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INITIATION OF DAMAGE TO THE HOT PART OF AIRCRAFT TURBINE ENGINES

In the paper, the initiation causes of damage to flame tubes of a basic combustion chamber and turbine units, which are the most common in the operation process of aircraft turbine engines (ATE), were presented. They were illustrated with the use of numerous examples of progressing degradation of the surface condition of parts and components of various types of aircraft engines which was found during endoscopic controls.
On the basis of the systematic observation results, the process of destruction of the turbine rotor ring blades' surface was discussed. The attention was paid to the current and still valid evaluation of the aircraft turbine engine's suitability for further operation, taking into account the specifics of its use.

Keywords: aircraft turbine engine, fuel injection, basic combustion chamber, turbine unit, afterburner, process of destruction of parts and components.

1. Introduction

Aircraft turbine engines (ATE) of the high-performance military aircraft are operated in the conditions of frequent changes of dynamic and heat loads.

The particularly serious damage found in the aircraft turbine engine includes: fatigue cracks of shafts and carrier discs of the compressor or turbine rotor units' rings, especially of blade leaves of the palisades of guide vanes or working rings, as well as bearing units. They have a large impact on the aircraft turbine engine's reliability level, because not only do they reduce the resource between repairs, but they also endanger the safety of performed tasks.

The surface visual inspection of elements of the machine and industrial equipment internal space, and, especially, the aircraft turbine engine, with the use of specialised penetration probes is currently one of the main technical diagnostics methods. The damage to the flow part was previously diagnosed on the basis of

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changes in values of the measured and recorded thermodynamic parameters. The proper interpretation of symptoms arising from defects causes numerous problems, because they are still often identified as symptoms of the inevitable and continuous wearing processes in a period of expected operation. Even the convergence of symptoms is a major difficulty in interpretation of the obtained results.

In such cases, non-destructive tests are helpful, and more specifically – endoscopy, because it does not require disassembly of a tested object to components and component parts, and the appropriate equipment does not affect the tested object. The results obtained in this way allow to locate the damage outbreak early, and then to carry out the periodical observation of the progressing degradation of elements. Such damage as: fatigue cracks, mechanical deformation and heat distortion, overheating and burnout or chemical and/or high temperature corrosion, and mechanical and gas erosion, are the main causes of premature decommissioning of machines, and if they are not detected in due time, they can pose a threat to users. It probably had an impact on the fact that endoscopy became one of the primary methods of non-destructive tests, which were used in air transport.

Many-year participation in the research with the use of a visual (endoscopic) method and the associated technical condition analysis of the aircraft turbine engine's components allows the authors to make some generalisations, including those concerning the damage initiation.

2. Causes of damage

The fuel and air mixture ignition arises from the impact of the high temperature external source (ignition) on it, as well as electric discharge or the start-up flame charcoal formed in the igniter chamber, that is a local initiator of the start-up flame. If the released heat amount is sufficient to heat up constantly flowing air and fuel, which are mixed in the flame chamber's combustion zone to a temperature exceeding the ignition value, this process begins to proceed spontaneously, and the initiation source is automatically disconnected.

However, it is only the completion of the first initial stage of the aircraft turbine engine's start-up. Then, the maintenance of the already started combustion process should be provided. However, it requires, i.e. air and fuel pre-heating, the supply of a substantial amount of oxidiser to the basic combustion chamber, and the proper fuel spraying in the chamber, so that its surface evaporation and contact with oxygen contained in air will be increased, quick and accurate mixing of fuel vapour with the oxidiser, as well as intensive mixing of an agent in the flame by its turbulence and swirl, the maintenance of an appropriate and uniform air–fuel ratio

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in its entire combustion zone and the use of ignition stabilisers, including e.g. initial chambers (start-up igniters) or turbulators [1, 5÷8].

However, as a result of possible disorders in the inflow of the air stream from the outside of the compressor to the combustion chamber, or pressure pulsation of the supplied fuel, the local excessive mixture enrichment may occur in the mixing zone. The size of fuel drops injecting into this area is directly proportional to the flow rate through the nozzle, including its cross-sectional area, and inversely proportional to the third stage root of the pressure difference of fuel in the pipeline before the injector, and pressure in the flame chamber for each injector type. As a result, the greater mass flow rate is, and hence the flowing stream dimensions are definitely greater, the more difficult it is deformed by forces of inertia, viscosity and the ones resulting in pressure pulsation of the flow resistance through the nozzle.

It contributes to the excessive heating of some areas as well as release of incomplete combustion products [1, 5÷8]. Aviation fuel, which is characterised by a high percentage of resins and aromatics (to approx. 28%), in case of incomplete combustion, becomes a source of release of the fine crystalline type of graphite (soot) and coke. During formation and combustion of the air and fuel mixture, the fission process of large hydrocarbon particles to those with a smaller number of carbon atoms (cracking of hydrocarbons) as well as the formation of the incomplete combustion particles in the form of resins, coke and ash (carbon deposits) may occur (Fig. 1).

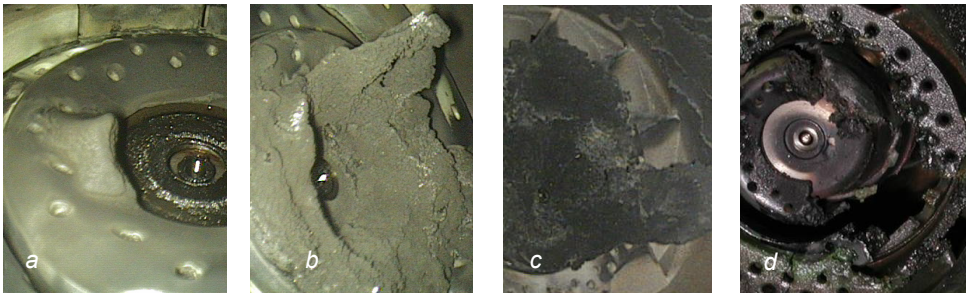


Fig. 1. The gradual build-up of incomplete combustion products (coke) on the face of one of the units of the aircraft turbine engine's air turbulator - fuel injector units (a÷c); oxidising and chipping material of a shaft hub of one of the aircraft turbine engine's injectors (d) [2]

The raised content of sulphur in the fuel resulting in the fact that the product of combustion is characterised by increased hardness. Even not very large parts that get torn off e.g. the injector units' elements and which are carried by the flowing exhaust streams, are not only a cause of gradual erosion, and then corrosion of the

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surface of the fire pipe's elements of the basic combustion chamber (Fig. 1b÷c), but also the turbine unit's elements of the aircraft turbine engine (Fig. 3÷6).

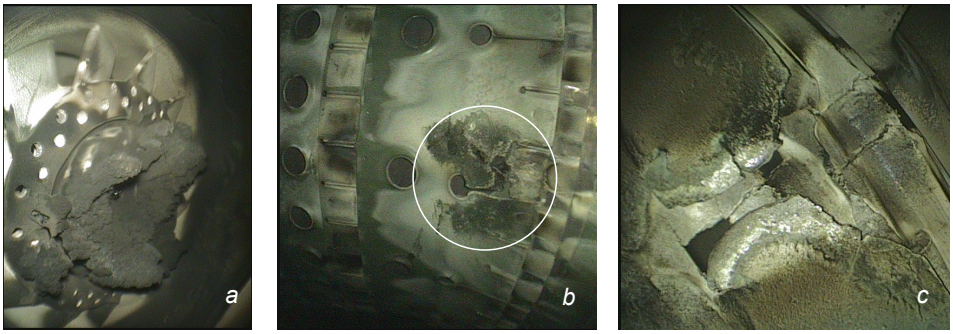


Fig. 2. The retention of incomplete combustion products on the face of one of the air turbulator - fuel injector units (a), local cracks, burning and material losses in the zone of mixing and temperature adjustment of the combustion chamber flame tube's inner ring of the aircraft turbine engine (b, c) [2]

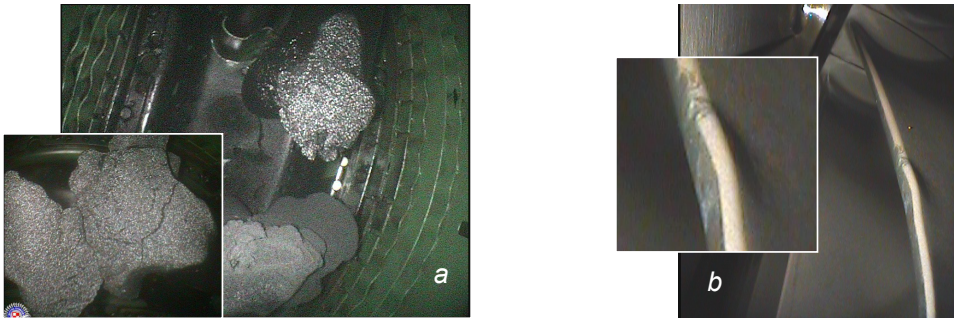


Fig. 3. Coke and slag which remain on the surfaces of pipelines of the initial fuel evaporation unit (a), buckled as a result of the slag particle impact (torn off from the injector and carried by the exhaust stream), the leading edge of one of the leaves in the turbine rotor blades' ring of the aircraft turbine engine (b) [2]

Another source of damage can include too intense swirl in the mixing and combustion zones. They contribute not only to the increase of flow losses, but also to the increase in the carbon deposit weight on the chamber wall surfaces, which in turn, causes uneven temperature distribution and the associated risk of the local areas' overheating, or even the material burning and cracking. However, the accumulation of the incomplete combustion product on the face of the injector not only results in a change of its operation conditions in the form of changing the angle of

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spraying and grading of the sprayed fuel drops, but it can also lead to its permanent damage (Fig. 1).

This process can also be accompanied by the exceeding combustion zone, which results in the temperature field non-stationary distribution, as well as afterburning of the fuel exhaust or drops in the turbine unit area. It leads to, i.e. combustion of seals and overheating of its components, in the absence of clear symptoms of exceeding the operation technical conditions, because a time constant of this phenomenon is often significantly lower than a time constant of the classical temperature measurement system [1, 5÷8].

The zone surface burning, cracks and material losses, as well as other faults and defects are found in each type of the aircraft turbine engine, regardless of whether the mixture's inflaming in them is a result of the start-up flame generated in the igniter, or in case of electric discharge (Fig. 2÷4).

Similar consequences of damage can result from the fuel injector improper operation caused by its leakage, the nozzle decalibration (Fig. 4f) or other mechanical damage, as well as its misalignment in relation to the turbulator [1, 5÷8].

There is also damage, the sources of which should be found in improper organisation of the combustion process, i.e. when there is the local, short-term expansion of the mixture combustion zone and its moving to further sections of the flame tube, which leads to the fuel vapour afterburning in the area of the guide vanes' palisade and turbine rotor ring, especially during its start-up. The evidence of an important way, in which this process was subject to temporary interference, includes the determined changes of the surface condition.

The damage may be also a result of the delayed ignition initiation (in relation to the fuel injection time) after inclusion of the high temperature source, which for example can indicate damage to the spark plugs' electrodes or their too shallow embedding in mounting seats. However, at this time, there is injection of an excessive amount of fuel to the flame chamber area, and if there is the one that entered after shut off the aircraft turbine engine as a result of leakage (incomplete closing) of valves isolating its flow, or it remained there as a result of the incomplete opening of discharge (drainage) valves, then after its ignition, it can result in the local excessive extension of its combustion zone up to the chamber's rear part (mixing zone and formation of the temperature profile), or even in the turbine unit area. Even if it is a short-term process, after some period of time, at this point, initiation will occur, followed by a progressive degradation process of the technical condition related to the turbine's parts or components.

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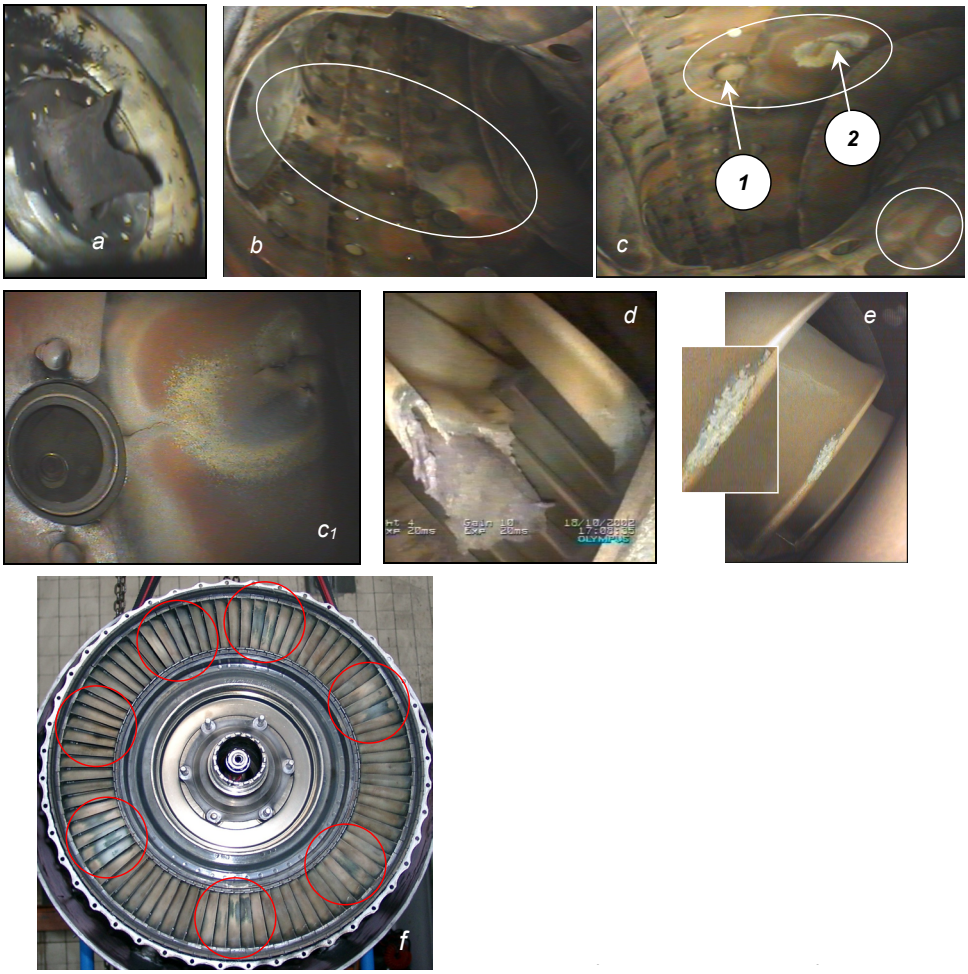


Fig. 4. The retention of incomplete combustion products on the face of one of the operating injectors (a), burning of a protective layer of the flame tube's surface part (b), the outlet of one of the (1) fuel igniters and burning as a result of the start-up flame charcoal, and the protective layer with a crack, perforation and hollow of (2) material of the exterior ring of the last section of the aircraft turbine engine's flame tube combustion chamber (c, c_1), burning with the material loss of one of the leaves in the turbine guide vanes' palisade (d), local burning of the leading edge material and the trough surface of one of the leaves in the turbine blades' ring (e), zone overheating of the material of the guide vanes palisade's blades of the II degree turbine (f) [2]

The cooling with air taken from the compressor area, which has to produce a properly shaped outside thermal barrier, will not prevent it. The calculation cooling intensity, and thus the heat exchange between the material of an individual blade

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leaf and the factor that reduces its temperature, is effective only if this process is run in a correct (calculation) manner.

Example I

During the periodic inspection of the technical condition of the internal space elements, numerous damage to the leaves' surface in the blade rings of the turbine rotors of drive units of the high-performance aircraft. They can be caused by foreign particles, which are carried by a stream of flowing exhaust and hit their surface, as well as the protective layer's material that is split and chipped, or erosionally "eluted" in the leading edges' zones, and evaporated.

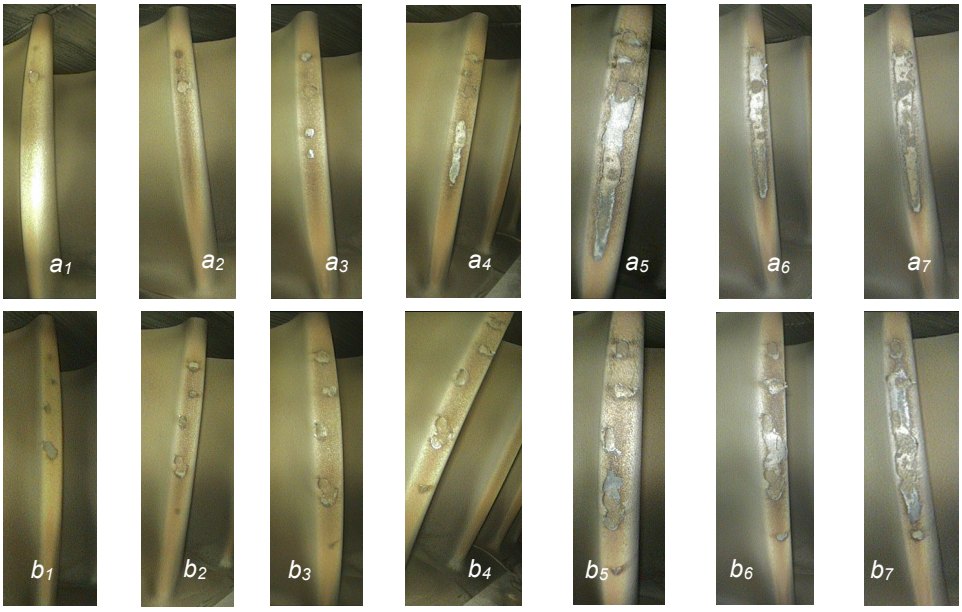


Fig. 5. Blades (a and b) of the turbine unit's rotor of the aircraft turbine engine. The progressing technical condition degradation ($a_1 \div a_7$ and $b_1 \div b_7$) in the area of the leading edge of the ring's leaves [9]

During a periodic inspection of the technical condition of one of the aircraft turbine engine, the local losses of the leading edge surface layers of two non-consecutive blades' leaves of the turbine unit rotor in the ring, were found (Fig. $5a_1$ and $5b_1$) [4]. Due to technical conditions applicable for this aircraft turbine engine type and the progressing degradation, a time period between successive visual inspections of the technical conditions of a diagnosed component was decreased from 50 to 25±5 hours of its

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operation time. The supervision over the condition of these elements was started when the engine operated approx. 170 hours and was continued to the time when it was out of approx. 90% of the expected lifetime (resources between repairs).

In the mentioned period, a gradually progressing degradation process in the leading edge zone, not only in the form of the damage area increase – chipping, evaporation and eluting of the insulating and protective (thermal insulation) layer's material) (Fig. $5a_1 \div a_2$ i $5b_1 \div b_2$), but also in the base material increase (Fig. $5a_3 \div a_7$ i $5b_3 \div b_7$) [4] was observed. However, in the final operation period under control, the formation of pits was found (Fig. $5a_5 \div a_7$ i $5b_5 \div b_7$) [4], which in turn, not only started to be a threat of the further loss of the base material (and the formation of "scars"), but also its perforation and cracks.

At the time of making the decision on a way of further operation, the tested aircraft turbine engine was started up 226 times, and 382 times in case of its completion. According to the results of the operation and maintenance manual, during all subsequent 25±5 operation hours, it was started up from 21 to 24 times.

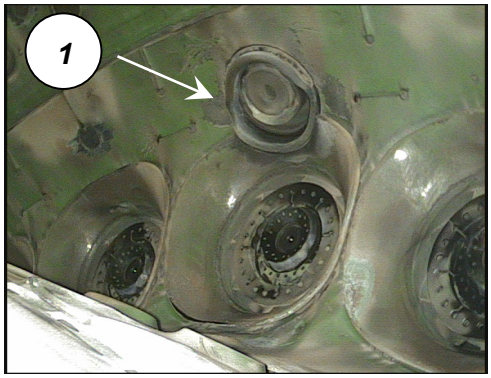


Fig. 6a. The head fragment of the flame tube with fuel injector units – air turbulator, 1 – a head of the spark plug

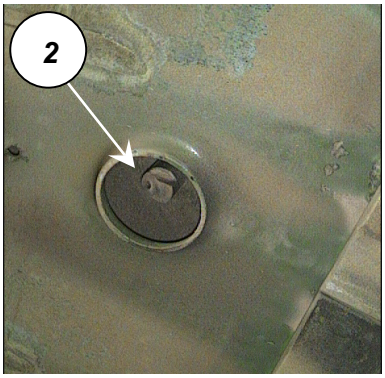


Fig. 6b. The interior of the flame tube of the aircraft turbine engine's combustion chamber, 2 – a head of the stream injector of the start-up afterburner system

However, while starting the periodic analysis and assessment of the diagnosed engine's components, not only the existing (current) technical condition is considered and referred to the previous archived images, but also the type and time of the occurrence of exceeding the operation parameters during individual departures of the aircraft, the drive unit of which it constitutes. The type and scope of the conducted operation as well as found and possible damage, and the way of their removal were determined. The total number of operated hours – from the time of the aircraft turbine engine's entry into service, as well as after the last general renovation is

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also crucial. It is one of the factors that determines the further operation of the used object so far. In the light of the found and above-illustrated damage, it is an insufficient assessment. The Polish military aviation also operates the aircraft turbine engine type, in which the ignition of fuel entered into the zone of its afterburner chamber is made by the burning start-up fuel charcoal inflaming in the basic combustion chamber and moving with a stream of gases behind its turbine units (Fig. 6b).

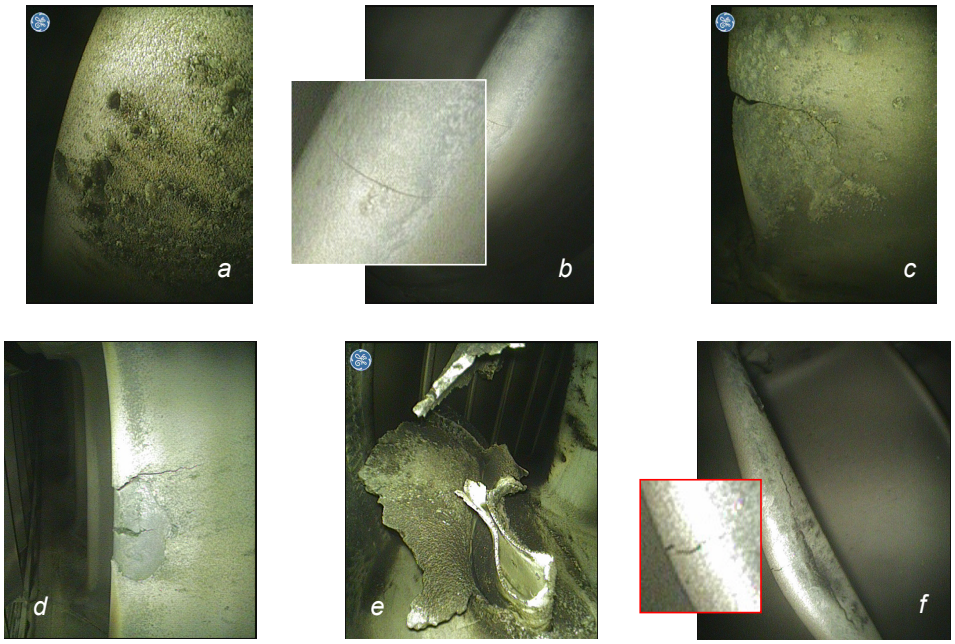


Fig. 7. Deposition of soot and corrosion pits on the surface of the trough of one of the leaves (a), the leading edge crack in the place of the leaf surface refurbishment (b), crack with perforation of the leading edge of one of the leaves (c), double crack with perforation and the material loss of the leading edge of one of the leaves (d), burning with breaking of a profile's fragment of one of the blades in the turbine guide vanes' palisade of the aircraft turbine engine (e), deformation with a longitudinal crack of the edge surface, as well as buckling with a transverse crack of the leading edge of one of the leaves in the turbine rotor blades' ring of the aircraft turbine engine (f) [2]

Such a way of ignition promotes the damage initiation illustrated in figures 5, 7 and 8, and reduces the service life (useful life) of the turbine's parts and components. During all consecutive 25±5 operation hours, the system is started up on average from 50 to 60 times (306 times during 143 operation hours under control). Therefore, when deciding on the further operation of the aircraft turbine engine, in

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our opinion, not only the total number of operated hours should be taken into account, but also the number of its start-ups (operation cycles calculated from the time of its start-up to shut-off) and the number of its afterburner system's start-ups.

In Fig. 7, the impact effects of the ignition charcoal flame of the afterburner system moving through the turbine units: gradual degradation (Fig. 7a÷e) of one of the leaves in the guide vanes' palisade and damage to the turbine rotor blade of low pressure of the aircraft turbine engine (Fig. 7f).

Example II

In the flow part of the turbine unit of the same aircraft turbine engine type, a transverse crack of the leading edge of the leaf is sometimes found (Fig. 8a). This defect can be noticed after some time – approx. 25 operation hours (Fig. 8b÷c), which qualifies the tested object to the premature decommissioning. What is more, in the next stage of destruction, the perforation of the edge with parallel gradual propagation of the crack toward the surface of the edge's and leaf's trough takes place (Fig. 8d), and in the final stage, its top breaking occurs (Fig. 8e).

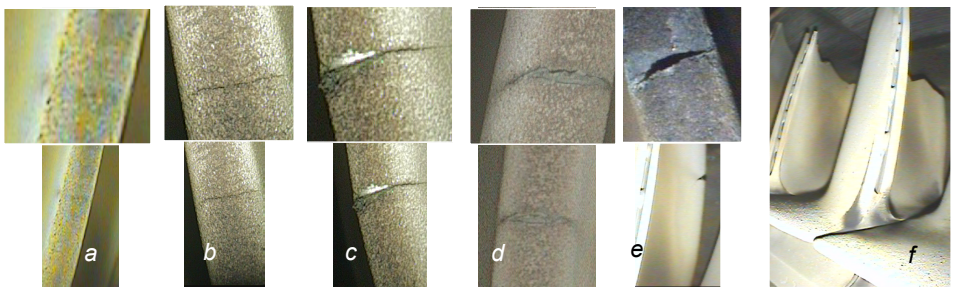


Fig. 8. The gradual degradation of the blade ring leaf of the turbine unit rotor of the aircraft turbine engine: suspicion of a crack (a), crack (b), crack with the material chipping (c), crack with the initial leading edge perforation (d), crack with the leading edge perforation (e), breaking of a top part of adjacent blades in the leaves' ring (f) [2]

It happens as a result of cyclically occurring interference in the combustion process, and thus the local exceeding of the allowable temperature in the turbine unit area. It is accompanied by the material alternating contraction and expansion, and consequently, there are variables related to a stress mark of the first kind, generated by a difference of the cooling rate of the element core and its surface. The negative impact also includes loads related to the flow of an operating medium through the rotor unit rotating at a variable speed. In some areas of the leaf, it can

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result in clearance of stresses corresponding to its yield strength and the appearance of plastic deformation. These deformations, in turn, increase with a growing number of the unit operation cycles causing the formation of the leaves' material cracks (due to a decrease in the modulus of elasticity), and in the final stage, it results in breaking of the blade's top fragment.

The strength of the material intended for the turbine unit blade of the aircraft turbine engine can be successfully assessed using linear damage mechanics [3,4]. The basic parameter, which specifies an elastic stress field in the fatigue crack area, constitutes a stress intensity factor. The development of cracks in the leaves operating at high temperature depends on the load cycles, time, combination of the cycle dependence and its duration, the type of material, temperature, load and its frequency or operation environment.

The turbine blades operate under dynamic load conditions, and therefore, their cracks have a fatigue nature, and as it was stated, in case of cyclically repeated loads, the crack propagation can occur at values of the load factor lower than the critical ones [3, 4].

Example III

During the combustion of the fuel and air mixture with a higher sulphur content, the carbon deposit, which is a product of glass surface and increased harness, is created. The detachment of its even not very large fragments from the injector units' surface, and then their carrying by the flowing exhaust streams not only cause surface damage and their gradual erosion, but also corrosion of particular elements of the combustion chamber's flame tube, and the turbine unit of the aircraft turbine engine.

It was also stated that the deposition of another incomplete combustion product – soot, is a result of all the defects in workmanship, which appear on the elements eluted by flowing exhaust (Fig. 9÷10), and their presence in these areas only accelerates a destruction process of the tested elements. After each subsequent start-up of the drive unit, soot, which is subject to combustion (and thus locally raising the temperature), firstly leads them to local burnings of the insulating and protective layer, and then to losses by melting and evaporation of the parent metal. Furthermore, additional stresses, which are included there in this case, also become a source of cracks and chips (Fig. 10d and 11b÷c).

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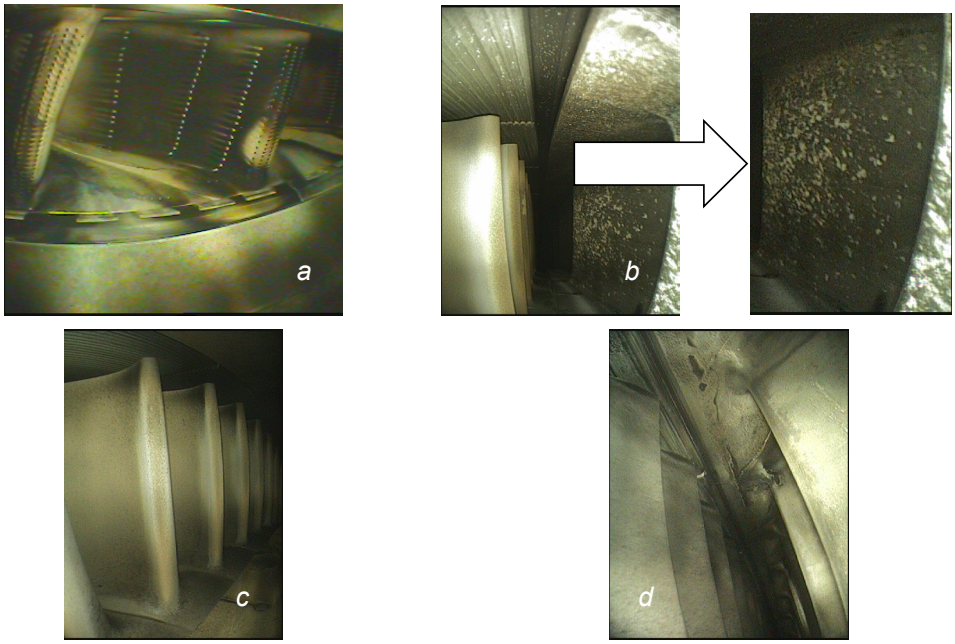


Fig. 9. Soot lingering on the surface of the turbine guide vanes' palisade: the view from the side of the leading edge and troughs (a), the view from the side of the trailing edge and troughs – local burning of the surface layer (b), on the side of the leading edge and troughs (c) and on the side of the leading edge and the turbine unit's edge of the aircraft turbine engine (d) [2]

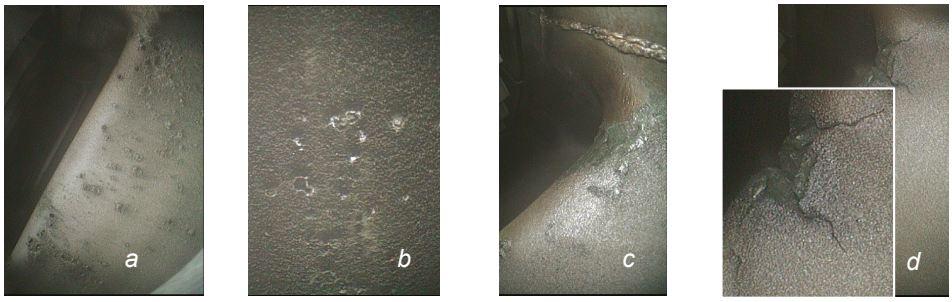


Fig. 10. Corrosion pits (a), deposition of soot and corrosion pits on the surface of the leaf's trough (b), corrosion pits with losses of the surface layer (c), multiple cracks and losses of material from the surface of the transition radius of the leaf to the inner ring of the turbine unit guide vanes' palisade body of the aircraft turbine engine (d) [2]

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Conclusion

In the operation process of military aircraft, the turbine units of the above-discussed aircraft turbine engine type are at least twice (in each aviation cycle) exposed to a direct impact of extreme exhaust temperatures or even a stream of the burning air and fuel mixture. In case of the first time, it was during their start-up, and the second time – during the start-up of the afterburner system. During some departures, this system can be started up a few times, which without a doubt, has a direct impact on the service life of the turbine's controlled elements (and the aircraft turbine engine's period of the used resource).

The technical condition control of the aircraft turbine engine's components can be allowed by systematic endoscopic penetration of the inner space, and a comparison of the existing current image with the previously archived one facilitates making a diagnosis.

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