COMPLEX APPROACH TO AIRCRAFT SYSTEMS AND STRUCTURE SAFETY AND REALIBILITY

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Abstract

This paper presents new technologies employed in aircraft system engineering that are necessary to ensure a sufficient level of aviation equipment operation safety. New technical condition identification and examination technologies involving non destructive testing methods are presented, as well as methods of hourly and calendar TBOs' extension. A computer system for reliability assessment SAN is presented and the system's extension into a comprehensive system of flight security assessment and appraisal that enables assurance of a sufficient level of aviation equipment operation security. Reliability assessment system SAN, methods of aircraft technical condition assessment, digital flight performance recorders, in-flight load recording system KAM-500, rotating machine diagnostic system, with real-time diagnostics, comprehensive system of flight safety analysis and assessment are among other presented in the paper. Rapid development of research equipment, software tools, and more and more complex tested items (aircrafts and their modules) enforce development and refinement of applied research methodologies selected research methodologies applied by the Air Force Institute of Technology in aircraft systems examination.

Keywords*: aircraft systems, aviation equipment, novel technologies, safety reliability, research methodologies*

1. Introduction

Shaping directions of technological advancements in aviation engineering requires consideration of the following issues:

- What technologies are of key importance for safety and reliability assurance?
- Is development of new technologies more important than integration of the existing systems?
- To what extent investing in extension of aviation equipment life cycle is justified?

New programs of civil and military aviation development have resulted and will surely continue resulting from various studies, within which implementation of new technologies shall ensure not only information advantage, control over air and space, high mobility, and precise fire, but shall also affect improved and ensured aviation and space equipment operation safety and reliability. Use of unmanned aircrafts in military conflicts is already a fact of life, but problems of assurance of sufficient reliability level and lack of acceptable air traffic regulations limit their civil sector applications. Improvement in safety and reliability may follow implementation of advanced technologies that enable steering system redundancy, development of digital technology based navigation systems, as well as fine tuning of power unit engineering.

Today reliability and safety need to be ensured of the military aircraft systems operated domestically, as launching new generation multitask aircraft is expected to trigger significant development in the area. Relevant research and development is therefore not only the Air Force

Institute's of Technology duty but also a real need of the Air Forces' engineering/aviation services.

The research and development currently in progress is therefore focused on computer-aided aircraft system operation, development of technical condition assessment methods, particularly non-destructive testing (NDT), development of new diagnostic systems and methods to enable extension of aircraft's and its drive set's times between overhauls (TBOs). Conducting such study required development of a number of flight performance digital recorder types, for both operation and research flights, and implementation thereof as standard aircraft equipment. Digital recorders on board of selected aircraft units enable developments of a real in-flight load profile, therefore having assessed factual technical condition of an airframe determination of a so called expected airframe structure operation resource.

2. Reliability assessment system SAN

The Air Force Institute of Technology has been for many years involved in research of processes occurring in aircraft operation system. It was the first in Poland, and as early as in early 1960-ties, to develop a system of aircraft operational reliability assessment.

Rapid development in computer technologies enabled in mid-1960-ties commencing work on a new quality system enabling multifaceted assessment of operational process (including reliability and safety) of all aircrafts currently operated in the military aviation.

Basic developments of the system, commercially known as SAN (Fig. 1), are local, Oracle database technology based computer data banks called SAMANTA. The SAN system is installed at each air force units. Current details of each aircraft's operations are collected therein. The data are processed as aircraft direct users require, as well as periodically fed to cumulative banks on higher level of aircraft system operation management (tactical and operating-tactical units) and to the central bank.

The local databanks have been also installed at aircraft repair bases (Wojskowe Zakłady Lotnicze - WZL).

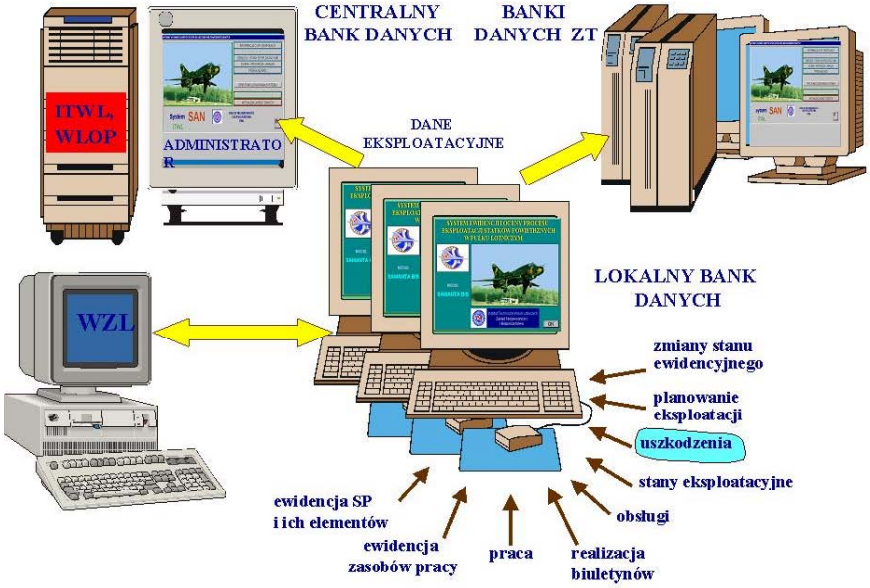

Fig. 1. SAN system structure

The SAN system is under permanent development. This year its functionality has been extended by elements related to aircraft durability assessment, aircraft times between overhauls (TBOs) extensions, and aircraft operation monitoring at air forces units.

3. Methods of aircraft technical condition assessment

Assessment of technical condition of airframe structures of aircrafts and helicopters is necessary if only because that aircrafts do age. This process leads to adverse effects and phenomena that may contribute to damage that may threaten further aircraft operation. Such damage includes stress cracking of monolithic structures, hidden corrosion, corrosion and multi-layered joint structure cracking, SCC (Stress Corrosion Cracking) type cracking in thick structures, damage to structures with cell refill of composite and metal plating (deglutination, delamination, porosity, foreign object inclusion).

An important problem is to be able to detect such damage without having to disassembly-tested components, using appropriate research techniques. These techniques are called NDT – Non Destructive Testing. Another research methodologies applied in such studies include: ultrasonic method, rotary current method, resonance method, D-Sight phenomenon-based optical methods, or interference effects.

The DAIS (DSight^{TM} Aircraft Inspection System) system enables fast and accurate examination of planting surfaces and detection of hidden corrosion and surface damage, for both, monolithic structured components and composite materials.

The MOI system (Fig.2) – enables very fast assessment of damage developed in rivet connections and hidden corrosion. System operation's ease and result display, as well as collected data archiving capability, enable examining by crash-course trained operators.

Fig. 2. MOI diagnostic system

The MAUS system is the latest version of an automatic system of assessment of technical condition of structural elements applied in aircraft construction. The system enables examination by the following three measurement methods:

- Ultrasonic method (in Pulse – Echo and Through Transmission configuration) with a vast array of measurement sensors that enable examination using longitudinal and lateral waves.
- Rotary current method (in single or dual frequency configurations) together with numerical tools enabling performing operations on measured data.
- Resonance methods (resonance, Pitch – Catch, MIA – acoustic impedance methods) enabling examination of elements with cellular filler (control surfaces, flaps, ailerons, helicopter main ad rear rotor vanes) as well as composite materials.

4. Digital flight performance recorders

The Institute has been for many ears involved in an effort to upgrade flight performance recording systems, both operating and emergency, and a whole family of airborne test recorders was developed. A system, S2-3ap, was designed and implemented of airborne test recording. The system, compared to earlier recorders (e.g. RPCM4b system), enables measurement of more flight parameters, including those read-out from aircraft data bus. The system is more compact and enables faster adjustment to specific research task (also airborne). The S2-3ap system is currently used by the ITWL Institute for airborne tests.

Fig. 3. S2-3a/P recording system for airborne tests

The Institute has implemented S2-3 recorders for TC-130 „Orlik", and I-22 „Iryda" aircrafts, the S2-3a system of emergency flight performance recorders for AN-28 „Bryza" aircrafts, for W-3WA „Sokół" and S2-3ai helicopters, and for TS-11 „Iskra" aircrafts. Hence the S2-3a (S2-3ai) recording system is among basic and most advanced systems operated on board of Polish Air Force aircrafts.

Operating efficiency of our recording system was evaluated and verified by many years of operation, including air catastrophe events. Data recorded by the recording systems were the key reference material in determining the catastrophe causes.

Fig. 4. Flight performance recorders by ITWL

5. In-flight load recording system KAM-500

Aircraft design and operation according to „safe durability" philosophy implies the aircraft resource concept. A resource is the duration of safe operation as established by the manufacturer or another authorised body. In practice the resource is not always a good indicator of structural wear and tear.

Research programs were undertaken in many countries aimed at researching feasibility of extending aircraft operating lifecycle outside predetermined usage times between overhauls (TBOs). Many such programs were successful and quite profitable too.

Also the Polish Air Forces carry on projects aimed at extension of times between overhauls (TBOs) of aircrafts currently in operation. The research so far was focused on extending so called „calendar resource", i.e. total operating lifecycle. Calendar times between overhauls (TBOs) are extended mainly based on assessment of intensity of age-related changes in aircraft structure. The main areas of interest are: corrosion damage and effects of plastic items' (seals and electric insolation) aging. Different than calendar resource, a technical resource, also known as hourly resource, is a stress wear and tear measure. Its extension must be based on assessment of aircrafts stress durability. This requires carrying out much more complex assessment and measurement of actual load of aircraft structure when tested airborne. The Air Force Institute of Technology implements programs of resource extension for aircrafts and helicopters operated by all types of Polish Armed Forces. So far calendar TBOs have been extended for Jak-40, An-24, Mig-21, and Mig-21 Bis aircrafts, as well as Mi-8 helicopters. Also a program of technical TBO's extension has been completed for Mi-14 helicopters operated by the Navy. In-flight examination has been completed for the following aircrafts:

- PZL-130 „Orlik" in 2000;
- Mi-14 in 2002;
- Su-22 in 2004.

Ensuring safe operation of an aircraft with an extended TBO requires intensified diagnostics and implementing a system of additional reviews and service. Identification of a tested aircraft's critical structural components bearing large loads is a priceless knowledge. Engineering expertise used in designing must be supplemented with an appropriate computer aid assessment of the stress condition. A computer model development and definite elements method (MES) computing based approach have fared the best so far. When dealing with Soviet Union made airframes missing accurate technical documentation is often an issue, as it makes computer model development difficult. Owing to reverse engineering techniques, development of computer models based on a real item is possible. Large items are measured using digital photogrametry technology, which involves computer processing of their digital photographs taken at various angles. Owing to appropriate processing of such digital images it is possible to restore an item's three-dimensional shape. Microscribe scanners have similar applications and can be used for small items and structural details. A variety of computer analyses may be performed on an aircraft's computer model and its airframe load details, providing premises for the aircraft's durability assessment.

6. Rotating machine diagnostic system

Real-time diagnostics

Engineering complexity and specific working condition of aircraft turbine engines, particularly those operated in Air Force, make their diagnostics quite difficult for their users. Limited credibility of test results obtained by existing methods provided incentive to develop a diagnostic system for single-flow, SO-3 type turbine propeller engines (driving TS-11 „Iskra" aircrafts), based on discrete/phase method (MDF) of minimum number of recorded signals measurement, the SNDŁ-1b/SPŁ-2b blade excessive vibration and cracking signalling device.

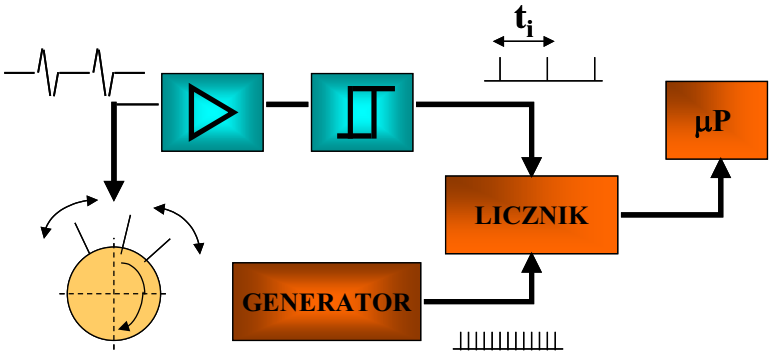

Fig.5. Structure of measurement tract used by diagnostic system SNDŁ-1b/SPŁ-2

This method, benefiting from digital signal screening, enables real-time assessment of technical condition of the following:

- Istage compressor blades,
- engine fuel feeding systems,
- rotor bearings.

Non-contact vane vibration measurement with displacement sensor (mounted in compressor body above rotating vanes) was proposed for further analysis and analysis of a portrait obtained on the phase plane. Engine's momentary performance is monitored not only based on current value of the monitored signal, but also on the signal's first and second derivatives mapping the value change trend and associated inputs. This enables mapping out so far typically hidden engine's disabilities or a specific module or unit excessively out of tune.

At the Air Force Institute of Technology a microwave sensor has been developed that, based on MDF methodology, enables monitoring of aircraft engine's hot parts, i.e. their gas turbines.

This supplements the previous solutions and enables a comprehensive aircraft engine real time diagnostic system's development

Liquid media testing

Testing liquid media used in aircraft systems is materially important for their safety and reliability assurance. In terms of technical condition assessment the Air Force Institute of Technology researches oil products (mostly fuels, grease and hydraulic oils). Experienced staff and high-end measurement equipment enable early detection of pre-emergency conditions, at the same time effecting enhanced operating safety.

How fast and user-friendly, yet effective, is the emission spectrometry methodology, commonly used not only in Poland but also worldwide! It enables oil product examination in order to determine metal concentrations (process waste and liquid media additives) in tested liquids. More accurate is ferrography that enables detailed quantitative and visual analysis of process waste and contamination concentration in liquid media. Monitoring changes in tear and wear rate, shape, size an surface of particles produced by friction is a significant source of knowledge of wear and tear process workings and assists in damage part identification.

Also oil filter analysis should be referred to here, as a proactive methodology in the context of aircraft systems safety and reliability assurance. As filters are where all kinds of trash gather, analysing that process waste material provides wealth of information on the technical condition of bearings and hydraulic systems. Washed out filings are subject to x-ray analysis to determine their chemical composition, which ultimately leads to damage component's identification.

Liquid media cleanness is of extreme importance for hydraulic systems. The Institute uses an automatic particles counter using laser to count contamination and referencing the results so

obtained to applicable standards. On the obtained result level the diagnostic levels are developed using statistical methods for assessment of diagnosed item's technical condition.

The aforementioned diagnostic methodologies enable assessment of the technical condition of systems employing a liquid medium as a diagnostic data carrier. Currently updated based on actual results, such diagnostic levels enable safe operation of aircraft systems.

7. Comprehensive system of flight safety analysis and assessment

A comprehensive system of flight safety analysis and assessment, closely interoperable with the SAN system, is now under development.

It shall enable development of a mechanism to rationalise actions and costs of flight personnel training and aircraft system maintenance, and at the same time ensuring required flight safety level. The following four basic data sets shall be stored in the system:

- flying personnel details (personal, health, dwelling, training, other),
- detailed data of all aviation events occurred,
- details of aircraft reliability, safety, and operating performance,
- details of each flight.

This information shall be procured predominantly from aviation training process, i.e. fro Air Force units. The data processing system shall enable performing current and long-term flight safety analyses, allowing for, among other things, identification and assessment of flight safety risks, design, implementation and effectiveness assessment of preventive measures applied, and weak link detection in flight management, aviation training, and aircraft operation systems, as well as support for decision making processes in the flight safety area.

The system is developed based on ORACLE products, using three-layer architecture. There are database and application servers and user computers included in such architecture. Owing to this solution inexpensive user computers may be used and system updates are immediately visible to them. The development is scheduled to complete by the end of 2005.

8. Summary

This paper presents selected research methodologies applied by the Air Force Institute of Technology in aircraft systems examination. Rapid development of research equipment, software tools, and more and more complex tested items (aircrafts and their modules) enforce development and refinement of applied research methodologies. This is the purpose served by PCB accredited laboratories currently established at the Institute.