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Research Article

TBO LIFE EXTENSION OF A MILITARY TURBOJET ENGINE BY SAMPLING

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ABSTRACT
Time between overhaul (TBO) is an important measure of overall serviceability and life cycle cost of an aero engine. TBO is a time recommended by the designer/manufacturer based on the engine's complexity, operational envelope and severity of the mission cycles it is intended for. In the present study, the methodology for TBO life extension by sampling of a military turbojet engine is presented. It starts with identification of sample engines and carrying out evaluation checks and tests on the engines, their modules and accessories. Lead engines are allowed for service up to the extended life and are examined for their potential to withstand to any accumulation of damages and deterioration of performance. Engine performance, health monitoring parameters, condition of components and systems, functioning of accessories and bearings are taken as the basis for considering for TBO life extension in the present case. This procedure may be used for further extension of TBO life progressively for any similar engines.

INTRODUCTION
Time between overhaul (TBO) is an important measure of an aircraft engine's serviceability and overall economy. Since the overhaul process requires the engine to be taken apart, it is an expensive and time consuming process. TBO is a time recommended by the designer/manufacturer based on the engine's complexity, operational envelope and severity of the mission cycles it is intended for. It depends on a number of variables such as aircraft stage length, experience on engine type, operational procedures, environmental conditions and modification standards etc. From the safety point of view, overhauling the engine at this time is mandatory and has to be complied. If not properly managed, the down time required for overhaul causes great inconvenience for the fleet operators both in civil and military sectors as well as for power generation houses. Therefore selection of engines with high TBO and its extension are playing important roles in life management of engines for any application. For aircrafts used for non-commercial purposes overhauls are not mandatory, but highly recommended. Likewise, the TBO time recommended doesn't guarantee that all the engines will last that long but majority of them will do so.

Concept of TBO
Aero engine components accumulate damage in service as a result of their operational environment and mission conditions. The damage may take many forms depending on the component, engine type and operating environment (Woloziuk *et al.,* 1991). The damage may be external, affecting geometrically or surface quality as a result of mechanical and chemical effects such as fretting, wear, erosion, corrosion or oxidation. On the other hand, internal damages may affect the microstructure of highly stressed components due to aging of the material microstructure or due to creep or fatigue.

External damage impacts significantly on functionality of the parts, including the aerodynamic performance of components as well as reduces their load bearing capacity. Surface damage in the form of low cycle fatigue (LCF) cracks, scars or dents, fretting-wear or foreign object damage (FOD), respectively, may lead to high cycle fatigue (HCF) failures (Nicholas, 1999). Internal damage may reduce component strength and lead to component distortion. Its accumulation also causes the initiation of flaws, which may ultimately lead to cracking and component failure.

These service-induced damages limit the usable life of many engine components and these are usually taken by designers and manufacturers to define a very logical and reasonable TBO life. In gas turbine engines generally three life parameters are considered which are: (1) Time between overhauls (TBO) and (2) Cyclic life also called as low cycle fatigue (LCF) life and (3) Calendar life. The LCF life is the number of times the engine is started, accelerated to full power, and eventually shut down, between overhauls. The TBO is governed mainly by creep and oxidation life of the hot end components, while cyclic life is dictated by thermal stress levels. The calendar life is generally monitored for expendable components such as sealing rings, gaskets, rubber bushes, diaphragms etc to cater the issues arising from operational environments. Typical life requirements for the major gas turbine applications are as presented in table 1 (Philip and Paul, 2004).

Table 1: TBO Life of Major Gas Turbine Applications (Philip and Paul, 2004)

Application	TBO (hours)
Power generation – Base load	
Gas and oil pumping	25000–50000
Automotive – Family saloon	25000-100000
Automotive – Truck	
Marine – Military	5000
Marine – Fast ferry	10000
Aero-engines	5000-20000
– Civil	5000–10000
– Fighters	
	15000
	25–3000

Over-estimation of TBO may lead to premature failures and engine withdrawals whereas under-estimation can cause under-utilization of the engine components and early overhauls. When damage becomes excessive as revealed by inspection or when component design lives are reached, the components are replaced with new ones. Replacing service-damaged parts is costly and is a significant contributing factor in the overall life cycle cost of engines. Therefore, TBO is generally extended progressively based on engine service and track record. This paper presents the methodology adopted for extending TBO life of a military turbojet engine. This can be used as a guideline for similar life extension in other engines.

Engine Configuration

The schematic layout of the turbojet engine without air intake and exhaust nozzle is shown in figure 1. It is a single spool straight flow engine with axial compressor driven by an axial turbine. It has a can-annular type combustion system incorporating duplex atomizers. The main rotating assembly comprises a single unit in which the compressor rotor is coupled by a rigid shaft to turbine wheel, the unit being mounted on two bearings only.

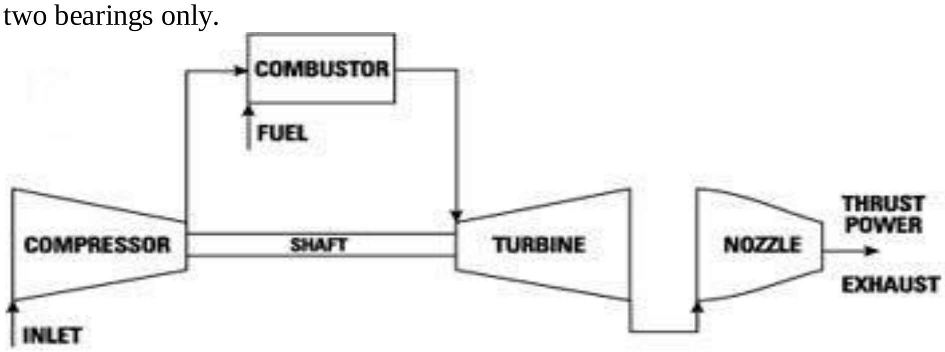

Figure 1: Schematic Layout of Gas Turbine engine

MATERIALS AND METHODS

Methodology

For extension of TBO life of aero engines, the approach of engine sampling at extended life is extensively used by engine houses particularly for military engines. In-flight performance, failure data and sampling checks of the engines are considered as the basis of life extension in this approach. The potential of the engine and its critical components for expected service degradation or damage are examined. Compatibility of consumable items like sealing, coating etc and accessories with the extended life is also studied. The various activities involved in this life extension methodology are as follows.

- Overhaul experience at the existing TBO life.
- Endurance test of the engine for number of cycles or duration equivalent to the extension of life.
- Identification of engines with no operational abnormalities for operation up to the extended life for sample evaluation.
- Study of defects/snags report of the engines and premature withdrawals if any of critical components after the last overhaul.
- Release of engines for 10% extended service after satisfactory ground run checks at 100% TBO.
- Aero thermodynamics behavior of various components or modules at design and off-design conditions and transients while undergoing extended operation.
- Analysis of operating or mission cycle of the engine and flight sortie details.
- Assessment of engine performance during and after completion of extended service.
- Performance assessment of engines before and after compressor wash.
- Vibration survey of the engines
- Detailed strip examination of the engines
- NDT checks of critical components
- Dimensional check of components as per overhaul manual
- Hardness check of rubber sealing rings
- NDT and serviceability check of bearings
- Rig test followed by tear-down inspection of accessories
- Rejection pattern of critical components during overhaul which are having life implications.

Various tools are currently available for residual life estimation for critical components. Based on the operational conditions and flight missions undertaken by the engine, the life of the components can be reasonably found out (Ashok *et al.,* 2009). Also energy based fatigue life prediction framework is available for calculation of residual fatigue life of in-service gas turbine materials. These approaches account the material aging effect on fatigue strength of gas turbine engines structural components, which are usually designed for infinite life or very long life (Hakan and Jeremy, 2009).

Engine Identification

Based on performance records in service and having components with sufficient fatigue life, four engines were identified. These engines were allowed for flight evaluation for a period of 10% above the existing TBO life. These engines were scheduled to undergo ground runs first and then released for flight trials based on their satisfactory performance. Again, prior to flight trials, one engine was subjected to endurance on ground test bed for 10% of TBO life. It was ensured that during this extended period the engines were subjected to similar mission profiles that they generally encounter or have encountered during the existing life. These four engines are designated as case-1 to case-4.

RESULTS AND DISCUSSION

Assessment of engine performance during test bed acceptance test procedure prior to fitment in aircraft and during flight with different mission cycles is a continuous practice. Analysis of the performance data bank for over a reasonable period and trend analysis of defects becomes the base for life extension study. With limited instrumentation in service engines, the critical health monitoring parameters such as jet pipe temperature, oil pressure, oil temperature, vibration levels (in test bed only) are continuously recorded and analyzed. These parameters represent the performance and general condition of the engine. Malfunction or deterioration in any component is reflected on these parameters and needs corrective measure at the earliest depending on the criticality. For example, low oil pressure indicates increase in flow area, i.e., crack in pipe lines and low oil flow to the bearing chamber. This can cause overheating the bearings and deterioration of their performance. Prolong operation in this condition can lead to seizure of rotor system leading to premature withdrawal of the engine. Extending TBO life in this scenario will compromise safety of the engine and the aircraft. Similarly, record of jet pipe temperature which is another health monitoring parameter can dictate the suitability of the engine for TBO life extension. This parameter is addressed in detail in the next section. Failure of critical components and frequency of their occurrence gives their design efficacy for the intended mission and potential for life extension. Based on the mission cycle of the engine and flight sortie details, the residual life of critical components is estimated and TBO life extension of those engines is considered which have components with sufficient life. The four sample cases which have completed service up to the extended TBO life were subjected to detail strip examination and evaluation checks/tests. Some of the important results of the engine and accessories are presented in this paper. Under this program, engines were tested to determine the overall performance such as thrust and specific fuel consumption. The thrust in terms of minimum acceptable value is presented in figure 2 before and after the compressor wash, which is a general practice for these engines. The performance of these engines was acceptable with the compressor wash after completion of extended life. Compressor deposits and fouling are indicated by a drop in compressor efficiency, which is more readily seen as a drop in compressor discharge pressure at a constant speed and load (Tony, 2003). This is generally manifested itself as a reduction in load capacity and power or thrust output at a constant compressor inlet temperature. Compressor wash improves the efficiency and engine mass flow rate resulting in an increase in engine thrust. Jet pipe temperature (JPT) or turbine exhaust gas temperature is one of the most critical parameters in a gas turbine engine. In the absence of turbine inlet temperature measurements in service engines, JPT and compressor outlet pressure are used for cycle analysis (Cohen *et al.,* 1996).

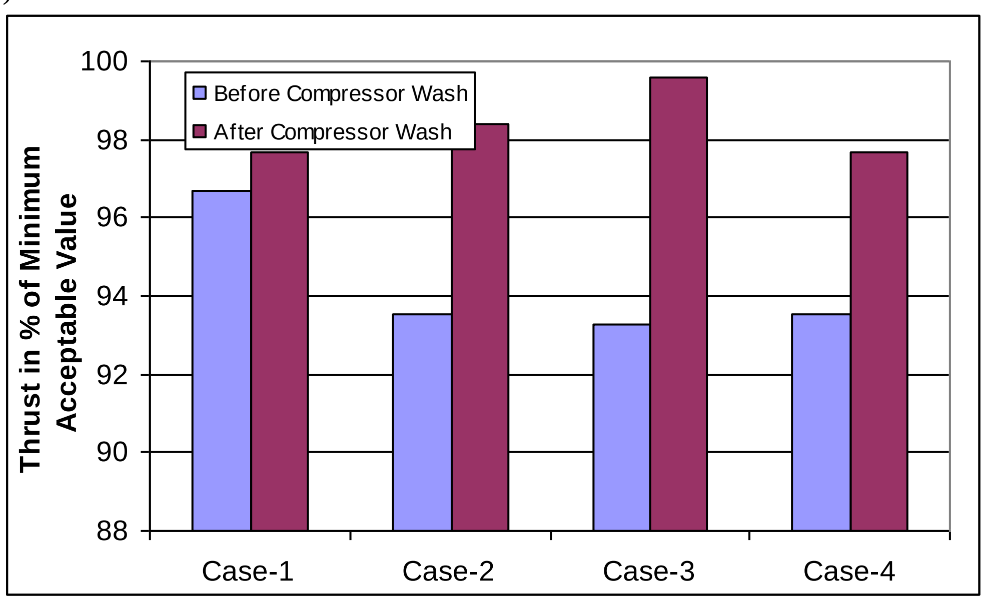

Figure 2 Thrust of the sampled engines

During the engine runs in ground test bed, the engine thrust is measured and JPT is calibrated against thrust. Therefore JPT becomes a measure of thrust during flight where in-flight measurement of thrust is

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not possible. It becomes an important engine health monitoring parameters as higher JPT indicates higher turbine entry temperature which can lead to erosion of hot end components (Mishra *et al.,* 2010).
The JPT monitored during the sampling tests as it is and after the compressor wash are presented in figure 3.

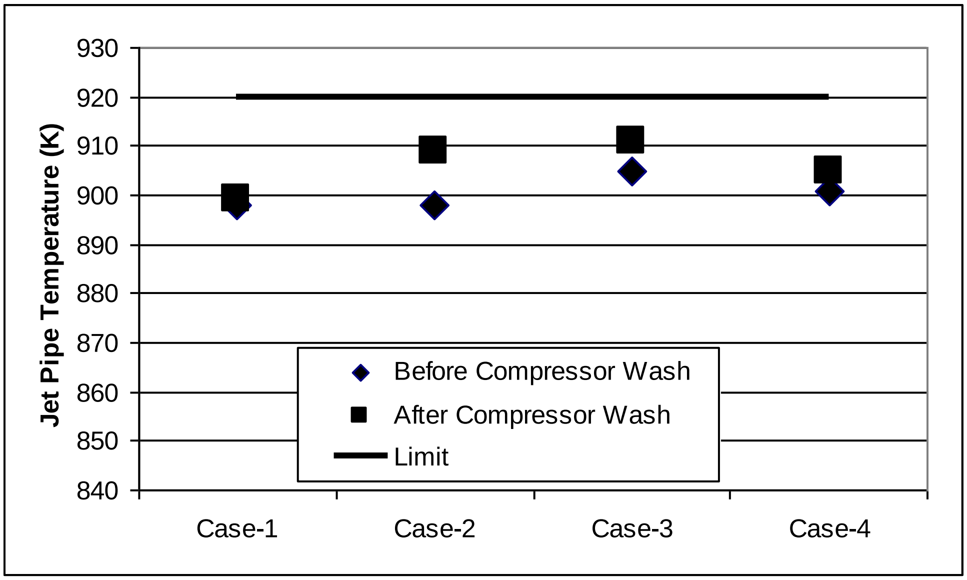

Figure 3: Jet Pipe Temperatures of the sampled engines

JPT is found well within the limit for all the cases that indicates that there is a scope for further service with safe running of hot end components. Compressor wash improves the compressor efficiency improving the thrust and marginally increasing the JPT in a single spool engine as shown in figure 3. For further improvement in performance, trimming of exhaust nozzle area can be made as long as the JPT is within the limit. The procedure of nozzle trimming for thrust improvement has been specified by the original engine manufacturer (OEM) and is of proprietary nature. This shows the potential of the engines for service beyond the existing TBO till JPT reaches its limit.
Strip examination results of important modules are discussed below;

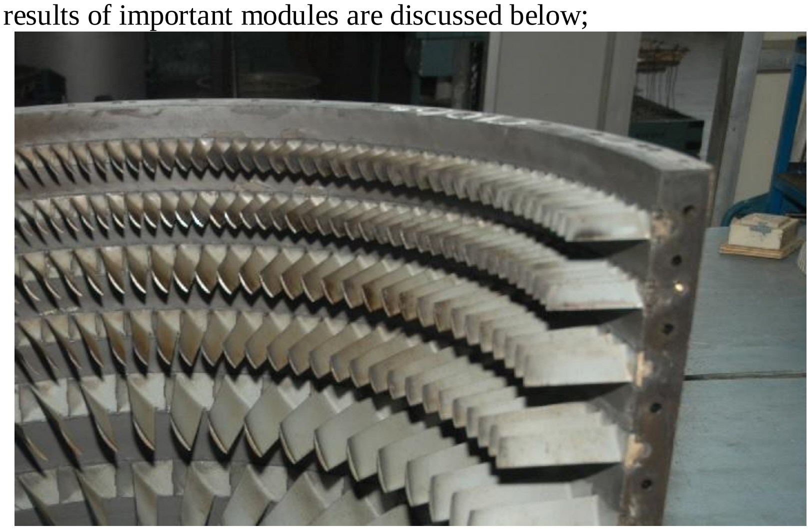

Figure 4: Compressor Casing and Stator vane assembly

Air Intake Assembly

Condition of casings, gears and oil wetted components were found satisfactory. NDT checks found satisfactory. Bearing locating bores on casing and cover were found with normal wear-out which can be reclaimed through repair scheme. Drained oil sample checked and no contamination was noticed. Specific gravity, flash point and viscosity of engine oil meet the specification.

Compressor Assembly

No abnormality was noticed in compressor assembly as shown in figure 4. Carbon dirt was deposited on stator and rotor vanes which is very normal after the service period. NDT checks carried out on casings, discs, stator and rotor vanes have not revealed any cracks and are found satisfactory.

Combustor Assembly

An NDT check on delivery casing had shown minor surface flaws near web trailing location which were not unusual and could be reclaimed by welding process. Dimensional check on delivery casing was found satisfactory. Thermal cracks observed on flame tubes as shown in figure 5 were within the acceptable limit and do not restrict the TBO life extension of the engines. Acceptance of these cracks for restoration by weld correction as defined by the OEM greatly depends on the location and size of the crack as well as presence of cracks in the adjacent areas.

Figure 5: Combustor Flame Tube Cracks

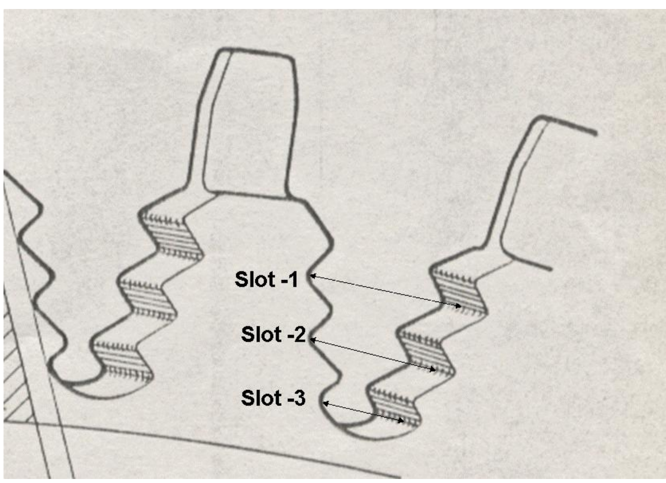

Figure 6: Critical Disk Slots

Turbine Assembly

General condition of turbine disc, blades & shaft are checked and NDT was carried out on blades and discs. Dimensional checks on the blade fir-tree serration sections have shown deviations within the overhaul limits and slots in the disc corresponding to blade serrations as defined in figure 6 are found satisfactory.

Deviations in serration slots beyond the limit will lead to fretting damage at blade and disc attachment surfaces and at fir tree sections. The creep check of turbine disc is very important as TBO is governed mainly by creep and oxidation life of the hot end components. This check determines the permanent growth during one TBO life which can decide its potential for further service. For a disc of about 500 mm nominal diameters where the technology allows a growth of 75 µm, the measurements as shown in table 2 are well within the limit. This shows the scope for further service. During service, turbine has undergone various thermal cycles and thermal distress. This is generally represented by change in colour and sometimes by mark of local hot spots as shown in figure 7.

Figure 7: Condition of Turbine Assembly after completion of one TBO Life

Measurement of tip clearance is another important parameter to ensure that the turbine assembly maintains the minimum specified gap between blade tip and casing diameter over the circumference. Any shortfall in tip clearance will lead to blade rubbing which may in turn rupture the casing. Therefore, the static tip clearance measurement in assembly condition has become one of the acceptance criteria for turbine assembly for fitment in the engine. Where the technology permits a minimum static tip clearance of 1.52 mm, the measurement shows that in all four cases they are well above this value to ensure the safe running of rotor. The measurement values are presented in table 2 for reference.

Table 2: Important Turbine Parameters after one TBO life

Case no.	Creep Value (µm) Upper Limit=75 µm	Static Tip Clearance (mm) Lower Limit=1.52 mm
1	12.7	1.654
2	7.62	1.727
3	2.54	1.923
4	15.24	1.625

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Exhaust Assembly

General condition of exhaust cone assembly was found satisfactory. Thermal distortion & cracks were observed on outer cone as shown in figure 8 which can be reclaimed through the overhaul process as specified by OEM.

Figure 8: Cracks in Exhaust Cone

Minor cracks were observed on thermal brackets which can be reclaimed through welding process. Condition of external pipes & connections was found satisfactory.

Fuel System

The accessories in the fuel circuit were checked thoroughly for their performance in terms of minimum and maximum flows. The fuel flow calibration presented in figure 9 shows the functional efficiency of the system. Rig test parameters of all accessories in the fuel system were found within limit and sea level calibration, altitude calibration and pressure switch calibration have shown no drift in the settings.

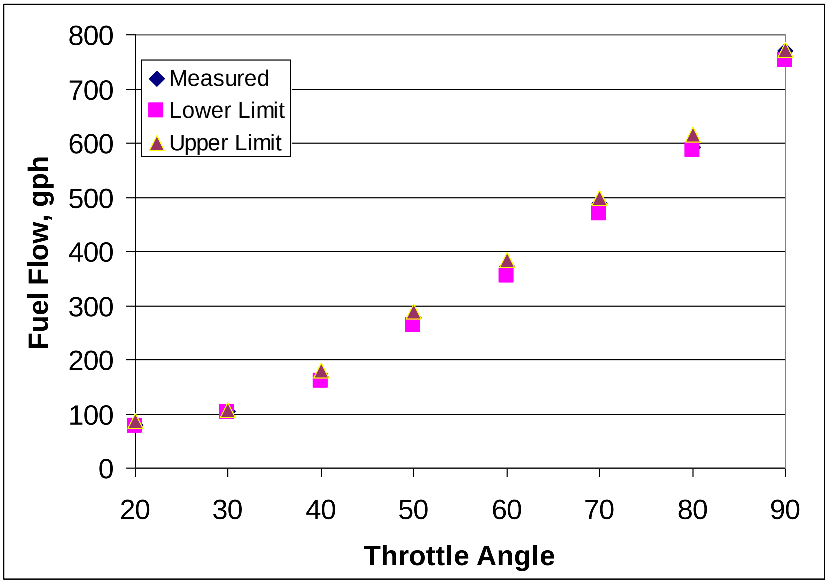

Figure 9: Throttle Valve Calibrations

Fuel manifold was checked for fuel distribution and atomizers calibration is found satisfactory and well within the limits as shown in figure 10. Flow spray angle and patternation of each atomizer were found satisfactory. Atomizers were stripped and no corrosion was noticed on the detail parts.

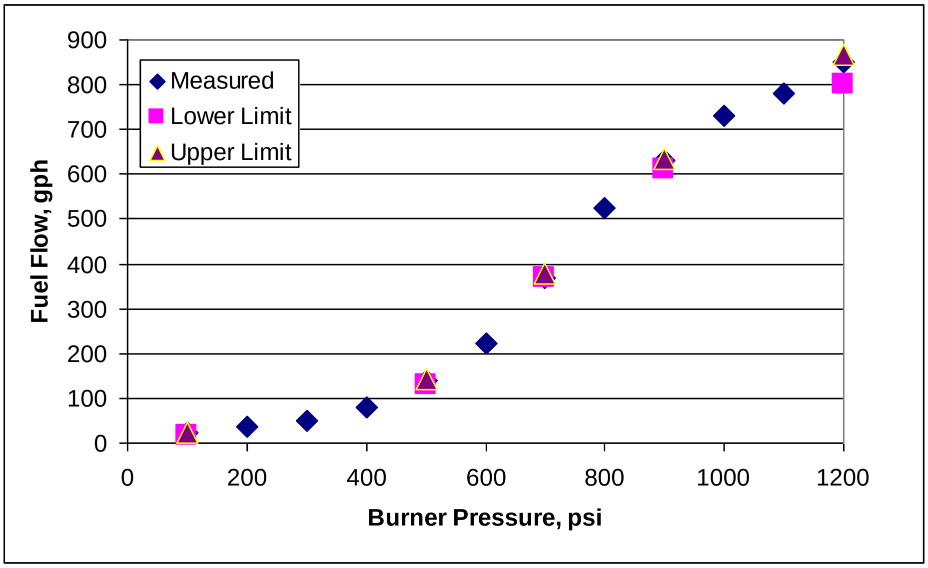

Figure 10: Atomizer Calibration

Main Line Bearings

Bearings were subjected to serviceability check and found satisfactory. During engine runs, vibration levels were within limit and no unusual noise was heard. Run down time (RDT) were measured for all the engines under sampling. RDT is defined as the time taken from engine shaft from idle condition to halt when the engine is cut-off at ground idle. It is a representative of the health of bearings which was found to be within limit specified by the OEM indicating their potential for further service.

Conclusion

The approach for TBO life extension by sampling of aero engines is a well planned task starting with identification of sample engines and carrying out evaluation exercise. It basically relies on service data and field evaluation followed by sampling of lead engines. The approach is much cost and time effective. Accumulation of damages and deterioration of performance beyond limit may be used as yardsticks in deciding for the TBO life extension. This methodology can be useful for progressive extension of TBO life of any military engines.

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REFERENCES

Ashok Koul *et al.*, (2009). Residual Life Assessment and Life Cycle Management of Design Life Expired Discs, GT2009-60352, *Proceedings of ASME Turbo Expo 2009*, Orlando, Florida, USA.

Cohen H, Rogers G F C and Saravanamuttoo HIH (1996). Gas turbine Theory, Longman Group Limited.

Hakan Ozaltun and Jeremy Seidt M *et al.*, (2009). An Energy-Based Method For Uni-Axial Fatigue Life Calculation, GT2009-59512, *Proceedings of ASME Turbo Expo 2009*, Orlando, Florida, USA.

Mishra RK, Mishra AK and Gouda G (2010). Causes and Remedies of High Jet Pipe Temperature in Turbo Shaft Engines: Case Studies, *Journal of Aerospace Sciences and Technologies* **62**(3) 203-208.

Nicholas T (1999). High Cycle Fatigue Life Management in Gas Turbine Engines, RTO-AVTP Workshop on Qualification of Life Extension Schemes for Engine Components, Corfu, Greece, October 1998, NATO Pub., RTO-MP- 17, AC/323(AVT)TP/7 **4** 114-9.

Philip P Walsh and Paul Fletcher (2004). Gas Turbine Performance, Blackwell Science Ltd.

Tony Giampaolo (2003). The Gas Turbine Hand book: Principles and Practices, 2^{nd} edition, Fairmont Press, Inc..

Woloziuk M, Dainty RV, Immarigeon JP and Taylor V (1991). Metallographic Evaluation of T56 Engine First Stage Turbine Blades Coated with C-30, NRC LTR-ST 18 11.