Strategy & investigating of different kinds of critical defects recognition in aircraft engine

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Abstract
The engine is a very important part of aircraft. So by developing the concepts and regulations of aviation safety, the inspection periods and preventive maintenance activities have a critical effect on aircraft engine to ensure that the engine is operational and maintain continuing airworthiness. Modern on condition monitoring-based method is used to reduce maintenance costs and increase aircraft safety. The purpose of the information contained in this article, is to eliminate misunderstanding and confusion caused by varying terminology, used to describe the condition of engine parts, particularly during inspection. This report assembles the detailed information required to understand the fundamentals of aircraft maintenance programs; requires that an appliance or part be periodically inspected or checked against some appropriate physical standard to determine whether it can continue in service. The purpose of the standard is to remove the unit from service before failure during normal operation occurs. A high pressure turbine blade of an aircraft engine was fractured during the ground test run. The failed as well as neighboring unfailed blades were studied during failure investigation.

Keywords: aircraft engine; inspection; on condition monitoring

1. Introduction
Aircraft engines produce power needed for aircraft. For this reason, aircraft engines are very important for flight safety. Today’s complex and advanced technology systems require advanced and expensive maintenance strategies. Maintenance services are costly for airline companies. For manufacturers, maintenance is a source of revenue. Because of the high cost of maintenance, gas turbine engines must be operated within specified physical limits. Today’s aircraft engines are made safer by increasing the number of control parameters and sensors. The engines have a Complex mechanical system. Because aircraft engines operate at high temperatures, high pressures, and high speeds, there are lots of possibilities of various faults in the aircrafts. Gas turbine engines show the effects of wear and tear over time. A small fault during flight does not prevent the engine from running, but if this fault is not detected, it could lead to a bigger fault. If these bigger faults cannot be prevented, it can lead to high maintenance costs and accidents. When aircrafts are taken for maintenance, the condition of the gas turbine engine is investigated by various tests and measurements [1]. The development of a safe for aircraft application measurement and registration technologies, enabled introduction of the on-condition exploitation method applied for airframes, power plants and specific aircraft parts [11]. The economic importance of the maintenance and regeneration of jet engines is increasing in comparison to the sale of new apparatus due to a growing fleet of aircraft. In order to reduce costs, as many components as possible should be regenerated and the total down time of each engine should be minimized. The acceleration of the process can be achieved if relevant information of damaged parts can be acquired as early as possible in order to plan the regeneration process in advance. Currently, defects and damage of engine components can be assessed either by a complete disassembly of the engine or by horoscopic examinations [2].

2. on condition monitoring
On-condition is a failure preventive process that requires the item be periodically inspected or tested against some appropriate physical standard to determine whether or not the item can continue in service. After failing an OC check, components must be overhauled or restored to the extent of at least replacing out-of-tolerance parts. The on-condition process also encompasses periodic collection of data that will reveal physical condition of a component, system, or engine. Through analysis and evaluation, OC data must be able to ascertain continued airworthiness and/or deterioration of failure resistance and imminence of failure. On-condition data must be directed to an individual component, system, or engine (by serial number). It is a priori (before the fact) failure data that can be used to measure decreasing life expectancy and/or predict failure imminence. Examples of OC checks are as follows:
   a) Scheduled borescope inspections of engines
   b) Engine oil /fuel analysis
   c) In-flight engine performance analysis (i.e. engine condition monitoring or ECM)
In each of the above states cases, one can measure degradation and determine, from established norms, how much life or serviceability remains. Most of the commercial airplane operators in the United States use the on-condition process to control engine overhaul. The determination of when to remove an engine is based on engine data collected by an
ECM program. Data shown engine performance degradation, such as oil and fuel consumption, borescope inspection results, trends in recorded in-flight instrument readings, oil analysis and fuel analysis, which are compared to standards to predict decreasing engine reliability and failure imminence. Engine data programs attempt to provide data to indicate the need to remove engines before an in-flight shutdown (IFSD) occurs; (i.e. they are failure preventive processes) [3].

2.1. Engine Modules
The engine modules for inspection are the fan module, the intercase module, the HPC\(^1\), the diffuser/combustor module, the HPT\(^2\), the LPT\(^3\) and the accessory drive gearbox figure 1.[10]

Figure 1. Engine-Schematic- IAE V2500 [10].

3. Inspection
As with any power equipment, gas turbine requires a program of planned inspections with repair or replacement of damaged components properly designed and conducted inspection and On condition monitoring can do much to increase the availability of gas turbines and reduced unscheduled maintenance. Inspections and on condition monitoring can be expensive, but not as costly as forced shutdowns. Nearly all manufacturers emphasize and describe on condition monitoring procedures to ensure the reliability of their machinery and also, any maintenance program should be based on manufacturers recommendations. Inspection and on condition monitoring procedures can be tailored to individual equipment application with references such as the manufacturer’s instruction book, the operator’s manual, and the On condition monitoring checklist [4].

3.1. Visual inspection
Visual testing is the oldest and most common form of inspection. It consists of an overview using human eye, a magnifying glass, a light source or special optical devices. The reliability of this method depends on the ability and experience of personnel who must know how to look for engine defects and how to identify an area where such defects are found. A visual examination with the help of optical devices can be considered an extension of the human eye. From inaccessible areas, an image on the screen is formed that can be electronically captured, increased, analyzed and recorded for future directions. Basic equipment for the visual inspection is endoscopes. Endoscopes allow the technician to view the interior of the equipment, components or structures that have closed or hidden areas not accessible to ordinary visual inspection. Endoscopes (flexible borescopes and inflexible fiberscopes) are optical devices with optical probe which can penetrate through small openings to the work area to be tested. These devices have the possibility of strong internal illumination of dark areas to make good visual inspection, photographing or video recording. Their

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1 High pressure compressor
2 High pressure turbine
3 Low pressure turbine
optical system transmits a clear picture of high resolution to the eyepiece or video monitor which is distant, but connected to the device. Eyepiece is used for direct visual inspection or it can be connected to a photographic or video camera. Videoscope is an electronic version of the optical fiberscope. Instead of the lens at the end of a flexible tube and coil which transmits the image, videoscope has a small video camera and a lens at the end. The camera, which is based on a compact chip technology, sends back a video image to the unit where it is shown on a video monitor. Example of video borescope is given in Fig. 2. [5]

![Video borescope](image)

**Figure 2 Video borescope [5]**

### 3.2. borescope inspection

Borescope inspection is carried out because of the following benefits it can provide in the maintenance program:

1. Perform internal on-site visual checks without disassembly.
2. Detect abnormal conditions early to avoid failures
3. Determine degradation rates
4. Extend period between scheduled inspections.
5. Allow accurate planning and scheduling of maintenance actions.
6. Monitor condition of internal components
7. Provide increased ability to predict required parts, special tools, and skilled manpower

Figure3. Shows the time savings by lowering the disassembly process. We may obtain by the proper use of borescopic inspection for planned maintenance. The borescope system must be capable of enough resolution, depth of field, focus, and magnification to first permit identification of defects and then permit close-up inspection and evaluation of such minute features as cracks, penetrations, deposits, corrosion/erosion and burning. [4].

![Cumulative maintenance costs](image)

*Figure 3. Effect of planned maintenance with usage of borescope.[4]*
3.21. Borescope Inspection of Low Pressure Compressor
Whenever borescope inspection of the fan rotor is required, On Condition defects and Special defects must be observed and assessed as to the applicable hardware limits for serviceability. It is recommended that in-limit defect conditions be documented for determination of subsequent deterioration rates, On Condition defects include of Cracks or tears, Nicks and scratches, Dents, Erosion, Tip curl, Pits, Distortion leading or trailing edges, Missing metal. Additionally, Special defects accompany some of the special check requirements in cluding Fan stall, foreign object damage (FOD) and suspected bird injection, High fan vibe, which are prevalent in engines having experienced a problem requiring special checks.

3.2.2. Borescope Inspection of High Pressure Compressor
Whenever borescope inspection of the HPC is required on condition defects and special defects must be observed and assessed as to the applicable hardware limits for serviceability. It is recommended that in limit defect conditions be documented for determination of subsequent deterioration rates, on condition defects include of Cracks, Nicks or scratches, Dents, Erosion, Tip curl, Pits, Distortion of leading or trailing edge, Missing metal, Dirt. Additionally, Special defects accompany some of the special check requirements including Core stall, Oil fumes detected in cabin air, Foreign object damage (FOD), High core vibration which are prevalent in engines having experienced a problem requiring the special check[12].

3.2.3. Borescope Inspection of Combustion Section
Whenever borescope inspection of the combustion section is required on condition defects and special defects must be observed and assessed as to the applicable hardware limits for serviceability, on condition defects include of Discoloration, Inner liner Additionally Special defects include of over temperature operation, Impact damage observed on high pressure turbine (HPT) rotor blades [12].

3.2.4. Borescope Inspection of High Pressure Turbine Nozzle
Whenever borescope inspection of the HPT nozzle assembly is required on condition defects and special defects must be assessed as to the applicable hardware limits for serviceability on condition defects including of Discoloration, Cracks, Burns, and blocked cooling air passages. Additionally Special defects include of Overtemperature operation, Engine stall, Exhaust gas temperature (EGT) trend step increase [12].

3.2.5. Borescope Inspection of High Pressure Turbine Blades
Whenever borescope inspections of the HPT section are required on condition defects and special defects must be observed and assessed as to the applicable hardware limits for serviceability. It is recommended that in-limit defect conditions be documented for determination of subsequent deterioration rates, On Condition defects include of (Trailing edge: Cracks), (Tip area: Cracks/ Bent, curled, or missing pieces/ Tip trailing edge wear), (Blade platform: Blade platform/ Cracks), (Concave and convex airfoil surface: Cracks/ Distortion/ Burning), (Cooling holes: Cracks/ Plugging) additionally Special defects include of Core stall (N2), Over temperature, Metal in the tailpipe, N2 overspeed, core vibe, and hard landing accompany some of the special check requirements. The following listing relates the special check to those typical defects which are prevalent in engine having experienced those problems requiring the special check [12].

3.2.6. Borescope Inspection of Low Pressure Turbine
Whenever borescope inspections of the LPT section are required, the following defects must be observed and assessed as to the applicable hardware limits for serviceability. It is recommended that in limit conditions be documented for determination of subsequent deterioration rates [12].

A. On Condition.
   1) Cracks in LPT rotor blades.
   2) Nicks and dents.
   3) Wear.
   4) Dirt, coloration, pitting, and corrosion.
B. Special Inspections.
   1) Over temperature inspection.
   2) Metal in the tailpipe.
4. 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. 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 [6]. This depends on the location of the engine in the airframe (table 1).

<table>
<thead>
<tr>
<th>Type of damage</th>
<th>Location</th>
<th>Source of the damage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy oxide deposits</td>
<td>HPT vanes, blades</td>
<td>Environment, fuel</td>
</tr>
<tr>
<td>Penetration</td>
<td>HPT vanes ,blades</td>
<td>Corrosion, erosion</td>
</tr>
<tr>
<td>Blade tips missing</td>
<td>HPT and compressors</td>
<td>Clearance, DOD¹/FOD²</td>
</tr>
<tr>
<td>Distortion</td>
<td>Combustor</td>
<td>Uneven combustion</td>
</tr>
<tr>
<td>Carbone deposite</td>
<td>Fuel nozzle assembly</td>
<td>Uneven combustion</td>
</tr>
<tr>
<td>penetration</td>
<td>Combustor</td>
<td>Uneven combustion</td>
</tr>
<tr>
<td>Cracks</td>
<td>Combustor liners</td>
<td>Thermal stress, wobble</td>
</tr>
<tr>
<td>Heavy corrosion</td>
<td>HPT vanes ,blades</td>
<td>Coating defect</td>
</tr>
<tr>
<td>Heavy erosion</td>
<td>HPT vanes ,blades</td>
<td>Loss of film cooling</td>
</tr>
<tr>
<td>Hot streaking</td>
<td>Combustor</td>
<td>Faulty fuel nozzle</td>
</tr>
<tr>
<td>Dents</td>
<td>Vanes, blades</td>
<td>DOD/FOD</td>
</tr>
<tr>
<td>Hot spots</td>
<td>HPT vanes ,blades</td>
<td>Faulty fuel spray pattern, liquid Hydrocarbons in NG fuel</td>
</tr>
<tr>
<td>TBC coating flaking</td>
<td>HPT blades</td>
<td>Tips rubbing, blocked</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cooling passages</td>
</tr>
<tr>
<td>Gouge</td>
<td>HPT blades</td>
<td>DOD/FOD</td>
</tr>
<tr>
<td>Pieces missing</td>
<td>Blades</td>
<td>DOD/FOD</td>
</tr>
</tbody>
</table>

Figure 4. Shows the deterioration of the high pressure turbine (HPT) blades with the turbine operating hours; to the casual observer they appear in mint condition. However, there is a leading edge defect on all visible blades adjacent to the first cooling hole.

Figure 4. Borescope view of high pressure turbine blades at various stages of life: a) Leading edge crack after 5591 hrs. b) Erosion after 3960hrs [7].

Impurities ingested by air vortex cause mechanical damages to individual components of gas path – in particular, to compressor rotor blades figure 5.
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. 6).

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 [6].

If the rubbing is severe, even with blade tip squealers, failures of the blades would occur as shown in figure.7

Figure 5. a) Schematic diagram of air vortex at engine intake [6], b) Nicked: a small cut on the surface or edge of a part caused when the part is hit with an object, c) Dented: Damage to the surface of a part when it is hit with an object. The material is distorted but not removed [8]

Figure 6. a) Exemplary types of thermal damages to leading edges of turbine rotor blades , b) Burned: A complete structural failure of the material because of very hot temperatures, c) Overheated: The part has become too hot, usually seen as a change in color or condition [8].

Figure 7. blade failures due to excessive tip rubs, a) Rubbed [7], b) curled: A rounded fold in the material such as a blade tip that has rubbed against the engine casing, c) broken: The separation of a part by force, into two or more pieces [8].
Subsequent damage to the rotor blades from this point indicated that with time the stage blade began to fatigue and fracture. This failure of the first-stage blade inflicted the bulk of the damage downstream. A severe gouge was cut into the leading edge of the downstream third-stage blade, as shown in figure 8. This served as a stress riser and an initiation point for a fatigue crack and subsequent propagation. The failure of this blade was also a fatigue failure, although some of the features were masked due to the initial contact damage.

![Figure 8](image)

Figure 8. Damaged blades due to domestic object damage (DOD), a) gouge: A large rough cut of large depth with the removal of some material, caused because a sharp object has hit the part, b) Battered: Is damage caused to a part when it is constantly hit.

Liquids in the fuel supply, especially liquid hydrocarbons, can lead to problems downstream of the combustor. Coating Impingement of liquid hydrocarbons on the turbine nozzle vanes and blades creates hot spots, which lead to turbine blistering and spalling and in some cases can attack the base material as seen in Figure 9.

![Figure 9](image)

Figure 9. Carbon deposit on the parts of a turbojet, a) Carbon: A quantity of carbon particles collected on the surface of a spark plug, b) Deposit: Particles of material collected on a part from a different part or NGV [8], c) damage on combustor [9]

Bearing problems are one of the most common failures that occur in gas turbines. Journal type rotor bearings usually experience a type of instability called oil whirl. In some cases this problem is alleviated by a change of oil temperature, otherwise the problem requires a change in bearing design such as going to a pressure-dam bearing, or in excessive cases, Figure 10. Shows the failed bearing.
Figure 10, types of bearing defects. a) brinelling: Circular surface damage on bearing races. Usually the cause is constant shock loads on the bearing, b) pitting: Small irregular shaped holes in the surface of a material. Usually caused by corrosion or electrical discharge, c) galling, Fretted, spiked: Damage caused when two materials are rubbed together at high pressure, d) peeling, Blistered, flaked, exfoliate: Is when the surface finish (layers, plating) breaks away, e) spalling, Plucked: A rough broken area on the surface of a material. Usually caused because of surface cracks or inclusions when a load is put on the surface, f) disintegrated, Shattered: Completely broken in pieces.

The increase in the exhaust gas temperature and vibration, was a direct result of the failure and separation of a single intermediate-pressure turbine blade. The turbine blade had fractured following the initiation and growth of a fatigue crack from an origin area near the blade inner root platform figure 11.
Creeping is the rate of deformation is a function of the material's properties, exposure time, exposure temperature and the applied structural load. Depending on the magnitude of the applied stress and its duration, the deformation may become so large that a component can no longer perform its function — for example creep of a turbine blade will cause the blade to contact the casing, resulting in the failure of the blade. Creep is usually of concern to engineers and metallurgists when evaluating components that operate under high stresses or high temperatures [13]. Creep rupture was identified as the likely failure mechanism in previous stage-1 LPT blade failures figure 12.

![Figure 12. LPT stage 1 blades on the damaged CFM56 [9].](image)

5. Conclusions

In this study, we understood 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 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 on condition monitoring) 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, also 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 engines.

References

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