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CRACK GROWTH ANALYSIS OF THE LANDING GEAR PULL ROD OF THE FIGHTER JET AIRCRAFT

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Abstract

This paper describes the problem of searching for the causes of damage in the form of rupture of a strength member of the main landing gear. There have been two incidents noted which both occurred during hangar storage. It should be pointed out that the two occurrences mentioned concern a particular aircraft currently in operation, and that these incidents occurred a few days after the last flight.

This article presents part of the investigation process needed to determine the causes of cracks in the test item. The crack growth analysis of the pull rod was performed using the NASGRO software. In order to perform the calculations, the information was gathered during previously conducted material studies and flight tests.

Keywords: crack growth, fatigue, flight tests, landing gear

1. INTRODUCTION

1.1. Su-22 Fitter – general information

Aircraft landing gears are a critical group of subsystems. Any damage to almost any of their components may lead to a crash. Providing some adequate level of safety during flights as well as during ground operations requires that the strictest quality criteria are fulfilled throughout the manufacturing process and subsequent operation.

Most aircraft in service with the Polish Air Force were manufactured over twenty years ago in the former Soviet Union or in Poland. Currently these aircraft have reached or have exceeded the planned period of operation. The high cost of buying a new aircraft and the fact that the currently operated aircraft have significant reserves of hourly service life have encouraged the operator to take effort in order to extend the aircraft operational lifetime. The process of extending the lifetime involves taking a series of measures designed to assess the usability of these aircraft.

Sukhoi Su-22 FITTER is a single engined supersonic fighter–bomber jet airplane. The aircraft was manufactured in the former Soviet Union in several variants. It has been operated by the Warsaw Pact countries as well as by some countries in the Middle East and Africa. Sukhoi Su-22 FITTER has been in service of the Polish Air Force since 1974, when the Su-20 variant was introduced as a successor to the Su-7. Since 1984 many Su-22 fighters have been operated, in two variants: Su-22M4 - an export combat version and Su-22UM3K - a two-seat training version.

Fig. 1. Su-22 FITTER aircraft

The airframe structure is a semi-monocoque with a variable sweep wing which improves the flight characteristics in the whole range of flight velocities. Top maximum velocity, depending on the variant, is 1.7 ÷ 2.1 Ma, while the landing speed is 280 ÷ 290 km/h.

The Su-22 aircraft is equipped with a three-strut landing gear. Main loading forces acting on the aircraft during landing, runway maneuvers and standby are transmitted by the main (rear) landing gear struts. The main landing gear struts are attached to the structural elements in the wing's landing gear recesses. Chief structural elements of the main landing gear include among others the strut, shock absorber cylinder, trailer arm, torsion links, and the pull rod.

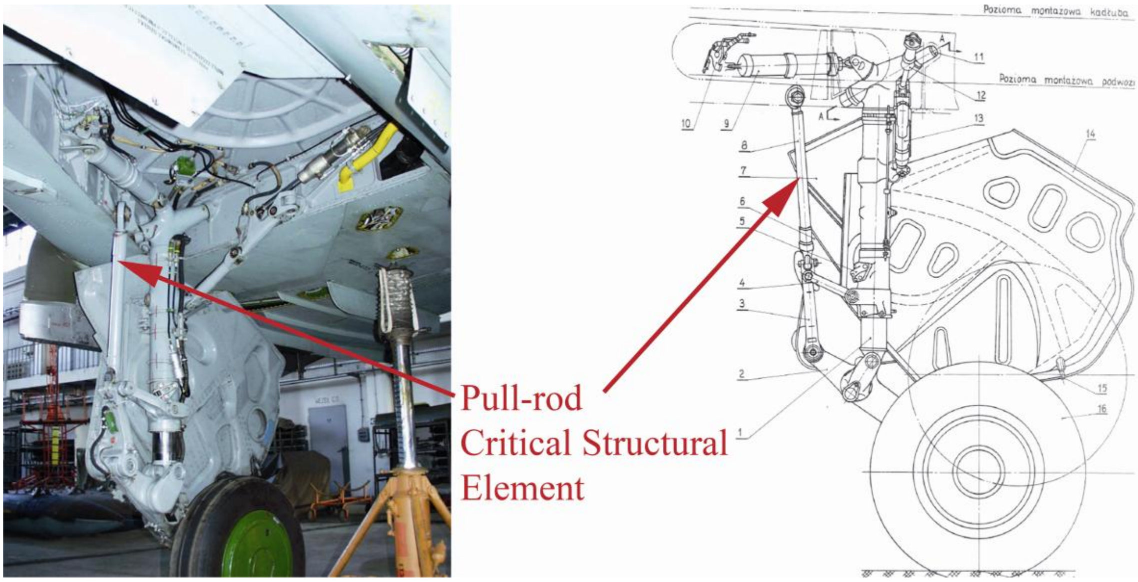

Fig. 2. Main landing gear schematics

The pull rod is the member responsible for transmitting the load to the wing's strength members via the torsion links. It consists of two structural elements, the lower eye and the pull rod cylinder (tube). These two elements are joined by welding. The tube is fastened to the other (upper) eye with a threaded connection which permits regulation of the pull rod's length.

The component set-up for the welding process utilizes a steel alignment ring. The ring is attached to the cylinder of the eye component (fig. 3) by three spot welds that are evenly placed on the tube's circumference.

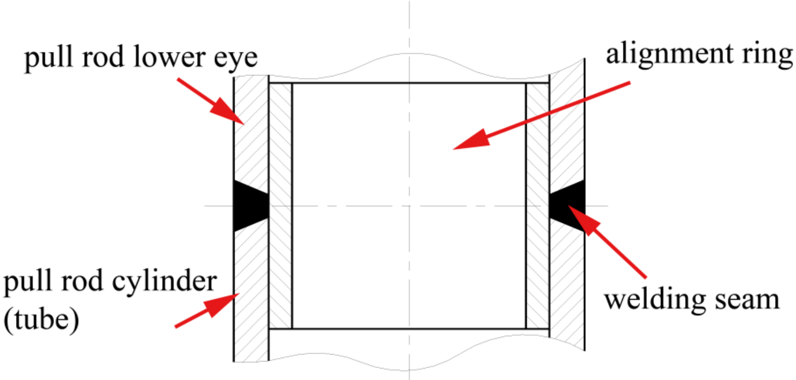

Fig. 3. Welded wiring diagram

1.2 Problem description

The problem described in the present paper concerns the pull rod of the Su-22's main landing gear – a critical structural element [3]. The problem is related to two incidents, of which the first (in 2004) was a surprise for the operator. During a morning inspection of the hangar buildings, the aircraft was observed lying in an untypical position. Preliminary visual inspection revealed a rupture of the pull rod (No. 8 on Fig. 2) of the left main landing gear. After the inspection, the aircraft was elevated and restored to a proper position and the damaged component was replaced. Subsequently, after a detailed inspection of the landing gear, all necessary repairs were carried out. After the repairs, necessary tests have been performed to verify the landing gear's performance – such as retraction and extension tests, automatic braking systems tests, cockpit signalization systems test and others. Next step in the landing gear's inspection was the inspection of the torsion links' structural health with the color defectoscopy method.

Fig. 4. Failure of the main landing gear

The Incident Board ordered an analysis of the flight parameter records over the last 5 months of service. Parameters were taken from the onboard flight data recorder "TESTER" and the last 5 months of service were analyzed. During this period the aircraft in question made 13 flights. This was the period between the last maintenance test flight and the day the gear damage occurred. In the course of investigation the following flight parameters were taken into account:

- aircraft velocity - at gear retraction and extension
- landing velocities and accelerations,
- level of fuel remaining on landing

The Incident Board recommended that the inspection of the fracture face be performed with the use of a magnifying glass (x5). The analysis of the fracture face character enabled the Incident

Board to evaluate the usefulness of the color defectoscopy method as a means of preliminary selection of pull rods that might present a flight safety hazard for the Su-22 fleet. During the tests and investigation of the rupture cause, macroscopic analyses using the magnifying glass as well as microscopic analyses with the use of microscopes were performed. Several defectoscopy methods have also been utilized i.e. the visual, eddy-current, magnetic particle and the ultrasonic methods.
It is important to note that the described incident took place during hangar standby, a few days after the aircraft's last flight. This indicates that the critical crack length had almost been reached, yet without the crack being noticed. Prior to the emergence of the critical crack on the pull rod, the aircraft had been in service for 19 years during which there were about 1700 take-offs and landings. The in-flight time for the described aircraft amounted to almost 1300 hours, with the designed service life being 2000 hours.

According to the instruction of the Board, tests were performed on the rest of the fleet. The tests consisted of color defectoscopy analysis of the critical welded connection. In some cases doubts were raised as to a particular pull rod's structural health.

Fig. 5. An example of a defect in the area of welded joint

Despite continuing diagnostic tests, the problem re-emerged in 2010. Similarly to the earlier incident, a rupture of the pull-rod of an in-service aircraft occurred. As before, a few days after the last flight a disjointing of the pull rod elements took place. This time, the incident happened on an aircraft that had been in service for 34 years/~1300 flight hours. In this service period the aircraft performed 1716 landings.

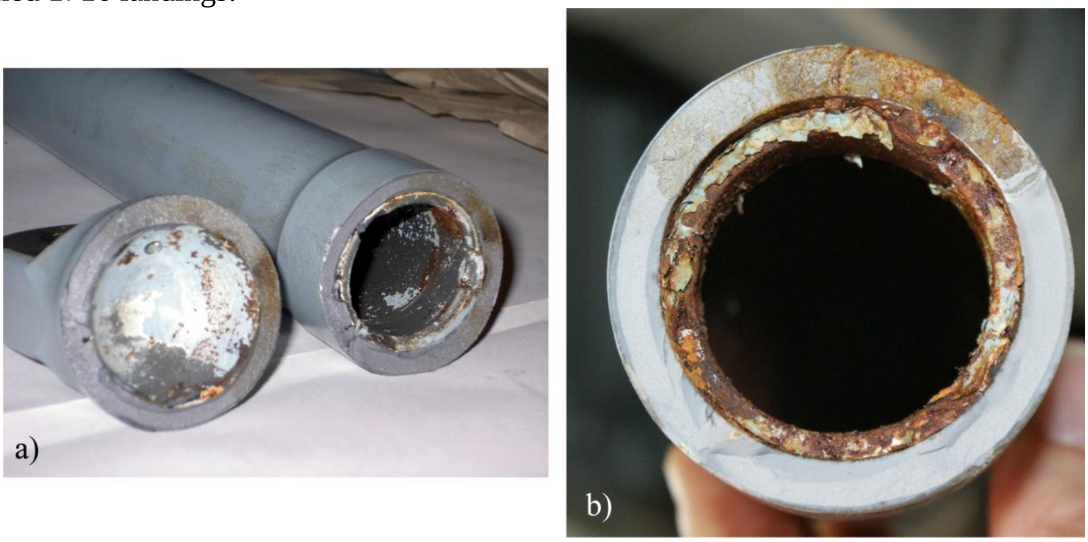

Fig. 6. Failures of the landing gear pull rod
a) year 2004, b) year 2010

Both rupture cases seem to have many common characteristics, and the damage occurred in the same area. The occurrence of another pull-rod rupture in an in-service aircraft suggests that the countermeasures applied following the first incident were insufficient. In consequence, further actions were carried out to determine the causes of damage. Also, NDI methods were devised and verified in an attempt to detect damage before the occurrence of the pull-rod ruptures.

2. CRACK GROWTH ANALYSIS

2.1. Maintenance/operation/service profile and flight tests.

Taking into account the 2010 service profile of the Su-22 in the Polish Air Force, an attempt has been made to work out the assumptions that would enable the extension of the Polish Su-22s' service life. The necessary research was carried out by the Polish Air Force Institute of Technology, which is the R&D support institution for the Polish Air Force (PAF). Su-22s operated by the PAF are aircraft which have already reached their designed calendar service life so, according to the initial assumptions, the fleet should be decommissioned. However, given the enormous cost of replacing the aged aircraft and the fact that the aircraft have significant reserves of hourly service life, they still remain in service. The designed service life was 2000 flight hours, yet its current realization in the PAF is ca. 1500 FH per single airplane.

As a part of preparations for the flight tests and the maintenance system modification program, an average service profile for the PAF's Su-22 aircraft has been determined. Service profile is the specification of percentage contributions to component fatigue damage from each of the flight phases distinguishable. In the course of the actions described, the landing gear's average performance profile has also been determined. The profile devised includes such elements as: take off, landing, taxiing, as well as any other operations that cause the loads on the landing gear components to vary in time. The elements - phases specified in the average service profile have been executed during the flight test program.

Most of the landing gear's fatigue damage can be attributed to the Ground-Air-Ground cycle. The dynamics as well as the range of the loads in this particular cycle inflict the most fatigue damage to the landing gear's elements. Because of that, the manufacturers often express the LG durability (fatigue life) as a number of permitted landings/take-offs.

Based on the service load profile, a flight test program was devised. This program was carried out in 2004. For the tests, one Su-22M4 (single-seat combat version) was employed. Prior to the tests, during an overhaul at the Military Aviation Depot no. 2, the aircraft had been prepared for the flight tests and fitted with the ACRA KAM-500 flight data recorder. The aircraft's preparation consisted of instrumenting the airframe with strain gauge sensors. The chosen structural elements and their corresponding strain gauges (including the LG pull rod) were calibrated (scaled) under known loads. This operation enabled to measure and record the load signal values in units of force. In all, 12 flight parameters and 62 strain gauge signals were recorded during the flights. Throughout the program the KAM-500 recorder was synchronized with the on-board recorder TESTER. In the program, 11 flights were performed - including the accompanying maneuvers - runway taxiing, aircraft hauling and engine tests. Flight tests were prepared so that all the flight element blocks could be executed. One of the signals recorded was the force acting on the landing gear pull rod, which is the subject of the present paper.

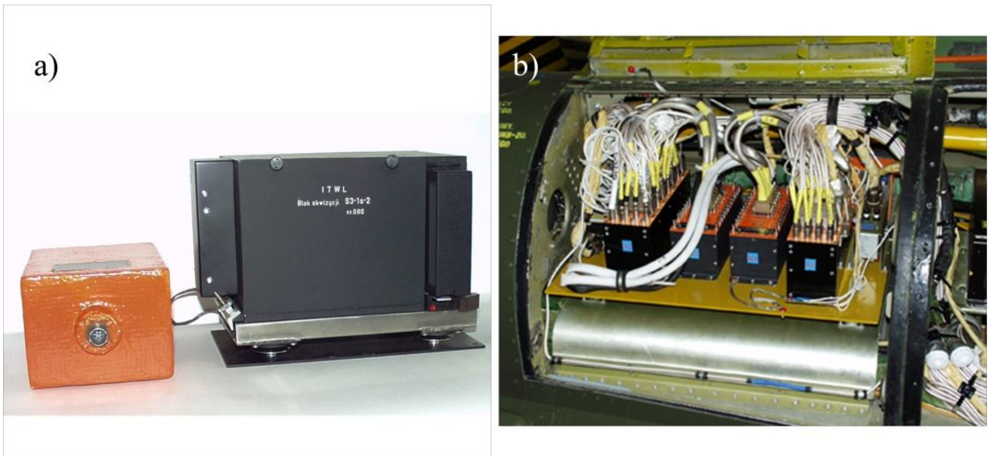

Fig. 7. Recording systems
a) TESTER U3L, b) ACRA KAM-500

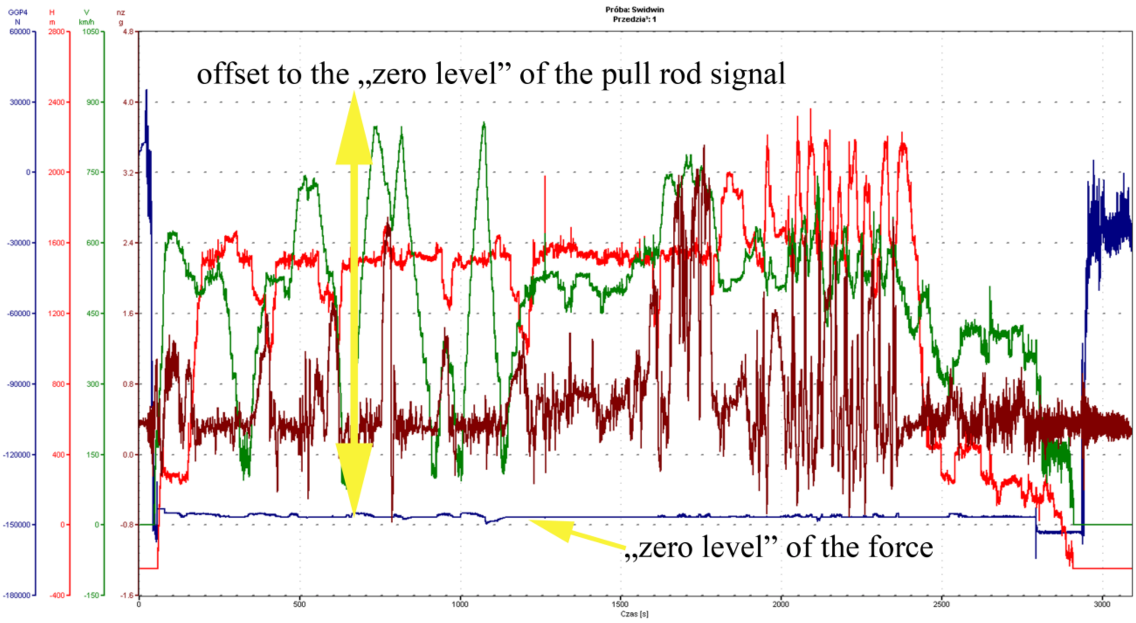

Fig. 8. Selected record of the test flight
H – altitude, V – speed, nz – vertical acceleration, GGP4 – load in pull rod signal

2.2. Crack growth analysis

Determination of both the critical crack length and the number of cycles necessary for the onset of critical damage is one of the most important tasks facing the durability (fatigue) engineers. The rupture incidents described in the paper resulted in performing fatigue calculations of the main LG. These crack growth analyses were performed with the NASGRO software. Such analyses require a database containing the investigated member's load and performance history and material data, as well as making an assumption regarding the suspected damage mode.

The pull rod's material properties were determined in the AFIT's Strength of Materials Laboratory. It was concluded that the pull rod was manufactured from a high-strength 30HGSNA steel (UTS = 1620 MPa, YS = 1370 MPa). The material test was performed with the use of the MTS 250 material test system.

The load sequence the analysed element is subjected to during a typical operation, was determined based on the flight test results. During the tests the time variation of load was recorded. Based on this record, the load profile needed for the computational analyses was devised. The load profile input in the simulation was composed from the following blocks: take off (1), landing (2), runway taxiing (3), runway towing (4). These blocks were set together in the sequence 4-4-4-1-2-1-2-1-2-4-4-4-3. This sequence is an equivalent of 3 GAG cycles along with the approximation of accompanying runway maneuvers. Hard and asymmetric landings were not considered because the AFIT does not keep records of such flight elements, and because their realisation during tests poses a significant safety hazard. The load sequence to which the element was subjected in the simulation is shown in fig. 9. The load sequence was adequately modified. The modifications consisted of filtering the load sequence with the cycle truncation in the range above ≤ 20 MPa and of counting the cycles with the Range-Pair method. Load value truncation reduces the number of fatigue cycles, which helps to reduce the calculation time with minimal error in calculating critical crack length and growth time. Cycle count reveals 3 GAG cycles in the load sequence. Not performing the cycle count for the load sequence assumed significantly influences the end result.

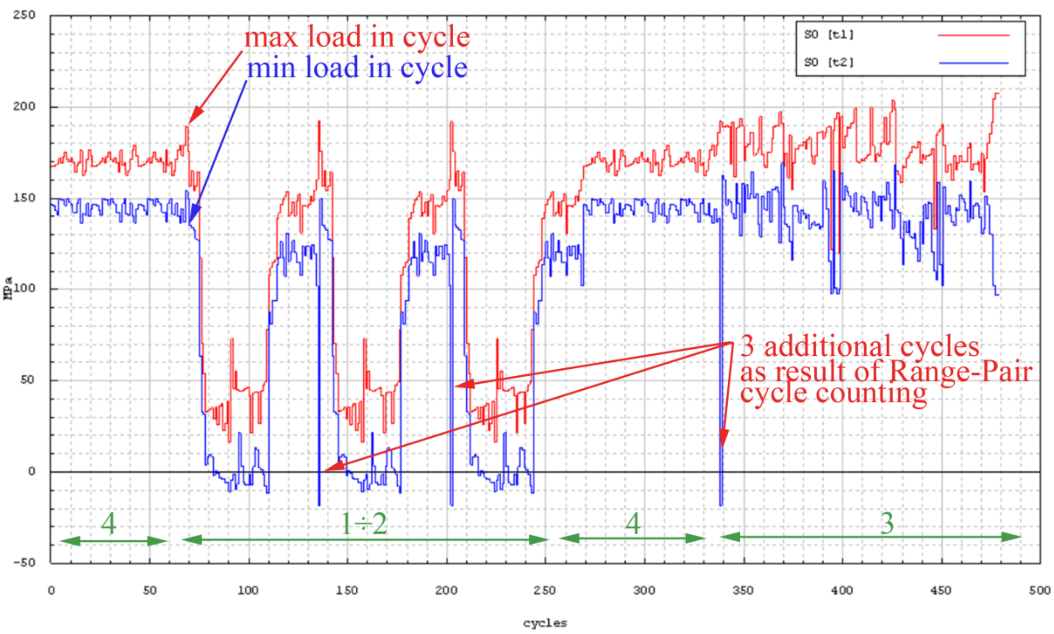

Fig. 9. Load sequence used in analysis – 3 GAG cycles with runway maneuvers

In the analysis performed, the resulting computed fatigue life is expressed as a number of take-off – landing cycles – with the assumption that a pre-existing crack of the length a_0 was present at the initial state. The results shown in Table 1 do not take into account the safety factors which adjust the number of cycles until critical crack length is reached. The calculated number of propagation cycles (NASGRO software) in the analysed critical element significantly exceeds the number of GAG cycles at which the discussed failure occurred. Since it was noted that the load sequence recorded might not represent the excess of loads faithfully, additional analyses with the use of a multiplier were performed. The sequence prepared from the records of the take-off – landing sequence and the runway maneuvers were multiplied by the factor of 1.2. The critical crack length determined then in the computational simulation came close to the length of the actual crack observed on the fracture face. Henceforth, it can be assumed that in the cracking process an additional factor must have been present that accelerated the crack growth. Apparently, this factor was not taken into account in the present simulation.

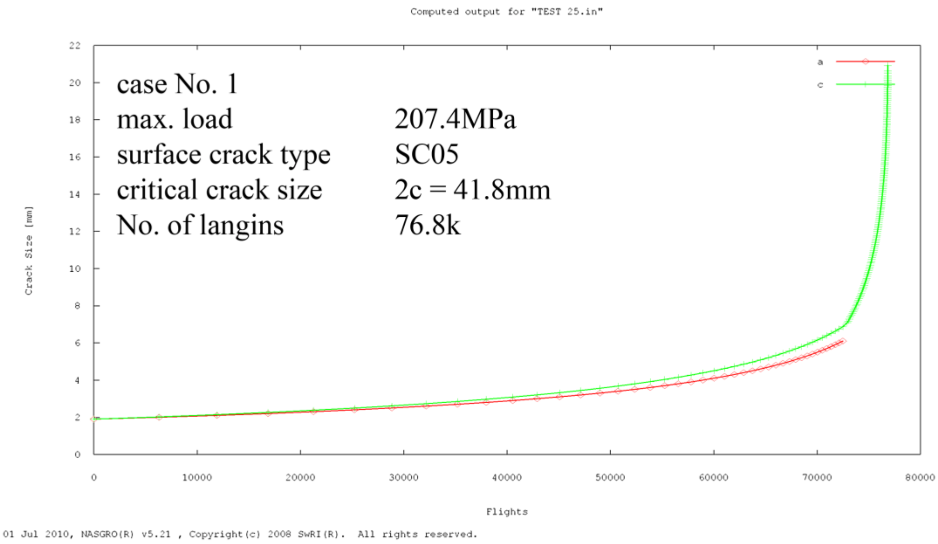

Fig. 10. Crack growth curve – case no. 1

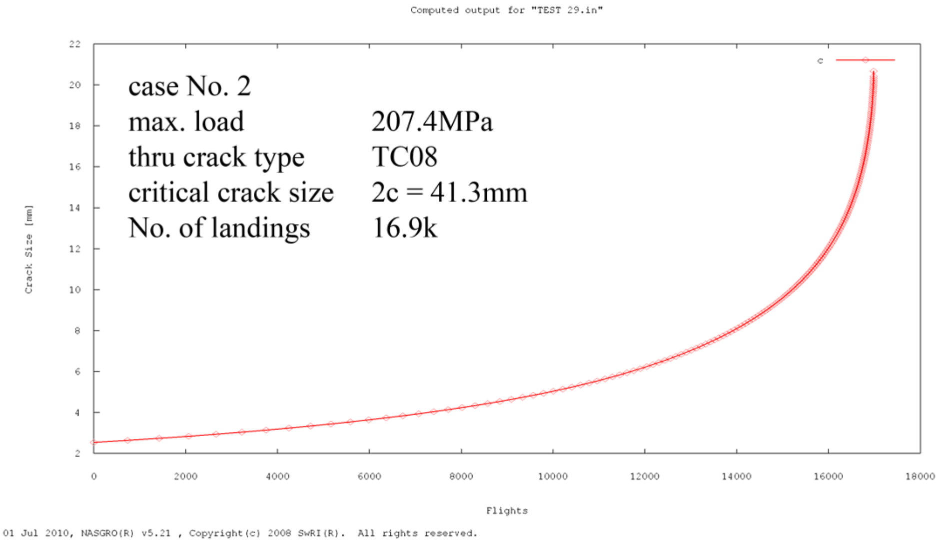

Fig. 11. Crack growth curve – case no. 2

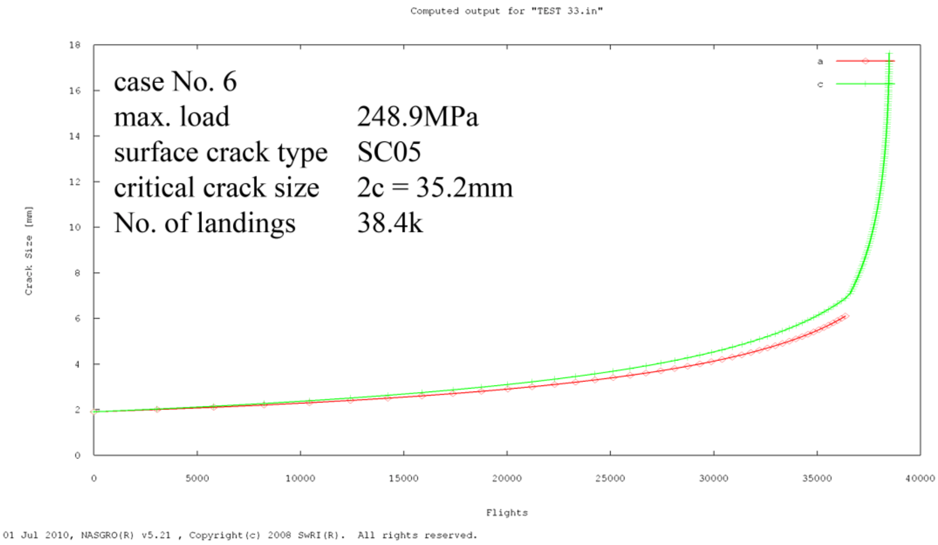

Fig. 12. Crack growth curve – case no. 6

Table 1. Sample of the analysis results

	Crack model	Max. load [MPa]	Initial crack size [mm]		Critical crack size [mm]		Number of flights
			a	C	a	2c	
1	SC05	207.4	1.905	1.905	6.20	41.86	76.8 k
2	TC08	207.4	-----	2.540	-----	41.34	16.9 k
3	TC08	207.4	-----	6.200	-----	21.32	5.00 k
4	TC08	207.4	-----	10.00	-----	22.38	1.70 k
5	TC08	207.4	-----	15.00	-----	20.87	0.36 k
6	SC05	248.9 *	1.905	1.905	6.20	35.28	38.4 k
7	TC08	248.9 *	-----	2.540	-----	34.74	8.80 k

*) multiplier – 120% of the load

3. SUMMARY AND CONCLUSIONS

During the service of Polish Su-22 aircraft, a serious problem was encountered that endangered the flight safety and the further service of the fleet. The first case of damage occurred in 2004 on an aircraft serviced according to the safe-life philosophy, even before the designed service life had been reached.

The material tests and other engineering analyses made at that time pointed to the fatigue fracture as the cause of damage. The cracking process originated in the area of a structural notch on the boundary of the pull-rod base material and one of the three spot welds. The calculated crack propagation time (number of cycles) for the case was determined to be considerable. The corrosion of the inner surface of the cylinder was the factor that accelerated the crack growth.

The occurrence of yet another rupture showed that the problem is more severe than initially assumed. The crack growth calculations suggest that there exists a factor that accelerates the crack growth. Stress-corrosion appears to be the factor in question. Investigation of the first (2004) incident did not determine the presence of stress corrosion. Corrosion was detected in the second (2010) case only. Contribution of stress-corrosion to the crack growth process is very probable as significant tensile stresses occur in the pull rod discussed during the aircraft hangar standby. The Su-22 aircraft are stored in non-conditioned hangar-shelters. The presence of stress-corrosion influences the determination of the NDI inspection interval. The exact determination of the corrosion's influence on the rate of crack propagation in the pull rod requires additional research.

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