Journal of POLISH CIMAC
Faculty of Ocean Engineering & Ship Technology
GDAŃSK UNIVERSITY OF TECHNOLOGY

TYPES OF DAMAGES TO TURBINES OF AIRCRAFT TURBINE ENGINES; DIAGNOSING CAPABILITIES

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Abstract

The article presents the analysis of damage to gas turbine blades influencing the reliability of aircraft turbine engines. Characterised are methods of non-destructive testing and capabilities of applying them to the computer-aided objective diagnosing of condition of blades [3]. The computer-aided diagnosing of condition of gas turbine blades will provide some increase in the reliability of the assessment of blade condition, thus will increase the flight safety and reduce cost of the aircraft engine service.

Keywords: *gas turbine, blade, damage, diagnostics*

1. Introduction

From the moment of development of the first aircraft jet engine by English designer Frank Whittle in the 1930s, as in the case of other machines, we observe persistent technological progress in the field of new designs as well as materials which they are made from. This is the result of increasing efficiency and effectiveness of operation of new designs, and consequently increase in their performance, optimisation of weight, dimensions, etc. The gas turbine being a part of a turbine jet engine is a rotor machine transforming the enthalpy of the working medium (called also the thermodynamic medium) into the mechanical work causing rotation of the rotor. The increase in efficiency of the turbine results in the increase in thrust (power) and reduction in specific fuel consumption, and vice versa. The efficiency of gas turbines in aircraft engines (lying usually 30% - 45%) depends essentially on the temperature of exhaust gas, which has grown in the course of a few recent years by 280 K, what caused the improvement in general efficiency of the turbine and increased the power ratio. The barrier to temperature increase are material problems, i.e. creep resistance, thermal fatigue, high-temperature sulphur corrosion, and erosion. For this reason necessary is application of expensive creep-resistant alloys, complicated geometrical shapes of blades, complicating technological processes of their production and various kinds of treatment, such as the cooling of blades. At present, depending on blade material and cooling intensity, the working temperature of blades lies within the range of 1120-1170 K (without special cooling), 1200-1300 K (with cooling), 1300-1500 K (high-intensity cooling). Unfortunately, operation of turbine blades under complex thermal and mechanical loads (overload and aggressive environment) is only possible at the temperature of blade material lower even by 350 K than the combustion temperature. Therefore, further development and improvement in turbine blade design has been aimed at applying the heat-resistant coatings of good resistance to high-temperature corrosion, low thermal conductivity and high stability of the structure.

2. Types of in-service damages

In the process of operation of aircraft turbine engines various types of damages to turbine components occur, especially to their blades. Analysis of current cases suggests that all types of damages can be rated – depending on used classification – in one or a few causal groups, which are often closely related. Thus, we can differentiate damage being the result of production faults, improper repair or operational errors.

Experience gained in the course of implementing and performing prophylactic programs in the Polish Air Force, aimed at securing high safety degree in the military aviation, has proved that in spite of employing huge forces and means it is impossible to completely avoid various kinds of damages while operating so great population of turbine engines. The most frequent damages – except foreign-matter ingestion – are damages to turbines resulting from disadvantageous changes in blade material structure caused by excessive temperature and time over which it affects the blade and aggressiveness of exhaust gas (overheating of material, thermal fatigue of blades). Therefore, it is important to detect and explain as early as possible the symptoms of possible hazards with available diagnostic methods and knowledge.

The structure and the principle of operation of a turbine jet engine is closely related with the high-intensity air flux flowing through its gas path – the intake, compressor, combustion chamber, turbine, exhaust nozzle. The air taken through the intake is not always free from impurities, which penetrate into the engine. This depends on the location of the engine in the airframe (Fig. 1), condition of airfield pavement (Fig. 2), errors made while operating the aircraft.

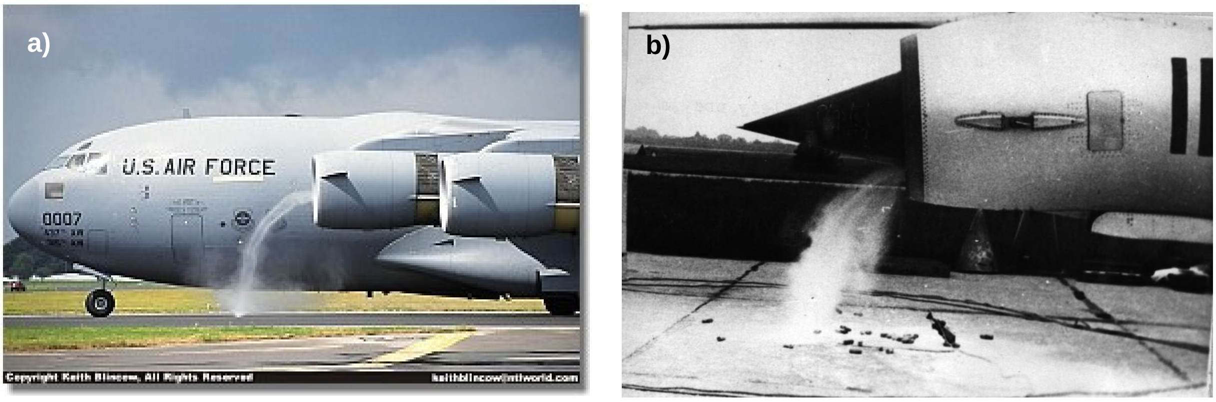

Fig. 1. Types of vortex at engine intakes [6][7]

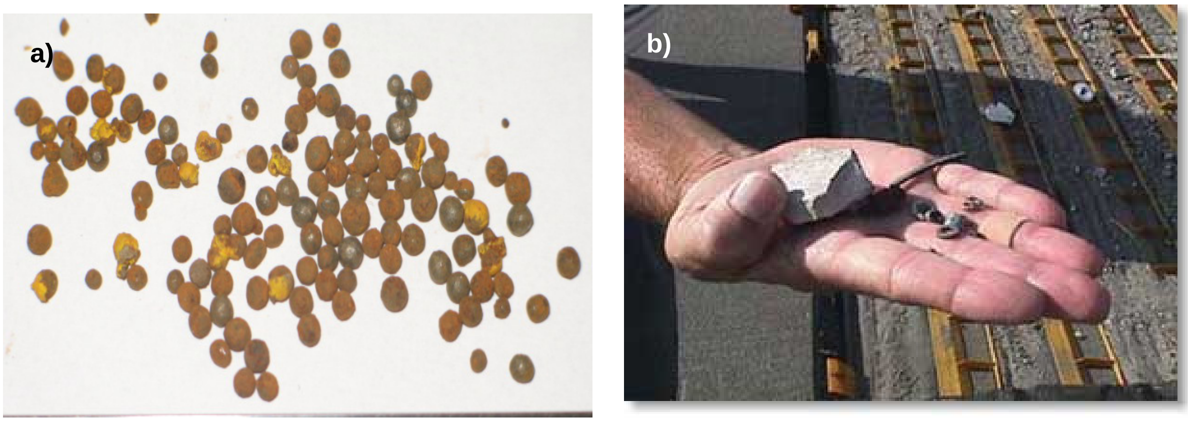

Fig. 2. Examples of impurities found on a runway: a) steel balls –paint-removing residues [3], b) fragments of concrete, washers, cotter pins [6]

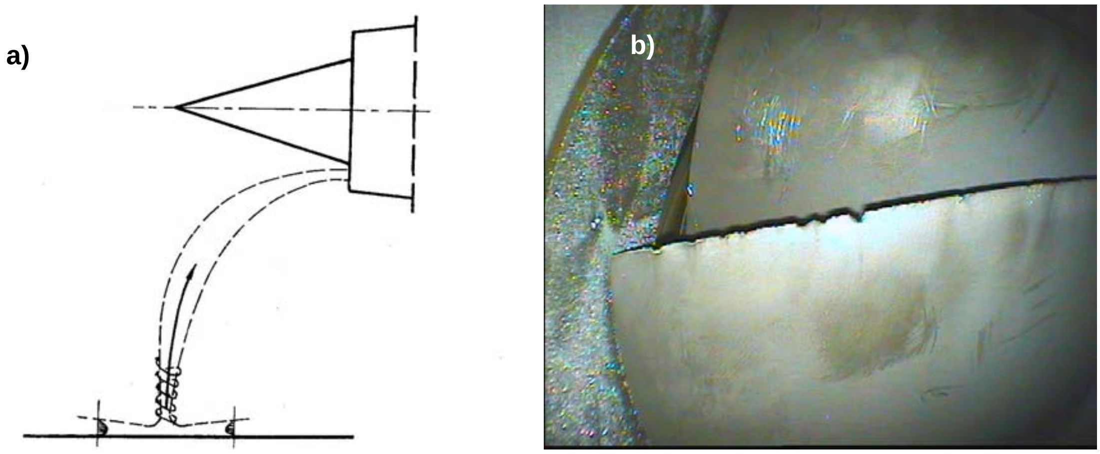

Fig. 3. Schematic diagram of air vortex at engine intake - a) [7], damage to compressor blades caused by impurities ingested by air vortex from the runway – b) [3]

Impurities ingested by air vortex cause mechanical damages to individual components of gas path – in particular, to compressor rotor blades (Fig. 3). The result of such damages is disturbance of engine performance parameters, what has also adverse influence on working temperature of the gas turbine. On account of the complicated nature of thermal and mechanical loads on turbine blades inadmissible are any mechanical and thermal damages to blades, because it may lead to the break-off of a blade, and consequently to the engine damage, and hence, hazard to flight safety. Some types of mechanical damages resulting from the foreign-matter ingestion are detected after finding damages to the compressor's first-stage components during pre- or after-flight maintenance, or in the course of the first borescope examination after the event, carried out during periodical maintenance of the engine (Fig. 4).

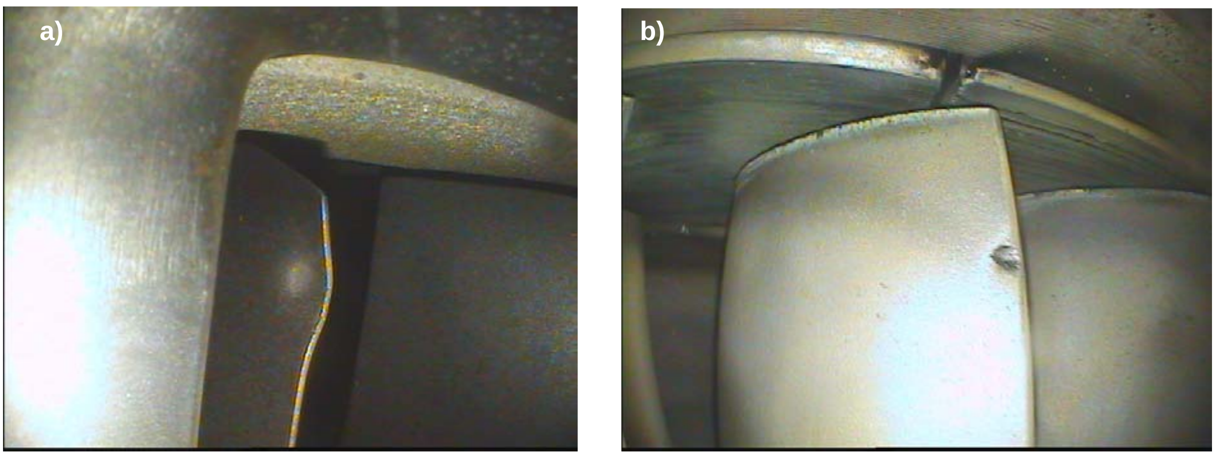

Fig. 4. Examples of damages to: a) compressor blades, b) turbine blades, effected by the ingestion of steel balls from the runway pavement [3]

Small spot damages or small abrasions of blade surface are often invisible during first hours of engine operation after the damage has occurred, and they are not detected by a diagnostician in the course of diagnostic examination. A damage to blade protective coating together with high temperature and exhaust-gas induced aggressive environment may result in the overheating and burnout of the native material of the blade (Fig. 5).

 

Fig. 5. Exemplary types of thermal damages to leading edges of turbine rotor blades [3]

Manufacturing and repair-effected defects are another group of damages detected within the hot section of the engine during preventive diagnostic tests. These are damages beyond the user's reach and can reveal throughout the entire period of engine operation.

The break-off of a turbine rotor blade caused by spreading a new type of a protective coating applied with diffusion method onto the blade material is one of the most interesting and at the same time the most dangerous events. In the course of turbine operation a fragile coating suffered cracking; the crack propagated into the native material of the blade and finally resulted in the break-off of the blade (Fig. 6).

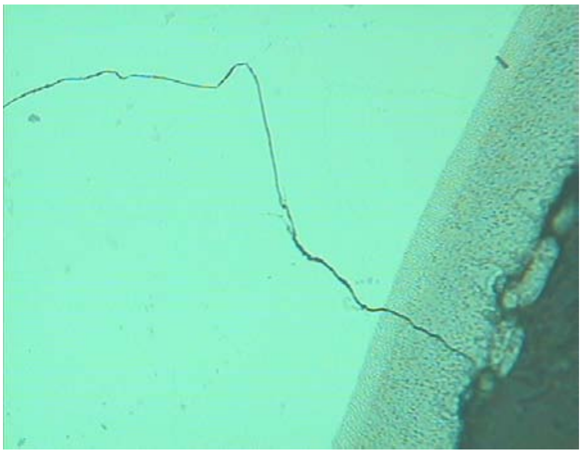

Fig. 6. Protective-coating cracking; the crack keeps propagating into the blade's native material [3]; magn. x 450

The hitherto experience gained in the course of research work at the Air Force Institute of Technology shows also that the majority of turbine defects are directly related with incorrect adjustments of the engine and poor quality of aviation fuel.

Incorrect fuel pressure, its physical and chemical properties deteriorated by various kinds of impurities, and misalignment of the flame tube injector prove conducive to the formation of carbon deposit on the injectors (Fig. 7) and other sub-assemblies, what results in faulty fuel spraying. This, in turn, results in disturbance of the combustion-process organisation, and consequently of temperature distribution and cooling of individual components of the hot section of the engine. What results is overheating of material of combustion chamber and turbine blades (Fig. 8).

Fig. 7. Carbon deposit on fuel injector of a turbojet [3]

Fig. 8. Thermal damage to turbine blades [3]

3. Capabilities of diagnosing health of turbine blades

The process of degradation of components in replaced sub-assemblies is specific to every engine type and is related with its structure, operating conditions, depends also on the repair process engineering. Therefore, the process of preventive diagnostic in-service testing of engines is extremely significant from the user's point of view.

Diagnostic methods can be divided into two groups:

- in-service (non-destructive) methods,
- in the process of repair (not-destructive or/and destructive).

Health of turbine blades while in service is mainly examined during borescope inspections. Detected are defects of the following types: cracks, deformations and erosion from foreign bodies, corrosion, burnout of protective coating or native material of the blade. This is exclusively visual, remote inspection by means of a videoscope. The reliability of such assessment depends mainly on the experience of the diagnostician and quality of available equipment.

The second method of assessing condition of turbine blades is the measurement of oscillation, e.g. measurement of oscillation using microwave sensors. This method makes use of the phenomenon of the reception of a homodyne signal reflected from the turbine blade. On the other hand, while measuring blade vibrations with inductive sensors, use is made of the phenomenon of changes in the magnetic field caused by rotating turbine blades that cross this field. The eddy current inspection is a direct method for checking condition of blade edges built in the airframe.

During any repair we have better access to turbine blades. Thus, more accurate, direct assessment of their health is possible. Among non-destructive methods widely used are:

- visual,
- penetrative,
- ultrasonic, and
- radiographic inspections.

Until now, all these methods do not allow of explicit assessment of changes in the structure of a blade resulting from the material overheating. The diagnostician makes the assessment of the level of the blade overheating with a visual method; his decision is verified with metallographic examination. Conducted are works on the development of a new computer-aided visual method to obtain more objective and reliable results [4].

The assessment of the level of blade-material overheating with a visual method can be verified with eddy-current inspection method. This is a comparative method that makes use of the phenomenon of eddy current generation in the (electrically conductive) material under the alternating magnetic field. Eddy currents generate, in turn, magnetic field opposite to the field that has initiated them. The eddy-current measuring technique is based on the electromagnetic induction.

In our work we have used the Wirotest 302 with the SNC/04/012 probe, with alternating magnetic field of 1.2 MHz frequency applied. The object under examination were blades made of the EI-867WD alloy with protective coatings made of aluminium alloy. Measurements were taken on a new blade (marked A), a blade withdrawn from service but not overheated (marked B) and an overheated, burnt-out blade (marked C). Results are shown in Tables 1 and 2.

Table 1. Turbine rotor blades

Marking	Measured value	Blade description
A	12	New blade
B	35	Used, not overheated blade
C	70	Overheated blade

Table 2. Turbine nozzle blades

Marking	Measured value	Blade description
A	1	Used, non-overheated blade
B	30	Used blade with burnouts

Measured values are very much diversified, what is advantageous from the point of view of the method’s sensitivity and proves that possible is the assessment of the level of blade overheating with eddy current inspection method. The overheating is caused by excessive temperature of the exhaust gas, time of affecting the material, and aggressiveness of the exhaust gas. The overheating causes some change to the microstructure, which consists – among other things – in modification of strengthening intercrystalline phase $Ni_3(Al,Ti)$ called the γ' phase. This phase proves decisive to heat resistance and high-temperature creep resistance of an alloy. In special cases, growth of the γ' phase results in the coagulation of precipitations, and then dissipation thereof in the solid solution. What results is reduction in heat resistance and high-temperature creep resistance of the alloy.

However, it is necessary to emphasise that results obtained with the eddy-current inspection method depend on many factors, i.e. the kind of blade material and protective coating, the eddy-current testing apparatus, the range of pre-set parameters, etc. To get more complete image of capabilities offered by this method it is necessary to carry out tests on much wider population of objects under examination (blades made of different materials). However, preliminary results of initial tests are promising.

4. The use of computer technology for the diagnosing of the gas-turbine blade’s condition

Diagnostic visual inspection being an element of preventive treatment to assure high safety level of operating aeronautical equipment has been from the very beginning closely connected with two elements - technical capabilities of available testing-and-measuring apparatus and the professionalism (knowledge, experience) of the diagnostician who carries out inspection. Introduction of a "human factor" and relying on his subjective assessment of the existing diagnostic reality was and still is the reason for many expensive errors resulting from the decisions taken. It often happens that, due to the application of outdated equipment and/or lack of suitable knowledge, engines are withdrawn from service and transferred for expensive overhaul, although their safe use is still possible. Taking into consideration the above-mentioned fact, the development of diagnostic apparatus has been aimed at the improvement of quality of vision by application of more perfect visual paths and elimination of the diagnostician from the laborious measuring activities and interpretation of observed images. Videoscopes facilitate measurements of: length, area, depth/height, distance from the straight line with accuracy of 0.01 mm, and at the same time they give the value of error that burdens the resulting measurement, depending on the distance of the measuring probe from the examined object. Special software enables measurements either directly during the inspection or later on, with computers of the PC class. At present, there are a few companies offering instruments/systems of similar capabilities and working parameters; however, differing in the method of calculating certain quantities. The Olympus company uses the stereoscopic method in their videoscopes, GE - the method of "shadow", and KARL STORZ - the most recent laser method. All these methods use mathematical relations between two images obtained with two lenses, properties of the shadow or laser markers thrown on examined object/defect, and hence, provide high-accuracy measurements of the above-mentioned quantities. They also allow to explicitly determine whether there is concavity or convexity of the material.

In [4] presented are methods of measurements of surface defects, which are based on digital recording of the videoscope image with the "Stereo" method ("Stereo Probe") and with the "Shadow" method ("Shadow Probe") - Fig. 9.

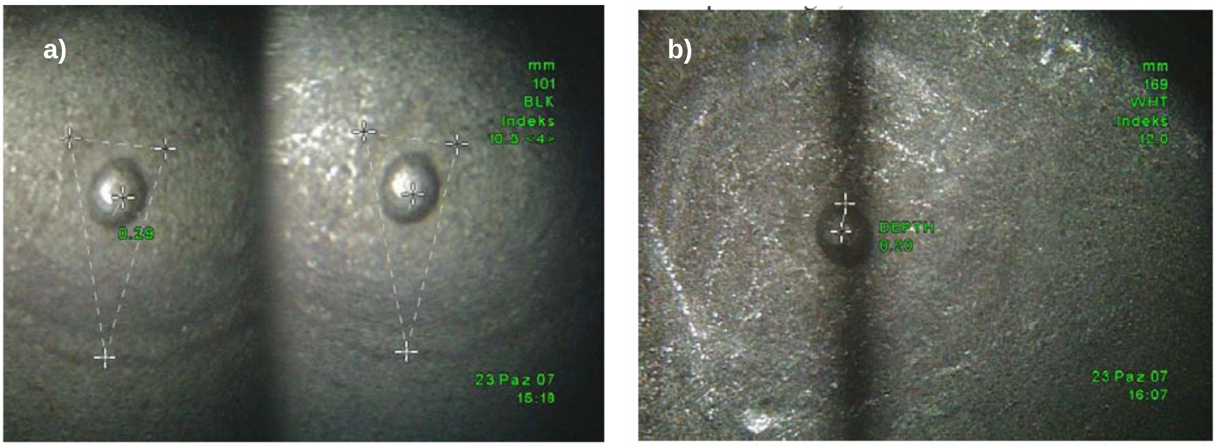

Fig. 9. Measurement of convexity radius with methods [4]: a) „Shadow”, b) „Stereo”

The next method developed as a diagnostic tool is the RGB method. In the RGB model identified are three component colours: **R**ed, **G**reen, **B**lue. The method employs relations between wave properties of light and physical-and-chemical properties of the examined surfaces, which affect angular relations between the falling and the from the surface reflected light and elimination of individual wave lengths in the spectrum of radiation that lights a given object [5]. Images recorded with the CCD matrix in the course of diagnostic tests are analysed with special computer software using complicated algorithms of image processing and earlier developed patterns that allow qualitative assessment of the condition of the examined surface. The RGB model is a theoretical model, the mapping of which depends on the device, which means that in every instrument/system a particular RGB component can show slightly different spectral characteristics. Therefore, every instrument/system can offer a slightly different range of colours. Thus, it is necessary to develop algorithms for a given type of an instrument/system as well as patterns for every individual type of examined surface, e.g. for turbine blades of particular turbine types.

The method more and more widely used in the technical diagnostics and based on the computer analysis is the recognition of images. Optical methods of image recognition can be classified into correlative and non-correlative. The correlative methods are based on visual comparison between a recognised and a pattern object, and then on the analysis of obtained correlative signal. The non-correlative methods consist in the analysis of characteristic features that describe the object and are applied – among other things - when it is difficult to explicitly determine the target pattern, which should be compared with the object. Until now, these methods have found their applications in the industry, mainly in the production inspection, for the recognition of face features and fingerprints, land relief, and building development on the basis of air photographs. Continued are also works on the development of methods of image recognition as a commonly used diagnostic tool to be applied in the process of operation/maintenance of aeronautical equipment – including the diagnosing of condition of gas turbine blades.

Implementation of modern computer-based diagnostic tools provides noticeable increase in reliability of the assessment of condition of gas turbine blades. This will also allow to gradually eliminate the adverse effect of the so-called "human factor" on investigation results, and thus to increase flight safety and reduce in-service cost of aircraft turbine engines.

5. Conclusions

In the process of operating aircraft turbine engines it may happen that turbine blades heat up to temperature exceeding normal working temperature. The process of he gas turbine blade getting damaged starts with destruction of the protective coating, which in turn results in that the blade native material is directly exposed to aggressive influence of exhaust gas. This causes the overheating of the material, which manifests itself with disadvantageous changes in the microstructure.

The reliable assessment of these changes with non-destructive inspection methods allows in some cases to prolong the period of engine operational use (the so-called controlled service) even after detection of a damage, or withdraw the engine from use before dramatic effects of turbine damage occur. However, any wrong decision of the diagnostician generates huge costs related with hazards to flight safety, or may result in unnecessary engine overhaul, the cost of which may reach even a few million PLZ.

Taking the above-mentioned facts into account it becomes evident that there is a real need to apply – on much wider scale – the non-destructive inspection methods for current assessment of the level of overheating of aircraft turbine engine blades.

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