate equivalent pressure makes the task easier and needing less time. The simplified model takes account of real boundary conditions and is made of 2D components (Fig.5).

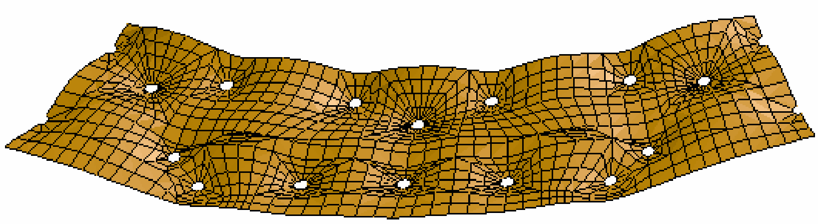

Figure 5. Deformation of a simplified model

Owing to numerical analysis of the riveted joint we can arrive at an accurate description of the state of stress inside the joint due to material corrosion. In particular, the analysis enables determination of the stress tensor in rivets and skin sheets. Together with testing work performed with the DAIS system, the numerical modelling provides us with information indispensable to evaluate actual safety level of the riveted joint. The numerical model can serve the aim of modelling the effects of microcracks occurring in the round-rivet areas. Analysis of how the rivet location affects the pillowing effect is also feasible and can deliver some clues on designing and developing riveted joints of such a kind as to minimise the effects of interlayer corrosion.

2.3 The process of constructing the model of the helicopter

The making of computations on fatigue life is undoubtedly a stage of significance to the whole process of extending service lives of aircraft. An aircraft designer assumes some specific operational-phase profile. If there are data that describe the actual process of aircraft operation/maintenance, the service life still left can be estimated. With such data available, the aircraft service lives can be extended with the level of the manufacturer-determined operational safety maintained. The algorithm to evaluate the fatigue life of aircraft (in short) is presented below:

- Operational loads monitoring (OLM)
- Developing of FEM helicopter model
- Stress analysis of CSE's (critical structural element)
- Calculation of fatigue life based on Def Stan 00-970

There are same softwares to calculate the fatigue life e.g. Afgrow, MSC.Fatigue. The fatigue life depends on the stress level wich can be estimated using computer model of a helicopter. Lack of precise design documentation is probably one of the most significant problems while constructing the FEM model of a helicopter. Therefore, to generate a model of the Mi-14 helicopter, digital photogrammetric technique was used. The process of constructing the FEM model of the helicopter comprised several stages. These were as follows:

1. Approximately 2000 markers were stuck upon the helicopter's airframe.
2. Approximately 200 photographs were taken with a digital calibrated camera.
3. The computer-arranged 3D orientation of the photos (with the PhotoModeler software) was accomplished.
4. Curves were extracted from the photos.
5. Shell model was built ,
6. Numerical model was generated (with the MSC.Patran).

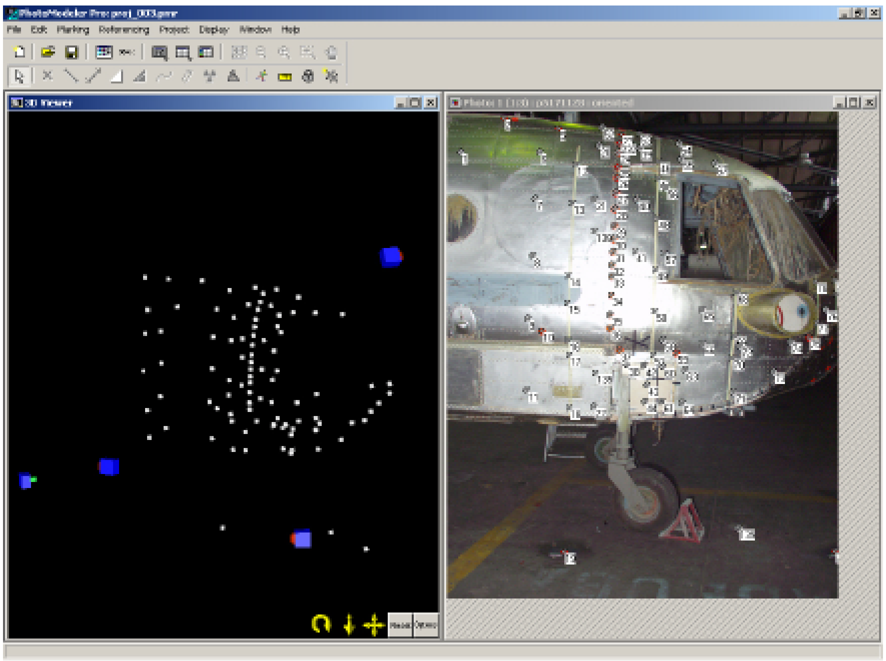

Figure 6. The screen of PhotoModeler software

3. Conclusion

Numerical modelling is a very convenient way of gaining knowledge on a real object. The FEM computations can be used to both determine fatigue life of an aircraft and prolong then the service lives thereof. If precise design documentation is lacking, measuring methods become necessary. Development of measuring techniques enables computer models to be quickly constructed with any suitable degree of accuracy. This paper present examples of use special measurement equipment to support revers design process. A mix of FEM and using the special measurement equipment enables to build models and to conduct numerical analysis even the original documentation remain unavailable at all. It is worth to stress that development of measuring techniques enables more and it reduces costs of modelling process but human knowledge is still necessary.

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