ENGINEERING NOTE

DEFECT TREND ANALYSIS FOR A MILITARY TURBOJET ENGINE: CASE STUDIES

K.S. Jayasimha, R.K. Mishra, S.N. Mistry
Regional Center for Military Airworthiness (RCMA) (Engines)
Center for Military Airworthiness and Certification (CEMILAC)
Bangalore-560 093, India
Email : rkmishra_gtre@yahoo.com

Abstract

Turbojet engines are currently used for military application under training and combat modes. Their operation at extreme conditions often unscheduled with need based throttle excursions lead to high cyclic stresses on engine components and unusual demands on line replaceable units and accessories. As a result, a number of engines are forced for premature withdrawal from service affecting the flight schedule of the operator. This present paper presents the trend analysis of various defects encountered in a military turbojet engine and its accessories. This analysis will help in identifying the probable causes of the defects, time of engine withdrawal and whether they are of reoccurring nature or isolated cases so that corrective action can be initiated to avoid such snags in future.

Introduction

Pure turbojet engines are used worldwide for various lightweight fighter-bomber and trainer application. They are in service for decades and form the backbone of any military command. The nature of their application leads them to operate at extreme conditions and often unscheduled and need based during training and combat modes. Rapid throttle excursions and 'g' load variations during different manoeuvres cause high cyclic stresses on engine components and unusual demands on engine accessories [1]. As a result, a number of engines develop snags forcing for premature withdrawal from service and affecting the flight schedule of the operator. Therefore investigating the snags/defects to analyse their root cause and taking remedial measure are essentially required for maintaining the airworthiness of these engines. This paper presents the defect trend analysis carried out for a military turbo jet engine. Nature of various defects encountered in the engine and its accessories, time of engine withdrawal, whether the defect is of reoccurring nature or an isolated case and cause of the defect are some of the important elements of this trend analysis. Corrective actions initiated to avoid such snags have also been highlighted in some cases.

Engine Configuration

The configuration of the turbojet engine under investigation without air intake is shown in Fig.1. It is a straight flow single spool turbojet engine of 20 kN thrust class. The compressor module comprises of multi stage axial compressor made of high alloy steel blades and vanes with aluminum alloy disc. It is driven by a single stage turbine which is made of nickel base alloys. 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 with maximum rotational speed of 10000 rpm and the rotor system is mounted on two ball type bearings. The turbine wheel assembly comprises the disc and blades. The blades have roots of "fir tree" form which mate with corresponding slots in the disc, each being retained by a hollow split dowel driven through a diagonal hole in the disc to engage a slot in the blade root.

Case Studies

The reported cases of snag/defect/incidents over a period of five years have been considered for the trend analysis. Fig.2 shows the number of engines investigated during the period 2005 to 2009.

Paper Code : V63 N4/741-2011. Manuscript received on 04 Jan 2011. Reviewed and accepted as an Engineering Note on 30 Jun 2011

These engines have been withdrawn for various snags/defects at different stages prior to their scheduled visit to the engine house for overhaul. Considering a time slot of 20% of time between overhaul (TBO), number of engines withdrawn between every 20% of TBO are shown in Fig.3. Total number of engines withdrawn at any time within the TBO prior to overhaul is presented in Fig.4.

Some of the defects are noticed within 20% of TBO during acceptance test or at operating units at an early stage. Engine vibration, high oil consumption and high jet pipe temperature are some of these defects have called for engine withdrawal affecting the fleet badly.

Rotor imbalance, damage of rubber sealing during engine assembly and fuel pump/idle-max fuel settings at the overhaul unit have attributed to such defects. Taking appropriate measures at assembly stage and proper settings at test bench have made these defects reduced drastically. Year-wise defects and reduction of early stage withdrawals are shown in Fig.5.

Defect Analysis

The defects reported for this engine are grouped in different categories such as, engine vibration, high Jet Pipe Temperature (JPT), turbine blade crack or failures, RPM fluctuation, surge etc. Number of engines withdrawn in different categories is presented in Fig.6. Some of these cases are analysed in the following sub-sections.

Engine Vibration

During flying, abnormal vibration experienced at engine rotational speed (RPM) above 80%. While shutting down the engine at ground, run down time (RDT) found to be 30 sec and engine was hard to rotate. Investigation has shown that the failure of turbine rear bearing and scoring marks in the front bearings due to insufficient lubrication has resulted in engine vibration and low RDT. While functioning of pumps and valves in lubrication circuit were found to be satisfactory, blockage of oil jets was found to be the probable cause for the reported defect. Following remedial measures were implemented in to address this category of defects.

- Priming of oil pump using a suitable pressure pump.
- Oil pump, valves and pipe lines are to be checked during overhaul.
- Air/oil pipes and rear bearing to be checked for any possible epoxy peel off.
- Cleanliness of oil to be maintained during replenishing oil.
- Proper preservation and storage procedure to be followed to avoid corrosion if any during inactive period of the engine.

There are also cases of engine vibration at idle and max rpm settings. Rotor balancing and engine assembly standard were studied to address these issues. Engine vibration data to be analyzed in detail to find the root cause of the problem [2].

Cracks on Turbine Blades

Cracks on turbine blade fir tree serrations are found in few engines during periodic crack detection checks at operating units. The cause for fir-tree crack was found due to be fretting fatigue resulting from non-uniform loading as shown in Fig.7 [3] [4].

Deficiency in lapping process and tear and wear in the blade serrations as well as disc slots have led to this failures. Strict adherence to serration/slot dimensional tolerances and proper lapping for to achieve 100% bedding were adopted to address this problem. This action has helped in avoiding engines to suffer blade cracks in future. As a precautionary measure, crack checks are introduced at regular intervals prior to engine overhaul.

RPM Fluctuation

Engine RPM fluctuation during flight or at idle and max rpm settings is a major defect reported. Sometimes the rotor gets stuck at speeds in between 95% to 98% rpm while engine is accelerating to max speed. This leads to fluctuation in JPT also.

Generally RPM fluctuation or RPM related defects are hardly confirmed at test bench as there is no test bench available to simulate the flight condition and engine attitude during ground test. In one case RPM dropped to an unacceptable value above 7 km during climb. Similarly, during slam acceleration, the engine surged with rpm stuck at 60% and JPT crossing the specified limit. When throttle was brought back, JPT came back to normal. When aircraft speed was increased thereafter, no abnormality was noticed in rpm and JPT. Such snags are impracticable to demonstrate in the test bench. However remedial measures are to be taken to address the probable causes.

The RPM fluctuation or getting stuck at a location are mainly attributed to the malfunction of the fuel pump, blockage in fuel lines or fuel injectors, fuel setting and jet nozzle area mismatch to the operating condition. Replacement of Fuel Pump, using correct size of fuel jet and setting the idle and max fuel flow rates properly has helped in addressing this issue.

Nicks on Compressor Blades

During engine servicing, compressor blades were found with nicks. Engine was completely examined for evidence of any internal object damage (IOD) and since all the parts including fasteners were found intact in their positions, IOD was ruled out. Metallurgical analysis has pointed out it as due to a small hard object of the order of 2 mm as a foreign object (FOD). The object has also left deep marks on turbine nozzle guide vanes and rotor blades and also in jet pipe. Preflight inspection of engine and engine surroundings can avoid FOD due to human error if any. Bird hit or entry of components dislodged from aircraft are highly unpredictable and to be dealt with emergency procedures.

High Oil Consumption

This category of defects is generally noticed at an early stage well before the TBO. Most of the cases are also confirmed during the confirmation test run of the engine in test bench. The defects are attributed to high rate of delivery flow as a result of damaged rubber sealing rings or damage in pipe lines. Improper assembly of metering pump during engine build is the most probable cause. Care should be taken during engine build to avoid such problems.

Engine Surge/Flame-out

Though this is an isolated case, it is very critical from safety and operational point of view. Immediately after take-off, pilot observed a loud bang sound followed by rapid winding down of RPM and JPT and subsequently engine flame out.

In this incident, the compressor was severely damaged with its casing failed. All the compressor rotor blades made of aluminum alloy have failed in shear and do not show any fatigue. The casing has failed instantaneously and does not show any progressive failure. The mutilated stator vanes are shown in Fig.8.

The rotor assembly including the turbine does not show any sign of movement and the bearings were intact without any signature of impact or excess loading. A drop in hardness on the turbine blades was noticed indicating momentary overheating. The flame tube nozzle guide vanes also indicated marks of oxidization and discoloration. The findings of the investigation led to confirm the compressor surge followed by flame out. However, the cause of compressor surge could not be ascertained precisely. The most probable reason for surge could be high angle of attack during climb and or excess inlet distortion, both going beyond the design limit. Further, it might be a result of incompatibility of inlet guide vane angle to the flight condition or mismatch of jet nozzle with throttle excursion [1]. However, insufficient flight data in the present case hindered in further investigation to identify any of these parameters responsible for the surge. The possibility of FOD also could not be ruled out which could have blocked the air passage causing a momentary imbalance in the stoichiometry. Advanced and intelligent surge detection and control mechanisms can be thought of to be introduced in the engine if feasible to address this problem [5,6,7].

Remedial Measures

Considering flight safety as the prime concern, it is necessary to implement the recommendations of the investigation team. It is the airworthiness agency who ensures the reliability and suitability of the repaired engine for fitment in aircrafts in service. Several approaches are commonly employed in gas turbine industries to address the defects or failures. The approach depends on the attributability, i.e., whether it is due to a design inefficiency, material failure, or due to lapses in manufacturing processes or in assembly. The failure sometimes attributes to the lapses on the part of user such as deviation from storage procedure, lapse during on-site maintenance and inspection or deviating from the operational limitations. There are also several instances where attributing the cause is not easily possible.

After the modification or rectification is implemented, the engine performance is demonstrated in test bench prior to its fitment in the aircraft. In some cases, it becomes necessary to carry out flight evaluation of the engine in a test aircraft or to monitor the performance of the repaired engine during operation. When it is not possible to evaluate or monitor the components performance or effectiveness of the modification, the repaired engine is called back to the overhaul unit at regular intervals. Residual life of the critical components should be monitored continuously to avoid catastrophic failures in-service [8].

A well laid procedure has to be followed for defect investigation, compliance of the recommendations, and adherence of instruction bulletins both at repair unit and operational units. The final clearance by airworthiness agency of the repaired engine for flight should aim for high reliability and safety of man and machine. The goal will be fulfilled when number of defects will be reduced to zero and that too over a short span of time bringing the engine down-time to a minimum.

Conclusion

Defect trend analysis is an essential approach for studying the snags/defects encountered by the engine over a period and the effectiveness of the remedial measures adopted for maintaining the airworthiness of aero engines. It categorises various type of defects encountered in the engine, time of engine withdrawal, whether the defect is of reoccurring nature and so on. It also highlights the attributability of the defect so that strict adherence to the quality, maintenance or operational schedule can be followed by the concerned agencies. The clearance of the repaired engine for fitment in aircraft should be based on successful demonstration of the post-modification performance. Number of engine premature withdrawals are to be reduced at a fast pace to ensure high reliability and safety of man and machine.

Acknowledgement

The authors are very grateful to Chief Executive (Airworthiness), CEMILAC for his kind permission to present this paper. The authors are also very thankful to the members of defect investigation team for their valuable suggestions and supports during these investigations.

References

1. Cohen, H., Rogers, G.F.C. and Saravanamuttoo, H.I.H., "Gas Turbine Theory", Longman Group Limited, 1996.

2. Alexandre Nairac., Neil Townsend., Roy Carr., Steve King., Peter Cowley and Lionel Tarassenko., "A System for the Analysis of Jet Engine Vibration Data", Journal of Integrated Computer aided Engineering, Vol.6, No.1, 1999, pp.53-66.

3. Suresh, S., "Fatigue of Materials", Second Edition, 2003, Cambridge University Press, pp. 256-257.

4. Hakan Ozaltun, Jeremy Seidt, M., et. al., "An Energy-Based Method for Uni-Axial Fatigue Life Calculation", GT2009-59512, Proceedings of ASME Turbo Expo 2009, June,Orlando, Florida, USA.

5. Garassino, A., Bois, P., "An Advanced Control System for Turbofan Engine: Multivariable Control and Fuzzy Logic (Application to the M88-2 Engine)", AGARD PEP Symposium "Advanced Aero-Engine Concepts and Controls", Seattle, USA, 1995.

6. Dambrosio, L., Camporeale, S., Fortunato, B., "Performance of Gas Turbine Power Plants Controlled by One Step Ahead Adaptive Technique", ASME Turbo Expo 2000, 2000-GT-0037, Munich, 2000.

7. Rysdyk, R., Leonhardt, B., Calise, A., "Development of an Intelligent Flight Propulsion and Control System; Nonlinear Adaptive Control", AIAA Guidance, Navigation, and Control Conference and Exhibit, AIAA-2000-3943, Denver, 2000.

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

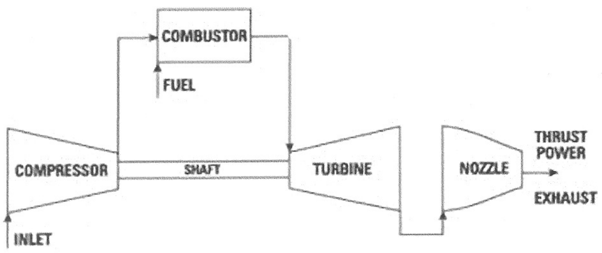

Fig.1 Schematic Layout of Gas Turbine Engine

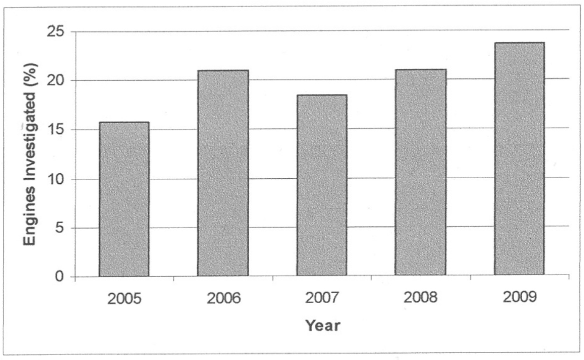

Fig.2 Number of Engine Investigated for Defect, Year-wise

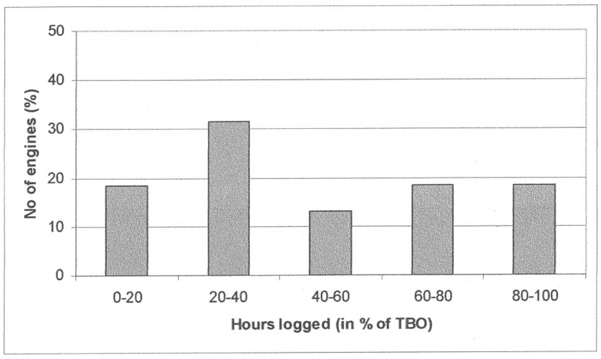

Fig.3 Engines Withdrawn at Various Stages before Scheduled Overhaul

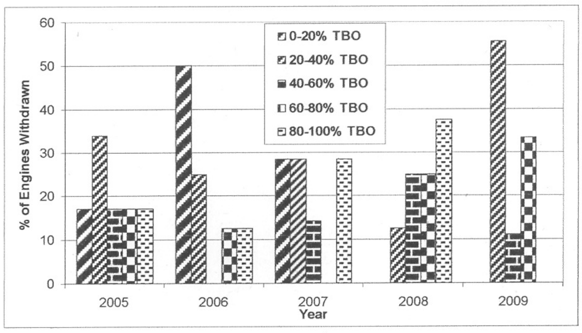

Fig.5 Year-wise Engine Withdrawals at Different Stages of TBO

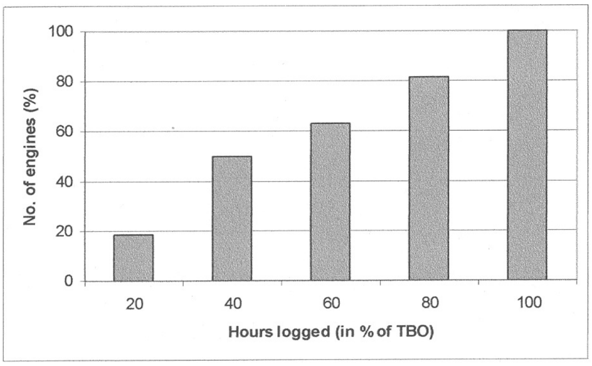

Fig.4 Cumulative Number of Engines Withdrawn at Any Time Before Scheduled Overhaul

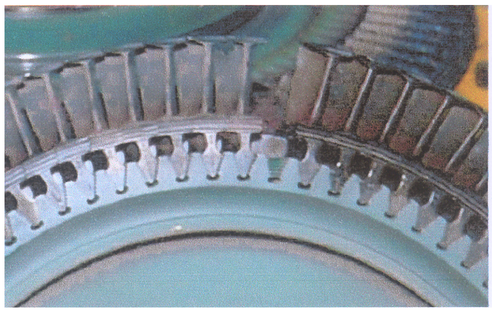

Fig.7 Turbine Blade Failures

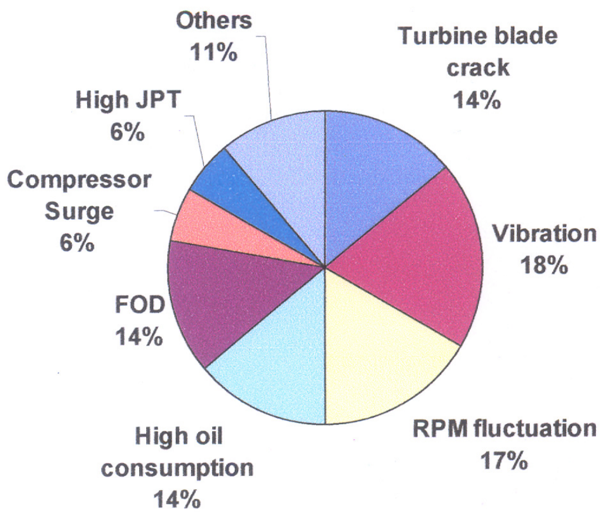

Fig.6 Number of Engines in Various Defect Categories

Fig.8 State of the Stator Vanes Due to Surge