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DAMAGES TO STRUCTURAL COMPONENTS AND UNITS OF A GAS TURBINE ENGINE

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Abstract

Safe operational use of an technical system, depends on properties and characteristics thereof, external excitations, and the correctly performed process of operation/maintenance of this system. Unserviceability and failures/damages to the system are the most essential problems, which – if not identified on time – can result in an accident (a crash or failure). The issues of safety, unserviceability and failures/damages have been exemplified with those occurring to gas turbine engines.

Keywords: *exploatation, failures, gas turbine engine*

1.Introduction

Causes of damages are pretty well recognized owing to rich maintenance experience and examination of engineering objects and units thereof. They are usually deeply rooted in physical and chemical phenomena (effect of the process of the IV type, according to description in [6.13]), but can also be effected by maintenance activities that may provoke the boundary limits, e.g. of strength/resistance, wear-and-tear limits, etc. of particular components are exceeded. Causes of damages/failures are grouped into four classes: direct, indirect, primary, and secondary ones.

Effects of damages have their impact on the performance of operational tasks, reliability, safety, and economic effectiveness of operation/maintenance. The more important component of an engineering object (from the point of view of its functionality), the more serious effects brought about by a damage/failure to this component. Damages/failures may occur in the course of operational use of the object as well as the maintenance thereof. It is obvious that damages to an engine (its structural component or unit) while it is operated in the air are essentially different from those occurring on the ground.

2. Damages/failures to engines

The term 'engine damage' comprises damages to the engine structure, units as well as particular components (structural members and parts) that the units are composed of. Damages to parts and structural members may bring about damages to the whole unit/assembly in the composition of which they enter; also, to other units/assemblies of a given object.

Any damage is defined as the loss of physical properties and/or peculiar features by the structural component, i.e. an event that results in the transition of the engineering structure from the fit-for-service condition into the unfit-for-service condition.

The most essential criterion of rating an engineering event among damages/failures is a change in a feature/a set of features or its/their deviation from those, on the grounds of which the structural component/unit is claimed to be either ‘fit-for-use’ or ’unfit-for-use’.

From the standpoint of the engineering-object operation, damages/failures may be either typical, i.e. well recognized and identified, described in operational/maintenance documentation, or new ones, or those taking new forms. The latter compose a new set and occur in the course of current operation/routine maintenance. These new forms of damages/failures or of the object’s remaining unserviceable may prove single events or system-attributable ones. In operational and maintenance practice they are responded to with suitable preventive actions.

Damages/failures occur due to the willfully or unwittingly exceeded permissible loads (e.g. by the aircrew, operator, servicing staff), externally originated effects and disturbances, or natural physical and chemical phenomena typical of the performed tasks (workload) or time. The following events may be numbered among them: the wear-and-tear of tribological nodes, corrosion, materials ageing, etc. [1, 9, 14].

The problem with damages to structural components/parts of an engineering object is typical of the whole operational phase thereof, although different causes predominate at different operational-phase stages.

Throughout the whole operational phase of an engineering object the structural members thereof get degraded. Operating conditions (material effort, deformations, wear-and-tear, etc.), to some extent unpredictable – extreme, conditions of externally induced actions/influences that are able to change randomly all of them prove decisive in the reduction of the ultimate strength of the structure(s) of the engineering object and parts/structural components in the object’s functional units/assemblies.

Damages to an engineering object, in particular while in operation, considerably affect safety, but also all rates of engineering availability that feature the operational readiness, i.e. readiness to perform tasks. Damages attributable to many and various causes can be classified as a) predictable, and b) unpredictable ones. Predictable damages develop at locations easy of access and subjected to the diagnosing (with different methods out of a variety of diagnostic techniques).

Damages to turbine engines apllied in aircraft power plants comprise approximately 25% of the total number of disadvantageous events of this kind.

Damages to engineering objects (such as turbine engines), units/assemblies and structural members thereof are classified according to various criteria. From the point of view of damage identification and preventive treatment, they are classified for what follows:

- type of an object (electrical, mechanical, hydraulic, etc. system),
- physical nature of the damage,
- causes of damages,
- ways of restoring the ‘fit-for-use’ state.

Damages/failures to engineering objects and structural components thereof may also be divided into the following groups:

- primary (independent),
- secondary (dependant),
- natural, and
- forced damages.

Primary damages are usually effected by:

- natural ageing and wear-and-tear processes, fatigue, corrosion, etc.,
- failures after permissible regimes have been exceeded,
- structural, manufacturing, and material-inherent latent defects,
- faulty operational and/or servicing practices.

Primary damages give grounds for statistical inference on the components' life and reliability [6, 7, 8]. Secondary damages are recorded as effects of primary damages.

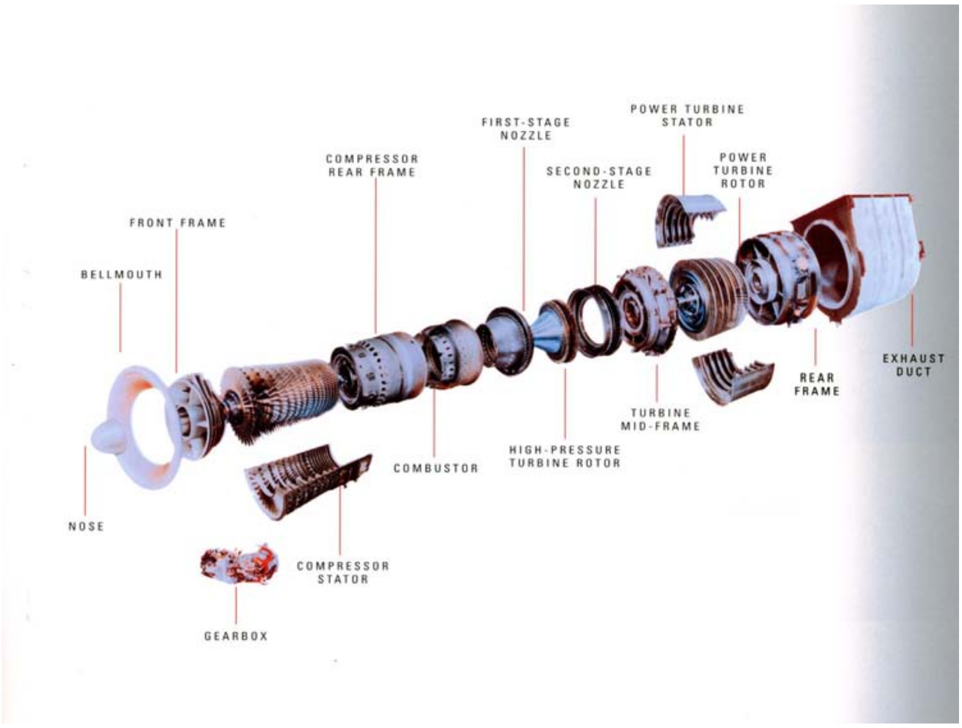

Fig. 1. Structure of turbine engine for maritime applications

Operational/maintenance practice proves that each and every structural member of a turbine engine (Fig. 1) is susceptible to damages/failures which occur for various reasons. The most essential causes comprise [2 - 7, 14]:

- variable aerodynamic loads,
- increase in loads (in particular, exceeding permissible values),
- impact loads,
- vibration of rotating components/parts and those exposed to cyclic changes of position, e.g. in the to-and-fro motion,
- acoustic vibration,
- heat effects,
- out-of-standard actions by aircrew members and engineering staff responsible for maintenance,
- weather effects (turbulence, corrosion) and nature-imposed ones (birds),
- effects of destructive warfare agents, foreign matter, etc.

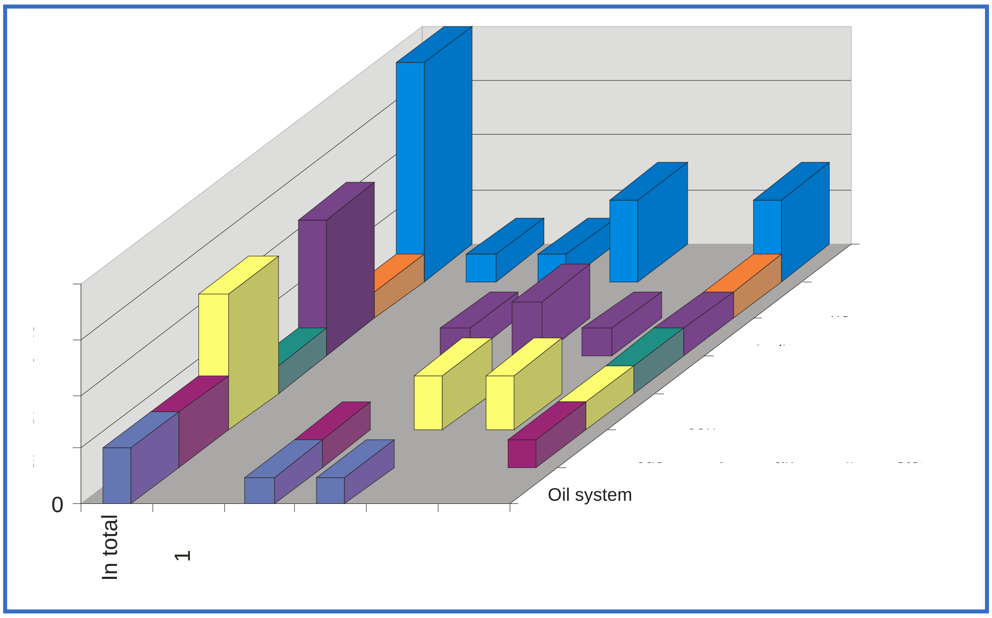

Fig. 2. Quantitative statement of damages/failures to systems and units/assemblies of turbine engines AI-25

Fig. 2 shows exemplary quantitative statements of damages to systems and units/assemblies of the AI-25 turbine engines, recorded while operating a small fleet of aircraft in the five years' period.

Damages to the engine due to the exceeding of specified values or symptoms of irregular engine operation often compels adjustments of engine units, replacement of a damaged unit, building the damaged/failed component/part or unit out of the engine. Such operations can be carried out either on the engine test bench (for engines after overhaul or withdrawal from service) or built in the object where it is operated (sea vessel or aircraft).

3. Mechanical damages

Damages of the mechanical type due to foreign-matter collisions contribute to the greatest extent to failures to the structures of the engine block, air inlets, and compressor, the fact being confirmed by the records. In aviation, they most often occur during the take-off and landing and are usually effected by concrete and/or soil chips, and birds. Detection of such damages during routine inspections/maintenance usually produces no difficulty, whereas any failure to detect them can generate top hazards (Figs 3 and 4) [1 - 3, 9, 11, 13].

4. Corrosion damages, tribological and fatigue failures

Primary causes of such damages/failures are physical and chemical phenomena, and exceeded performance parameters (service loads). Theses are as follows: corrosion (Fig. 4), erosion, cavitations, tribological wear, fatigue and brittle cracking. Detection of damages/failures effected by such phenomena often proves very difficult. They are usually found in the form of the unit's failure to operate, pits that weaken the structure, etc. The engineering diagnosis [1 - 4, 10 - 11, 13, 15] offers tools and techniques to detect and identify them. Figs 5 – 8 show examples of such damages/failures.

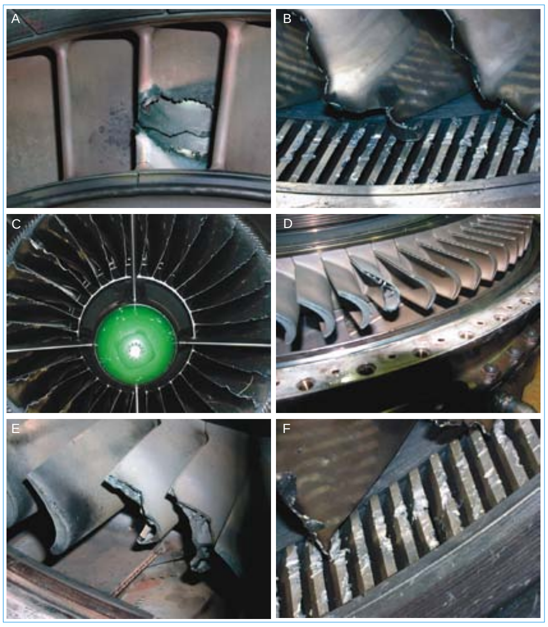

Fig. 3. Exemplary mechanical and heat-induced damages in the form of cracks and material defects in the turbine engine structure

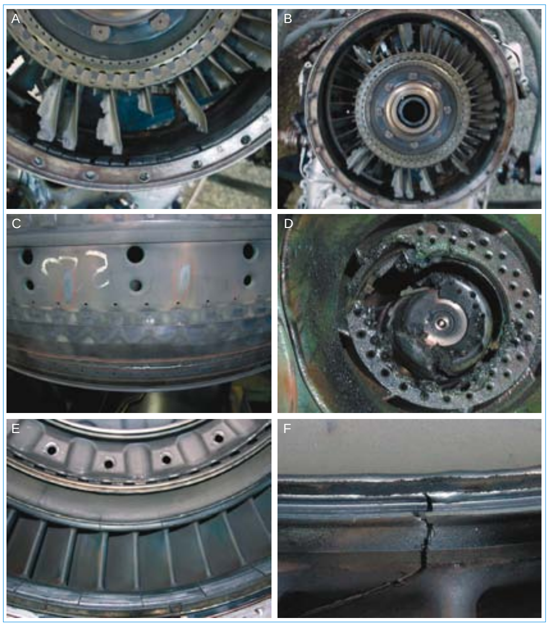

Fig. 4. Fatigue-corrosion-attributable damages to turbine-engine structural components

5. Description of the occurrence of damages/failures to a set of turbine engines

The occurrence of damages/failures to engineering systems (turbine engines included) that belong to a homogeneous set is featured with the ‘unfit-for-use’ states of structural components or units/(sub)assemblies. In the case of reparable systems (engines), any damages/failures are removed by means of the restoration process.

Fig. 5. Types of corrosion – macroscopic image of the surface-layer cross-section

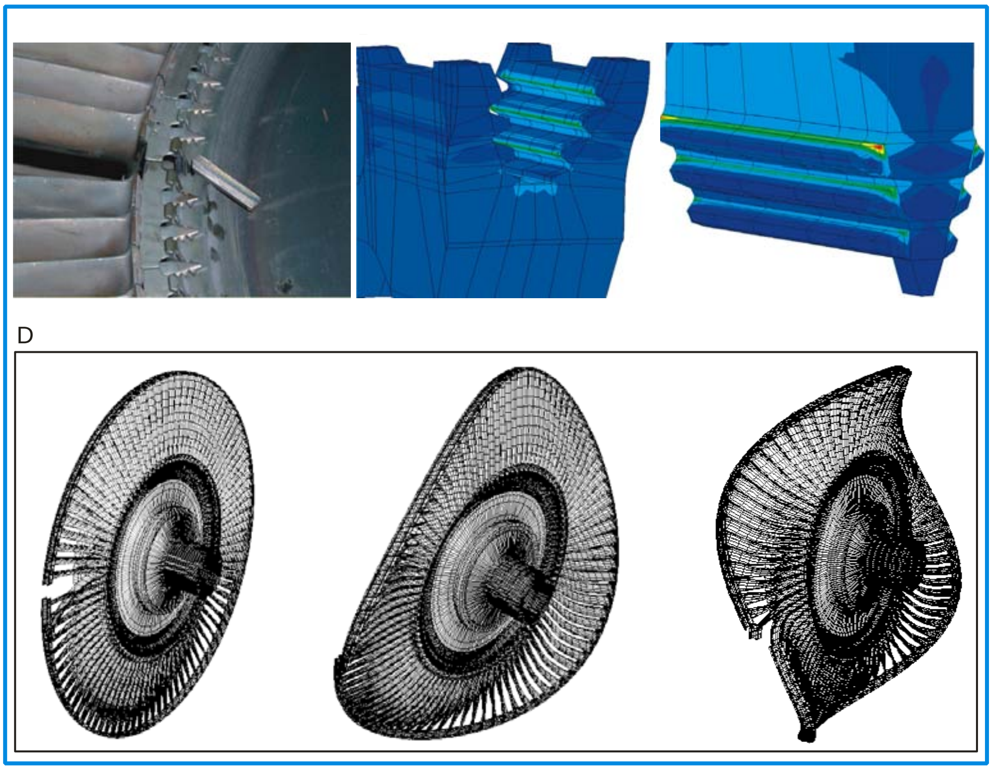

Fig. 6. Operation-induced III^{o} damage to the turbine of a jet engine [12]
A – blade ring of the turbine, one blade lacking; B – simulation of destruction of the blade locking piece; C- simulation of vibration destructive to the blade locking piece; D – simulation of vibration of turbine with one blade lacking

Fig. 7. Examples of fatigue failures to turbine engine's compressor blade

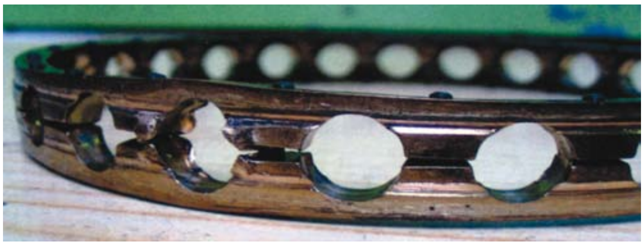

Fig. 8. A damaged bearing of the turbine engine shaft

The stochastic occurrence of damages/failures to a set of engines can be described as soon as probability distributions of emerging events (damages/failures) within a certain assumed time interval of system's operation.

Engines belong to the class of reparable engineering systems featured with that the reliability $R(t)$ after restoration should not change. Unfortunately, there are such engines for which both the number of observed damages/failures and failure rates increase after the major repair/general overhaul. The AŁ aero engine is a good example. This fact can be explained in the following way: the design structure proves faulty, or incorrect general-overhaul procedures have been developed and recommended by the manufacturer. For such systems, the probability P_τ of the random variable of the number of defects/failures U_τ in time interval of the system's operation $[0 \leq \tau \leq t]$ can be most often described with the following expression:

$$P_\tau(t) = \frac{(\lambda t)^n}{n!} \exp[-\lambda t] \tag{1}$$

where: λ - operational failure rate,
n - the number of observed damages/failures.

The expected value of equation (1) is as follows:

$$\mathbf{E}\ \{U_\tau\} = 8t = \Lambda \tag{2}$$

For any structural component/part, engine unit/assembly (κ), the probability P_κ of the random variable of the number of defects/failures U_κ in time interval of the system's operation $[0 \leq \tau \leq t]$ can be described with the following expression:

$$P_\kappa(t) = \binom{\Lambda}{m} p_\kappa^m (1 - p_\kappa)^{\Lambda - m} \tag{3}$$

of the expected value:

$$\mathbf{E}\ \{U_\kappa\} = \Lambda\ p_\kappa \tag{4}$$

where: p_κ - conditional probability that a given component, assembly/unit of the κ type gets failed if the engine is damaged,
m – the number of observed damages/failures.

For the *F* set of structural components, units/assemblies in engines in service the expected value takes the following form:

$$\mathbf{E}\ \{F\ U_к\} = F\ \Lambda\ p_к \tag{5}$$

All the above-mentioned values of parameters and conditional probabilities are arrived at by means of suitable statistical surveys under real operating conditions.

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