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Krzysztof OGONOWSKI[1], Jarosław KOZUBA[2]

POSSIBILITY OF PROCESSING PARAMETERS OBTAINED FROM ON-BOARD FLIGHT DATA RECORDERS FOR DIAGNOSTICS AND PREDICTING RELIABLE OPERATION PERIODS OF IMPORTANT AIRCRAFT EQUIPMENT

Summary. In recent years, much attention has been paid to the recording of flight data in order to provide objective information concerning routine and emergency in-flight situations. The data recorded can be used for assessing the air mission execution by the pilot and flight safety breaches, for specifying some damage to the equipment, and for preventing faulty equipment from being used in flights. Flight data recorders (FDRs) are commonly known as "black boxes". This article presents issues related to flight data acquisition and preparing the data for later use, as well as their impact on flight safety. The systems recording and processing selected parameters not only enable ongoing diagnostics, but also make it possible to predict the period of further reliable operations and to analyse the causes that led to possible damage. In addition to improving economic indicators of the aircraft operation, flight safety is improved. Obviously, the article will only discuss certain ways of enhancing safety by applying the processing of data obtained from FDRs. Nevertheless, I believe it will offer an overall view of how important it is to collect, process and properly analyse such data for diagnostics, prediction and flight safety.

[1] Faculty of National Security and Logistics, Polish Air Force Academy, Dęblin, Poland. E-mail: k.ogonowski@wsosp.pl
[2] Faculty of National Security and Logistics, Polish Air Force Academy, Dęblin, Poland. E-mail: j.kozuba@wsosp.pl

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1. INTRODUCTION

The FDR is an on-board device designed to record basic parameters characterizing the flight conditions, such as the position of the controls, the state of the individual instruments and installations, the radiotelephony communications conducted by the crew, the internal communication, the cockpit background sounds, the images from the cameras recording the operation of onboard instruments, the imagery from other sources (e.g., FLIR cameras or LLLTV), and even the pilot's psychophysical condition.

Although the elimination of accidents and major air incidents remains an ultimate goal, it is believed that aviation cannot be completely free from hazards and related risks. There is no guarantee that human activity and man-made systems will be completely free from operational errors and the consequences thereof. Therefore, safety is a dynamic feature of aeronautical systems in which safety hazards must be mitigated constantly.

The fatigue life of the aircraft's airframe depends on the manner in which the user operates the aircraft. Manoeuvre flights generate significantly higher structural loads in comparison to straight and level en route flights at a constant flight level. The bases for investigating the manner in which the user operates an aircraft are the flight data recorded in the on-board recorders. Modern aircraft, however, record a very large number of various parameters, including those that can be used for the assessment of the operation of their individual components. In order to do this, a technical analysis is performed, the main purpose of which is to detect conditions dangerous to the service life of the engine and other equipment. Numerous algorithms are developed, in a similar way as for operational analysis, which can detect excessive fuel consumption, overheating, vibrations or irregular engine operation.

The propulsion system is one of the most important and expensive parts of the aircraft. Flight safety depends on reliable operations. At the same time, aircraft are highly susceptible to damage due to the extremely high mechanical and thermal loads. Therefore, when seeking to reduce operating costs, along with maintaining the required reliability of the power plant, the methods of determining its current technical condition were sought. This led to the development of aircraft turbine engine diagnostics and the introduction of the condition-based maintenance (CBM).

Technical diagnostics represents a branch of knowledge, which is developing rapidly. It exerts a positive impact on improving and streamlining the use and operation of technical objects. It provides the technical and practical basis for the optimum (safe, reliable and cost-efficient) operation of a technical object in accordance with its "operating condition".

As a branch of science, diagnostics has clearly defined the objectives and tasks undertaken, whose objective is the evaluation, genesis and prediction of the technical object's operating condition using broadly understood indirect research methods. It may, therefore, be assumed that the purpose of diagnostics is to determine the activities, the operating decision, methods, commands, and means that will lead to the achievement of a detailed purpose. Technical diagnostics is based on its own, as well as original, principles and methods of testing objects and processes.

The general principle of diagnostics can be expressed in the words of W.R. Ashby: "the conditions of an object are dependent on its history".

This statement constitutes the basis of diagnostic methods and any other accompanying activities. Diagnostics is an interdisciplinary science, which by itself results from the scope and potentialities of its application, including the construction and operation of machines, automatics, mechanics, electrical engineering, electronics and ergonomics.

Technical objects are subject to wear-and-tear processes, which are due to the wearing-out of their components resulting from friction, corrosion, ageing, material fatigue etc. Due to construction deviations, and technological and material differences, the damage is not the same for all components of the same object, nor is it the same for identical elements within a set of objects of the same type. This applies, in particular, to complex technical components of an aircraft.

Aeronautical structures are characterized by specific design features, including the low mechanical safety factor of components, multiple joints and splines, and high durability and reliability under the conditions of mechanical and climatic exposure. Consequently, all on-board units are exposed to strong vibrations, which hamper the identification of unfit components using, for example, conventional vibroacoustic methods. Moreover, for obvious reasons, aircraft propulsion units are designed so as to minimize aerodynamic drag and weight, resulting in all elements being close together, thus making it difficult to further distinguish diagnostic signals coming from individual kinematic pairs. This is the reason why new diagnostic methods should be sought.

2. PROCESSING INFORMATION RECORDED IN THE OPERATIONAL RECORDER FOR THE PURPOSE OF DIAGNOSING THE CONDITION OF THE AVIATION TURBINE ENGINE

The implementation and widespread dissemination of aircraft engine parameter recording systems were possible owing to the benefits that result from their use. First of all, engine maintenance systems were changed from a system based on the period of reliable operation guaranteed by the manufacturer (according to the so-called “time between overhauls”), to a much more economical CBM system based on the engine’s current operating conditions. This progress was financed primarily from the budgets of the largest armies, as it allowed for the increased “combat readiness” of aircraft, owing to the earlier detection of various propulsion system failures. This, in effect, resulted in a reduced number of aircraft used. Engine manufacturing companies also showed interest in the implementation of those recording systems. The objective records of the operation make it possible to show that the damage results from non-compliance with the operating requirements and, especially, from exceeding the allowable parameter values. This means that these systems offer sufficient proof to dismiss many of the user warranty claims. Meanwhile, the sums in question are huge: the cost of a jet engine may be as high as several million dollars, and the cost of its repair may exceed a million. The introduction of automatic recording of engine operating and flight parameters was also supported by insurance companies, as this contributed to increased flight safety, fewer accidents and lower compensation payments. Carriers who use the methods described above in order to maintain a high level of flight safety pay lower insurance premiums, which reduces the airline operational costs and ensures the safety of passengers who use this means of transportation more and more frequently.

FDR design has evolved from automatic pens marking changes in selected parameters on a paper tape, through multitrack tape recorders, to modern data recorders equipped with semiconductor memory. State-of-the-art FDRs not only record the changes of many engine and airframe operating parameters, but are also equipped with software that processes signals from sensors, as well as generates real-time warnings or recommendations to the air crew. More and more frequently, there are systems that allow data transmission from a flying aircraft to users' or manufacturers' ground facilities.

When diagnostic systems were introduced, many methods were developed that could be divided into four groups:

- Checking selected engine parameters (parametric method)
- Vibroacoustic diagnostic methods
- Endoscopy (using fibre optics)
- Oil consumption testing and spectroscopic analysis of wear-out products (especially metals) accumulated in oil and filters

Operating parameter recording provides data used in the parametric method and vibroacoustic diagnostics.

When the automatic systems recording the propulsion and system operating parameters were introduced, both data recording and the cost of each measurement channel posed a great problem. The problem gradually subsided with the development of microprocessors and semiconductor memory technology. In the 1980s, it was possible to record the changes of a dozen or more parameters sampled several times a second during an 8 h flight on a 1.5 MB solid state semiconductor cartridge. This was possible owing to various techniques, such as data compression. Today, even several thousand parameters are recorded, with a large part of them being so-called binary parameters ("on/off"). Such amounts of data are unsuitable for human processing, especially with the growing number of aircraft equipped with data recorders. It is, therefore, natural to automate this process so as not to overlook the symptoms of potential emergency conditions, as well as in order to detect those symptoms already during the flight, not after its completion.

While activities related to measurement data recording have already become largely routine, the formulation of algorithms to analyse those data requires expert knowledge. Specialists in diagnostic systems should cooperate with engine designers, analysts and users who know the "weak points" of particular engines. It is particularly important to analyse the propulsion unit's performance under dynamic conditions, such as start-up, acceleration, deceleration or shutdown, as faults of the engine components, especially of its control system, will then appear sooner.

Consequently, the first task is to develop algorithms that recognize various phases of engine operation based on the values of recorded parameters. In order to identify the dynamic states of the turbine engine, Table 1 lists the characteristics of the engine and flight parameter recording. They concern an engine with an electric starter and a start-up fuel system activated with an electrovalve. The duration of the observed records arising from the nature of the observed phenomena was determined on the basis of the experience obtained in the research conducted during the ground and in-flight tests of the aircraft. It is included in the third column of Table 1. For the aircraft under examination, the duration of the particular phases is as follows: start-up on the ground approximately 60 s, airborne start-up approximately 2 min, acceleration approximately 10 s and deceleration 15 s, rotor coast-down after switching off the combustion chamber approximately 2 min.

Table 1. The characteristics of the particular phases of the turbine engine operation recording

Engine operation phase	Phase identification parameters	Observed recording duration
Start-up on the ground	1. Appearance of the supply voltage in the electric starter 2. Indicated airspeed less than, e.g., 200 kph	80 s from the moment supply voltage was delivered to the starter
In-flight engine start-up	1. Appearance of the supply voltage in the start-up fuel valve 2. Indicated airspeed less than, e.g., 200 kph	180 s from the moment supply voltage was delivered to the start-up fuel valve
Acceleration	1. Engine control lever (ECL) position change in the direction of increasing the rotor speed in less than 0.5 s 2. Pressure rise in the main injector manifold	30 s after the commencement of the ECL movement
Deceleration	1. ECL position change in the direction of decreasing the rotor speed in less than 0.5 s	30 s after the commencement of the ECL movement
Shutdown	1. Closing the fuel shut-off valve	150 s from the moment of fuel flow shut-off

For example, the differences between the airborne engine start-up and the ground start-up are as follows (Fig. 1):

- Idle speed is higher than on the ground and usually depends on the flight altitude and speed
- The rotor is not driven by the energy received from the starter, but by “windmilling”, i.e., the energy of the air flowing through the engine channel (this energy depends on the flight speed and the air density, i.e., the flight altitude)

Therefore, the algorithm for analysing this phase of the engine operation includes:

- Checking whether the flight conditions are within the so-called “engine performance envelope” specified for a given engine built on the aircraft by the values of maximum altitude and airspeed
- Checking whether the “windmilling” speed has reached the minimum value necessary to commence the start-up
- Calculating idle speed under conditions determined by speed and altitude

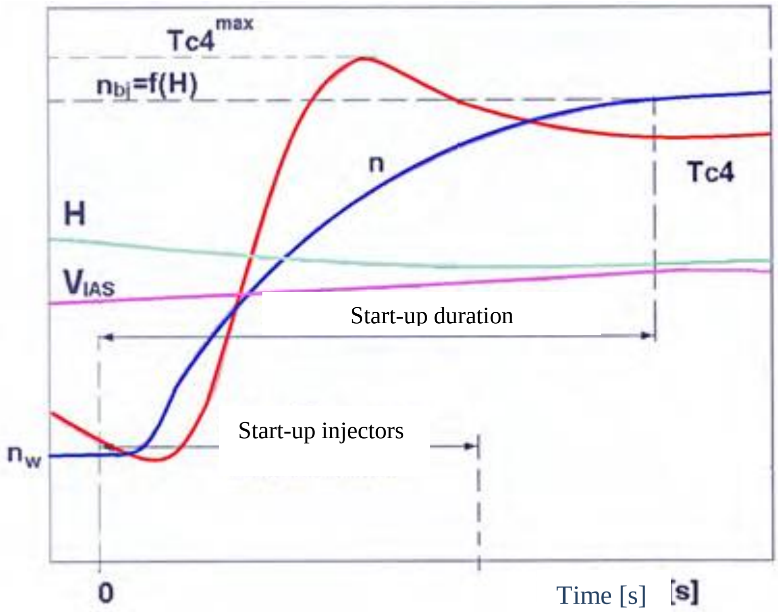

Fig. 1. Fragment of the rotor speed change (n), exhaust temperature after turbine (Tc4), altitude (H) and indicated airspeed (V_{IAS}) during the airborne engine start-up [1]

The results presented were applied in the engine diagnostic system of the I-22 Iryda aircraft. In addition to the above, numerous other parameter processings are used in the diagnostic system: observation of long-term trends, calculation of gas-dynamic indices, efficiency of components etc.

3. INCREASING SAFETY THROUGH THE USE OF ON-BOARD FLIGHT DATA RECORDERS AND PROGRAMS FOR THE ONGOING MONITORING OF FLIGHT SAFETY

In its half-century history, the analysis of flight parameters has undergone many changes. Today, flight parameter analysis is used not only in air accident investigation, but also in accident prevention. The detected breach that may affect flight safety or the technical condition of the aircraft is, in the first phase, a signal to immediately undertake tasks related to an additional or special inspection, and then to thoroughly analyse the process of crew training and in-flight methodology. Data from on-board flight recorders are used extensively in a variety of optimizations: crew working times, route planning, aircraft rotation etc. They also serve as the basis for programs that monitor the operation of engines and other equipment, which make it possible to control fuel and oil consumption, and even radiation levels at high altitudes. The results of specialized analyses are sent to programs that calculate crew working time, as well as the cycles and flying time of aircraft, engines and equipment.

For safety oversight purposes, documentation is controlled, analysed and archived. Such documentation includes:

- All documents received before the flight, records made during aviation observations, weather forecasts, loading sheets etc.
- Recordings from an FDR (when the aircraft is equipped with such equipment)
- Recordings from other flight data recording equipment

Recordings from the recorders are archived on electronic media and must be read at a frequency that will allow each flight to be analysed before "parameter overwriting" occurs.

Additionally, systematic reviews of "flight records" recorded on aviation monitoring systems are performed within the scope of air operation safety oversight.

The fatigue life of the aircraft's airframe depends on the manner in which the user operates the aircraft. Manoeuvre flights generate significantly higher structural loads in comparison to straight and level en route flights at a constant flight level. The bases for investigating the manner in which the user operates an aircraft are the flight data recorded in the on-board recorders. In the case of aircraft maintained according to their technical condition, the recording, storage and processing of content from onboard recorders constitute the basis of the Aircraft Structural Integrity Program (ASIP) for ensuring the structural integrity. A good example of this may be the F-16 aircraft purchased by Poland, for which recordings from the on-board recorders will be collected within the framework of the ASIP. Fatigue wear will be calculated for each aircraft individually on the basis of its actual operating history.

Individual aircraft tracking (IAT) is a standard activity within modern structural integrity programmes. For IAT to be possible, the following conditions are to be met:

- All aircraft must be equipped with digital FDRs
- Data reading and archiving systems must be organized at airbases
- The entire history of an aircraft must be known

4. AIRCRAFT CONDITION MONITORING SYSTEM

Modern aircraft are equipped with the means for performing multiple analyses and self-monitoring their systems. These solutions integrate almost the entire avionics with other aircraft components in order to both control them and determine their condition. At present, an aircraft condition monitoring system (ACMS) offers great capabilities for testing, diagnosing and helping with problem-solving. The major benefit of using these systems is the reduction of operating costs as a result of the reduced amount of maintenance required and, as originally intended by their developers, the improvement of air safety as a result of the reduced number of failures or non-optimal operating conditions.

What is an ACMS? It is a solution that allows for an analysis of multiple aircraft systems on the basis of the available parameters and reports, which may be obtained either in-flight, on board the aircraft or at ground-based ground support equipment service stations. The general operating principle of an ACMS and its interaction with other avionic and communication systems are illustrated by Fig. 2.

As can be seen from the above illustration (Fig. 2), the communication between the aircraft and the ground station may be two-track: data transfer using a variety of media, and radio communication. In the first case, information is both received and delivered, enabling us to load the software into a plane, as well as modify the assumptions according to different users' needs. This is most commonly done by means of a variety of data loader devices, such as floppy disc drives, magneto-optical drives, CDs or memory card readers. The same device is usually used for receiving information after the flight as a set of recorded parameters or maintenance reports generated on the basis thereof. An increasingly popular solution is the automatic bulk dump of the above data when the aircraft stops at the airport stand, e.g., by means of wireless devices mounted in the air bridges or through a LAN port located in an easily accessible place on the aircraft side. Information obtained from the aircraft is then analysed by the ground station and used in further applications, such as monitoring engine condition or performance. An alternative way of transmitting information to the ground is the radio, although, to date, more information is transmitted in this way from the ground to the aircraft than vice versa. This is due to the fact that, during the operation, the aircraft structures must not be interfered with. Obviously, there are examples of ground-aircraft radio transmissions, which do not involve an ACMS, rather involve, e.g., sending numerous auxiliary data, such as a flight plan or weather reports.

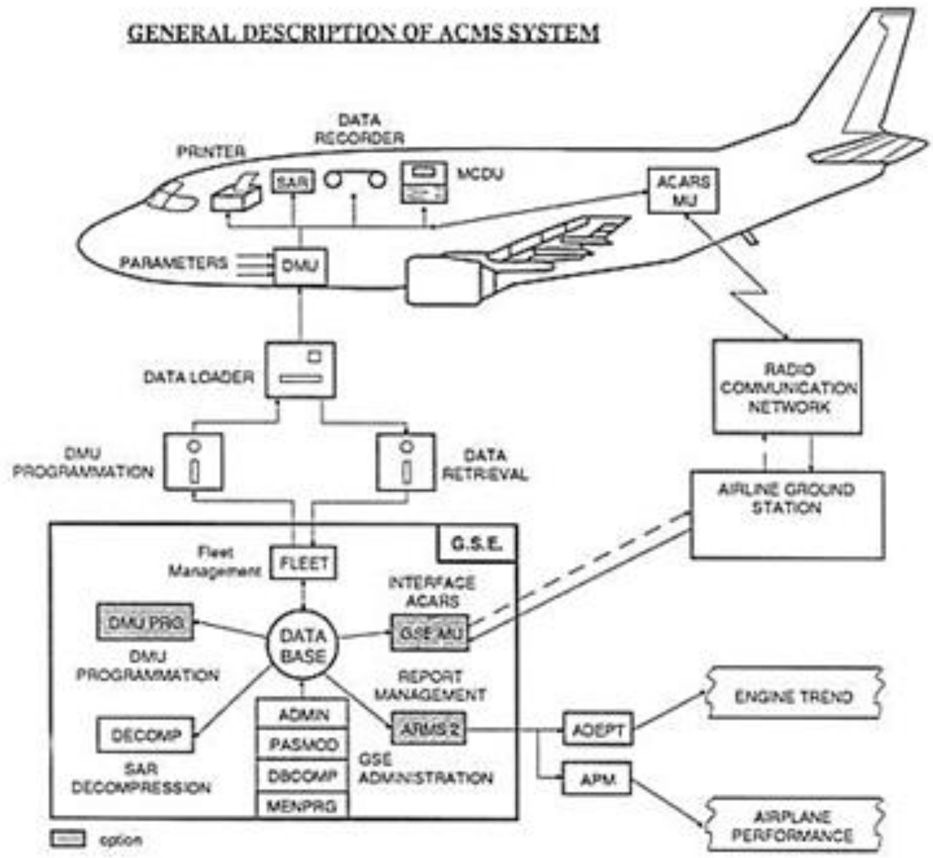

Fig. 2. General schematic diagram of an ACMS system [3]

5. ACMS: CAPABILITIES AND LIMITATIONS

The functionality and scalability of the ACMS system in a modern commercial airliner makes that particular system very useful to any aviation operator. The most valuable functions (problem-solving, flight parameter analysis, selection of data for monitoring aircraft engine trends/condition) will be applicable in air operations based on an extensive connection network. The capability of uploading analysis results via radio, even during the flight, increases the benefits from the use of an ACMS. In situations where immediate aircraft service action is required, the ability to receive ACMS messages in real time via the Aircraft Communications Addressing and Reporting System will be invaluable for the airline.

The complex and integrated system, however, imposes high requirements. The large number of parameters involved also requires an equally large number of sensors, transmitters, relays and similar technical devices, which must be of the highest quality and maintained in good operating conditions. This puts the highest demands both on the manufacturer of the aircraft and on its operator. A number of innovative solutions was incorporated into this area at the design stage of the prototype. However, it was impossible to apply so many of the above-mentioned transmitters powered by traditional electrical circuits, which is why manufacturers decided to introduce virtual circuit elements, such as virtual fuses and relays.

6. CONCLUSIONS

Constantly improved FDRs play an increasingly important role in ensuring the safety of air operations and improving the operational performance of aircraft. They are used in both civil and military aviation. Flight data recording systems can be used in almost every aircraft from commercial airliners and helicopters to general aviation aircraft. The complexity of problems related to contemporary air traffic requires the use of modern techniques and methods in the management process, as well as the conduct of broadly understood research. Dynamic technological changes cause both aircraft handling and air traffic management to increase skills and experience, which can no longer be gained solely by improving skills on real objects under normal operating conditions. Furthermore, increasing attention is being paid to the reduction of all costs associated with conducting such activities.

All this leads to the search for methods and tools that make it possible to replace the study of the actual object (aircraft) and actual conditions with mathematical models, which offer a high degree of accuracy in mapping the reality. In these models, it is necessary to use the flight data recorded by on-board recorders.

The level of safety depends on many factors. Human and technical factors can be mentioned here. Meanwhile, the research currently been carried out, on a global scale, on factors related to the means of transport, will significantly help to reduce their participation in contributing to accidents and their consequences. An interesting non-invasive diagnostic method is presented in [4-17].

Every modern ACMS is a powerful maintenance tool, which enables fuller and quicker diagnostics of aircraft in the air and on the ground. After a short period of operating the Embraer 170 aircraft, equipped with such systems, it was possible to observe that the time between traditional inspections carried out by maintenance personnel increased several times, while the scope of inspections was limited to necessary maintenance, such as fluid replenishment, tyre replacement or mechanical repairs. This has had a great impact on cost reduction. With proper design and use, monitoring systems will improve safety indicators and the effectiveness of air operations. Their development will continue towards the fullest possible use of computers and avionics, automation, and possibly even robotics in the future, in aircraft diagnostics and maintenance.

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