Evolution of Aircraft Maintenance/Support Concepts with Particular Reference to Aircraft Availability – Polish Air Force Perspective

Ryszard Szczepanik
Director General
Air Force Institute of Technology
01-949 Warszawa
POLAND

ryszard.szczepanik@itwl.pl

Andrzej Leski
Team Leader, Division for Aeronautical Systems' Reliability & Safety
Air Force Institute of Technology
01-949 Warszawa
POLAND

andrzej.leski@itwl.pl

ABSTRACT

The accession of Poland to NATO has considerably affected Polish military aviation. Changes of standards in force at that time as well as a demand for compatibility with the armed forces of other NATO member states have forced a number of changes in all areas of activity. This paper is an attempt to cover some selected areas of ITWL's (Polish Air Force Institute of Technology) activity dedicated to the Aircraft Maintenance/Support Concepts. Some specific solutions have been presented. Also, general conditions and the peculiarity of the Aircraft Maintenance/Support Concepts in Poland have also been discussed.

1.0 PECULIARITIES OF POLISH CONDITIONS

Polish military aviation comprises the Air Force, the Navy aviation and that of the Army. At present, there are 20 types of aircraft operated thereby. The operated fleet comprises, with only few exceptions, aircraft and other systems manufactured in the XX century in the ex-Soviet Union and Poland.

When the systems were being introduced into service, Poland was a member of the Warsaw Pact. Hence, the aircraft and other military equipment apart, also the Soviet maintenance system was adopted. All aircraft and helicopters introduced into service were provided with maintenance, following service life periods determined by the manufacturers. The maintenance practice was based on the 'safe-life' philosophy.

A difficult time of transition comprised political and economical changes, but not only. Poland joined NATO, and our relations with the Soviet Union (later on, with Russia) came loose. Aircraft in service were divested of the manufacturers' supervision, and the overhaul depots could gain the spares and introduce new technologies only with great difficulty.

The cold war came to its end, which resulted in the rapid reduction in expenses of purchasing new armaments. Such being the situation, ITWL (i.e. the Air Force Institute of Technology) initiated a number of projects to attain the following objectives:

- To provide for operation and maintenance of aircraft at the minimum manufacturer's contribution;
- To most advantageously use the manufacturer-determined service lives of systems in service;
- To find scientific grounds to decide whether operation lives should be extended; and
- To increase availability and accessibility of aircraft in service.

A number of projects initiated at the Institute resulted in quite a few developments introduced into service and everyday practice of the Polish military aviation. The SAN system to collect and analyse maintenance and operation-related information, flight parameters decoding system THETYS, and flight data recorders of the IP- and S- series are only few examples of implemented solutions. As far as lives of aircraft structures are concerned, lack of information from the FSFT (full-scale fatigue tests) on the Soviet-made aircraft is probably the greatest problem. Lack of design data has to be overcome, and it is usually done by means of reverse-engineering techniques.

The R&D work performed at ITWL is financed mainly by the Ministry of National Defence, the superior body to the Institute. The Institute is not a part of the Air Force. It provides support for all three Services that build up the Armed Forces, i.e. the Air Force, the Navy, and the Army. Since the Institute is a scientific organisation, some funds come from the Ministry of Science and Higher Education.

2.0 THE COLLECTING AND ANALYSIS OF MAINTENANCE & OPERATIONAL DATA

The Air Force, the Army, and the Navy of Poland use a unified system to collect, process, and analyse operation- and maintenance-related information on military aircraft, i.e. the SAN system [2].The SAN system consists of:

- Main system modules including subsystems to record and process data on aircraft operation;
- Cumulative operational-data bank with processing subsystems;
- Central operational and reliability data bank with processing subsystems; and
- Module to analyse military aircraft operation and reliability rates.

The system allows:

- To collect, process, and transmit data on the operational use and maintenance of military aircraft according to rules and regulations of the Polish Armed Forces, those issued by the Engineering Service for Aeronautical Systems, and documentation carried on board of military aircraft; and
- To control processes of military aircraft servicing, including routine and periodic maintenance and inspections to check aircraft health/maintenance status, and to examine availability and reliability of the fleet.

Verification and unification of information on damages to aircraft and helicopters, stored in some operation/ maintenance data collecting systems of older types, resulted in a coherent data bank. The following items are identified:

1) Object (aircraft):
   - Aircraft type and version.
   - Aircraft user (JW/air base number).

2) Total amount of operational use before failure:
   - Since commissioning:
     - How many hours.
     - Number of landings.
   - Since last maintenance:
     - How many hours.
     - Number of landings.

3) Circumstances of failure occurrence:
   - Date of failure.
   - Under what circumstances symptoms of failure were found.
   - Flight conditions.
   - Who found the failure.

4) Effects upon flight safety.

5) Effects upon the crew and their performing the task.

6) Way the failure was repaired, repair time, labour demand, and down-time.

7) Faulty part.

8) Failure symptoms:
   - Code and description of aircraft failure symptoms.
   - Code and description of symptoms of a failure to a device or unit.
   - Code and description of a failure to a part.

9) Cause of a failure:
   - Code and description of failure cause.

10) Faulty device or unit:
   - Serial number.
   - Year of production.
   - Number of repairs.
   - Work units since commissioning.
   - Work units since last repair.
   - Code of work unit.

11) Maintenance data of a faulty engine:
   - Code of a particular version of the engine type.

- Serial number of the engine.
- Operational-use time since commissioning.
- Code number of last repair.
- Operational-use time since last repair.

The recorded data are used to prepare analyses, forecasts, and reports. By way of example, percentage shares of failures to individual structures and systems of the Mi-14 helicopter are presented below, in Fig. 1. Predictions on reliability and safety rates supplement statistical analyses. A typical time interval covered by a forecast is two years. Predictions are prepared using the following techniques: statistical forecasting, time-sequence analysis, and artificial neural networks.

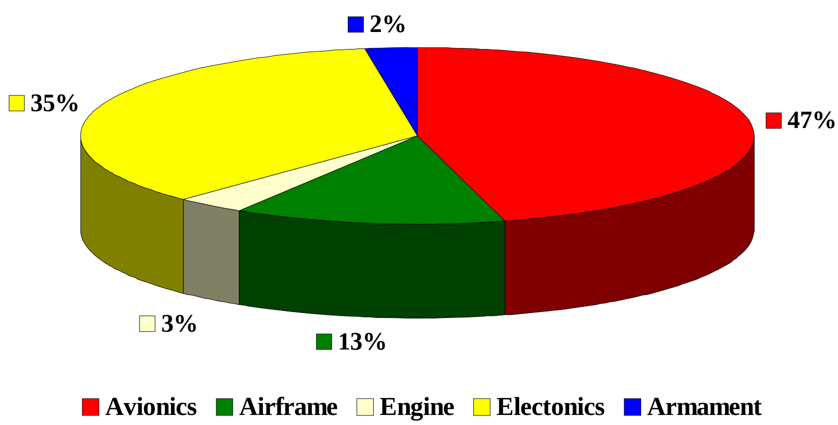

Figure 1: Percentage shares of failures to main structures and systems against the total number of failures recorded on the Mi-14 helicopters.

3.0 AIRCRAFT/HELICOPTER’S SERVICE LIFE EXTENSION

3.1 The Monitoring of Aircraft Service Loads

The monitoring of aircraft service loads is one of fundamental tasks performed to ensure safety of operating them. The task is of particular significance to structures operated according to the ‘damage tolerance’ concept. Structures operated according to the ‘safe life’ principle usually do not need service loads to be monitored all the time. Flight data recorders built in operated aircraft provide capabilities to monitor service loads, e.g. loading cycles nz. In the case of aircraft furnished with flight recorders, initiation of procedures that enable the monitoring of the airframe’s fatigue wear, even if these aircraft are operated according to the ‘safe life’ principle, is not too complicated and should bring long-term advantages. Data on service loads, collected by ITWL, are used in a few different ways presented further on.

3.1.1 A Comparison of Actual Service Loads to Those Assumed by the Manufacturer at the Stage of Defining the Airframe's Life

A comparison between an actual service profile of an airplane and that assumed while finding service life thereof enables verification of service lives (working-life limits) determined by the manufacturer. The knowledge of service profiles assumed by the manufacturer is a necessary condition. Fig. 2 shows the comparison between service profiles of two different groups of MiG-29s.

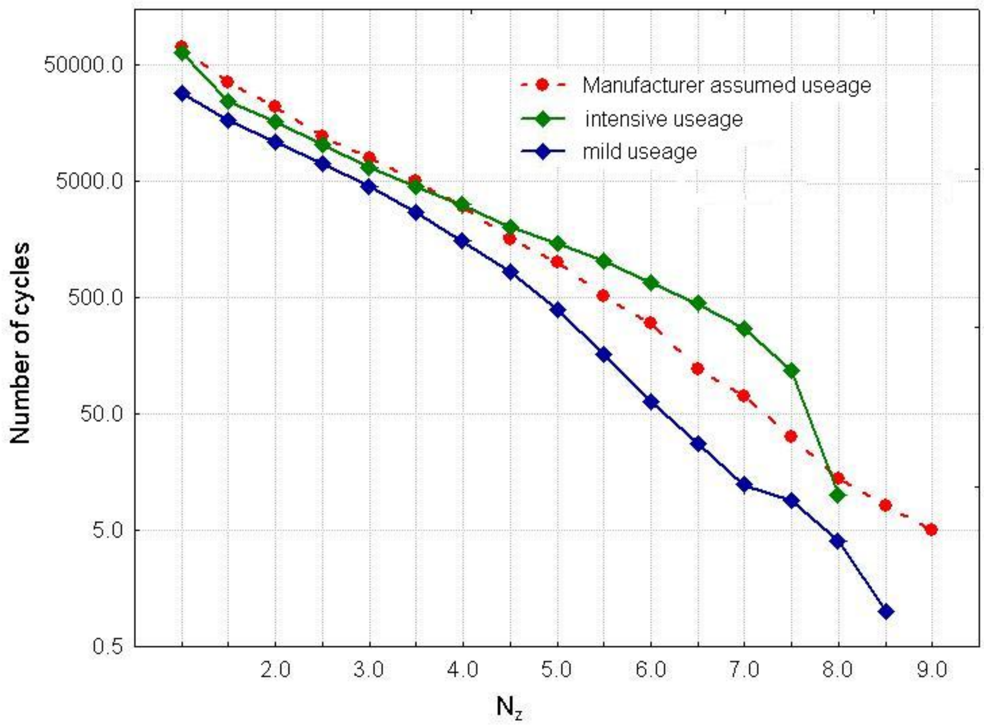

Figure 2: Service profiles of the two groups of MiG-29s.

The green line (the upper one) and the lower blue line illustrate the service profiles of a typical MiG-29 operated by the two different air forces.

The broken red line illustrates the service profile assumed by manufacturers while determining life of the MiG-29's airframe. Differences between the ways of operating the aircraft result in different rates of service lives getting exhausted. Service lives of the aircraft described by the first profile get exhausted twice as fast as the manufacturer has assumed, whereas the same rate for the second aircraft proves to be twice as low (as compared to the assumptions).

The above-shown comparison evidently proves advisability of monitoring loads that affect aircraft. Any decision on extending service lives of aircraft, on repairs/overhauls and inspections could be based on the information about actual fatigue wear. Results affect the aircraft availability.

3.1.2 Relative Comparisons of Actual Fatigue-Wear Rates of Lifting Structures of Aircraft Within Some Specific Population

If there is no information on the method of determining service life of an aircraft, including the assumed service profile, verification of the actual fatigue wear of the structure using the collected records on accomplished flights proves impossible. However, even such being the case, analysis of service loads can deliver some interesting conclusions. It is possible to compare fatigue-wear rates of individual aircraft. Such comparison gives a useful measure that facilitates classification of aircraft according to actual wear-and-tear and therefore, to indicate the aircraft that shows the highest fatigue damage.

Another way to compare loading spectra consists in making use of standard spectra defined for airplanes or helicopters of some specific type and application.

3.1.3 Estimation of Fatigue Life of Some Selected Structural Components

The utilisation of collected information on service loads to estimate fatigue lives of some selected structural members has been described in more detail in 3.2.

3.1.4 The Construction of Database on Service Loads for the Needs of Future Design Work

The collected data recorded with flight recorders can be used as a basis to find standard loading spectra for newly designed structures. Standardised spectra can be constructed using these records. They are to be used in laboratory testing work, any kinds of analytical and conceptual work.

3.2 Fatigue Life Estimation

If fatigue life is known, it is possible to control the scope of aircraft life still left. Fatigue lives of airplanes are determined in the course of a full-scale fatigue test (FSFT). High cost of full-scale fatigue tests is a real limitation. Analytical and numerical calculations offer an alternative way to estimate fatigue life; however, accuracy thereof is considerably lower. While calculating fatigue life, both the ‘safe S-N curve’ method and the da/dN analysis are used. Three elements are necessary to calculate fatigue life. These are as follows:

- Stress field in the structure under analysis;
- Loading spectrum; and
- Material characteristics.

The stress field in the structure under analysis is found by means of the finite-element (FE) technique. Prior to suitable numerical analyses intended to determine the stress field, a computer-based model is generated. When original technical documentation remains beyond our reach, the computer-based model is generated using measurements taken on a real object. A mechanical or optical scanner is used to take these measurements. Fig. 3 shows an exemplary application of the manually operated Microscribe 3DX scanner – here: to measure the shape of a wing-to-fuselage fixing node.

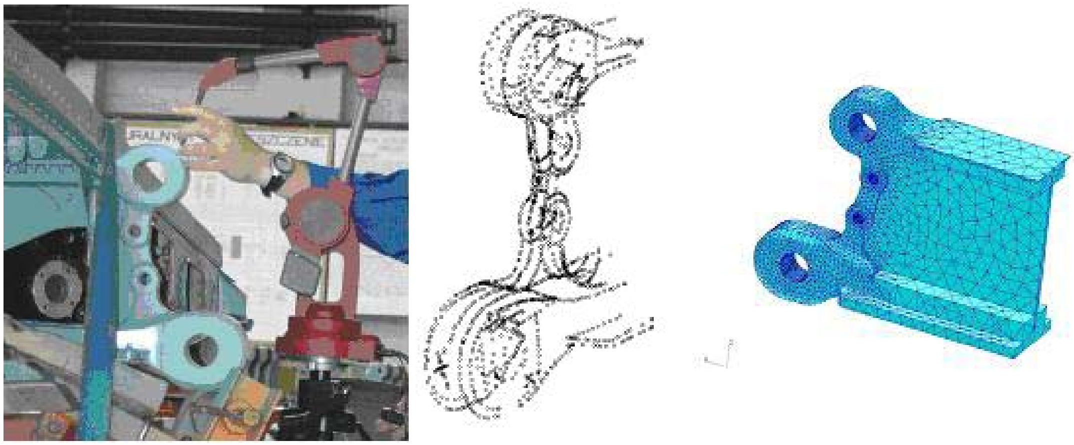

Figure 3: The reverse engineering technique in practice.

The loading spectrum is another element of great importance, which proves indispensable in fatigue computations. Records from flight recorders and flight-test results are both the source of information on aircraft-affecting loads. They are used in numerical calculations.

Up to the present, a number of different concepts of how to find loading spectra have been in use at ITWL while making calculations. One of them consists in finding average spectra equivalent to 10 hours of standard flight. Such a spectrum has proved representative for some specific population of airplanes or helicopters. The constructing of average spectra needs three stages. They are as follows:

- To find an average service profile;
- To examine strains/stresses in the course of flight; and
- To numerically define average spectra.

Finding an average service profile for some specific aircraft population consists in defining a number of flight components and the percentage share of each in the total time of operational use of the aircraft. Flight components are defined in such a way as to make them correspond to some characteristic portions of flight. Hence, hover, left turn, etc. are types of flight for a helicopter, whereas dive, climb, flight at some specific airspeed – for an airplane. Determination of flight components should be based on information recorded by a flight recorder, since any recorded time instance can be automatically assigned to only one of the flight components.

Measurements of loads and strains in some selected locations of the airframe structure are taken in the course of test flights with special-purpose monitoring and measuring instruments/systems engaged. Tests of this kind are carried out to collect loading spectra typical of all flight components flown by a given aircraft.

The construction of average spectra consists then in composing the recorded portions of test flights according to the proportion determined with the average service profile.

Apart from the above-mentioned concept of average spectra, other applications of data recorded with flight recorders and of in-flight taken measurements are also possible.

3.3 Diagnostic and NDI Systems

Many years' experience in the field of aircraft operation and maintenance proves that even in the course of operational use of systems designed and operated according to the 'safe life' principle, various kinds of failures to their structures may occur. These failures, e.g. cracks, are hazardous to safety of aircraft operation and introduce disturbances (resulting in, e.g. downtime) in the whole process of operating the system.

Application of advanced diagnostic systems, including the NDI ones, enables early detection of failures and malfunctions. The early detection means at least some increase in safety as well as some considerable reduction in repair/overhaul cost owing to having stopped failure growth/propagation.

ITWL's specialists have invented and manufactured numerous diagnostic instruments and systems to support ground staff responsible for aircraft maintenance. The SD-KSA field system to monitor health/maintenance status of the MiG-29's clutches is one of them. The principle of operation of this system is based on the examination of quality of current delivered by the Mig-29's generator. It has been assumed that the wear-and-tear of alternator-driving mechanisms (clutches) results in disturbances of angular velocity of alternator's rotor; this can be found in the course of spectral analysis of the alternator-delivered current.

Figure 4: The system in operation.

With all tests successfully completed, the system has been introduced into service at air bases, which operate the MiG-29s. The system is easy to use. Taking measurements consists in connecting the sensor to the power supply system of the aircraft. Checks of this type are performed in the course of maintenance and ground running of an aircraft engine.

Another diagnostic system is one to monitor health/maintenance status of blades of a turbojet. The tip-timing technique has been applied to measure vibrations of the compressor and turbine blades. A microwave probe enables examination of blades in the hot section of an engine.

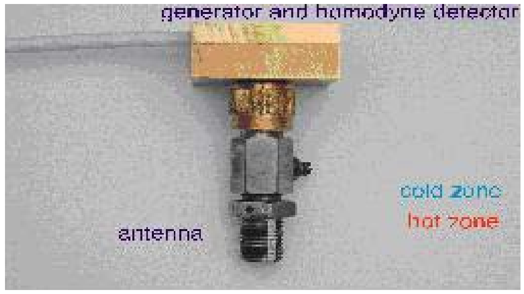

Figure 5: A microwave probe.

The large-scale introduction of such solutions results in considerable increase in safety of aircraft operation on the one hand, and on the other hand, in reduction of downtime/time of remaining grounded, because severe failures could be avoided and time for repairs – shortened.

As far as the non-destructive inspection (NDI) is concerned, application of automatic testing equipment results in similar time savings and increase in aircraft availability. Systems used by ITWL to assess aircraft health/maintenance status are, e.g. the MAUS and the DAIS.

The DAIS (D-Sight Aircraft Inspection System) is an optical system that enables us to quickly evaluate to what degree corrosion has affected rivet joints of the aircraft under examination. Furthermore, the system facilitates detection of dents, cracks, and faults in composite materials. The primary advantage of the system is that a pretty large area can be quickly inspected.

Figure 6: The DAIS in operation.

Another NDI system, i.e. the MAUS is an automatic scanner that enables various measuring probes/sensors to be mounted. The automatically imposed travel of the measuring head considerably reduces inspection time. The extended measurements-displaying module is another advantage of the system.

4.0 CHANGES IN MAINTENANCE SYSTEMS

As already mentioned, airplanes and helicopters operated in Poland are subject to maintenance according to the ‘safe life’ principle. The only exception is a group of the MiG-29s gained from Germany. Previously all these aircraft were subject to the on-condition maintenance. Some new approach, and consequently, a new way of providing maintenance for these aircraft resulted from collaboration between the previous user and the OEM. After Poland purchased these aircraft, a decision was made to adopt the same maintenance model hitherto in use. It proved to be a real challenge for the engineering and logistics services. In quite a short time, a plentiful set of documents that regulate formal affairs, manuals, technical reports, etc. had to be adopted and implemented. Problems with translation documents into Polish were also overcome.

A number of courses of instruction were carried out in close collaboration with the German party. The German Advisory Group was established. The Group stayed in Poland throughout the initial stage of implementing this new system.

Introduction of this new, MiG-29-dedicated maintenance model proved a labour-consuming task. However, considerable and comprehensive effects were gained. They included:

- 30% reduction in cost of overhauls (major repairs);
- Extension of times between Intermediate Inspections from 100 hrs to 150 hrs, and from 200 hrs to 300;
- Only 26 life-limited parts left (e.g. RD-33, KSA-2, K-36DM, ...);
- Improved spare parts management, e.g. extension of shelf lives of the spares;
- Service Loads Monitoring Program has been launched (indirect and direct); and
- Expected 35-40% reduction in total maintenance cost.

A split in the hitherto used system proved to be a disadvantage affected by implementation of the new maintenance model for the MiG-29 aircraft. Nowadays, there are two groups of the MiG-29s, each operated and maintained in a different way. The split has resulted in establishing two systems, i.e. the maintenance and the logistic ones. Such situation has proved impractical and causing problems at all levels. Hence, integration of both systems seems to be a natural solution: aircraft operated in Poland up to the present should be included in the new system.

Changes in the maintenance system are also introduced for aircraft of Polish design and construction. First and foremost, they refer to routine-maintenance schedules. The maintenance system originally introduced for aircraft of Polish design and construction proved very conservative and hence, time-consuming and inducing shutdowns for maintenance. The experience gained and a thorough analysis thereof have permitted modifications of relevant rules and regulations in force until now. New maintenance manuals have been based on both data collected in the SAN system, as well as knowledge and experience of scientists and users. In general, the changes consisted in reducing frequency of inspections and better synchronisation thereof with training programs (training aircraft); also, in modifications of the scope of particular inspections.

The above-mentioned changes are expected to bring about some increase in aircraft availability, with the hitherto reached reliability level – maintained.

5.0 CONCLUSIONS

Political and economical changes in the Central Europe at the end of XX century had considerable effect upon present status of military aviation in Poland, including aircraft maintenance strategies. The accession of Poland to NATO has forced changes aimed at reaching compatibility with armed forces of the NATO member states. The changes could not be introduced at once. The process to reach and meet West-European standards has been under way up to the present. The most evident change in the field of aircraft maintenance is that some elements of maintenance practice, based on the 'damage tolerance' philosophy, have been introduced into areas reserved for the 'safe life' concept.

Aircraft structures constructed according to the 'safe life' principles will never reach the 'damage-tolerant' level. Nevertheless, introduction of new maintenance systems, measuring techniques, algorithms to find fatigue wear, etc. has already resulted in the increased safety of operating these aircraft. It also brings about considerable savings.

Introduction of the F-16 into service with the Polish Air Force has proved a turning point as far as the military-aircraft maintenance system is concerned. It is only the operational use of the F-16 that will enable us to overcome problems of hardware and organisational compatibility with other NATO member countries.

All activities performed on and for the Soviet- and Polish-made aircraft have prepared us to face these new challenges.

6.0 REFERENCES

[1] Klimaszewski S., Leski A., Dragan K., Kurdelski M. Aircraft Structural Integrity Program of Polish Su-22 Fitter. ASIP 2006 Conference, San Antonio 30.11-06.12.2006. USA, www.asipcon.com.

[2] Klimaszewski S., Leski A., Dragan K. NDI approach for Structural Integrity Evaluation of MiG-29 Aircraft. ASIP 2005 Conference, Memphis 28.11-01.12.2005. USA, www.asipcon.com.

[3] Klimaszewski S., Leski A., Zurek J., The Role of AFIT in the Polish Aging Military Aircraft Programs, Proceedings of 7th Joint FAA/DoD/NASA Conference on Aging Aircraft, New Orleans, 9-11 September 2003.

[4] Barszcz P., Borgoń J., Leski A., Niezgoda T. Exemplary Applications of the Reverse-Engineering method in the Process of Extending Service Lives of Aircraft in Operation in the Polish Air Forces. Proceedings of Conference DESIGN 2002. Dubrownik 14-17 May 2002 r. Croatia. Vol I pp. 605-610.

[5] Szczepanik R., Witoś M. Aeroengine condition monitoring system based on compressor blade vibration measuring method. 20th AIMS Symposium (Aircraft Integrated Monitoring Systems) 22-25.05.2000 Garmisch. Germany.

[6] Loroch L., Szczepanik R., Witos M. Engine Maintenance Trends in the Polish Air Force Units. Proceedings of Conference on Maintenance Trends in Aviation. Delhi. India.

[7] Szczepanik R., Witoś M. Turbine Engine Health/Maintenance Status Monitoring with Use of Phase-Discrete Method of Blade Vibration Monitoring. Proceedings of RTO-M8-AVT-121.