

EFFECT OF LUBRICATION PATTERN ON THE PERFORMANCE OF A SMALL TURBOJET ENGINE

A.K. Mishra*, R.K. Mishra* and G. Gouda*

Abstract

A small turbojet engine has been designed for UAV application and is intended to operate at high altitude and high subsonic speed. The mist lubrication system adopted initially for bearing to support a rotor speed of about 30000 rpm has exhibited good performance under test bed condition but incurs oil starvation during altitude operation. The present paper evaluates the performance of a mist lubrication system during flight and its limitations and drawbacks. The paper also highlights the performance of a close-loop system at altitude operating conditions enabling the system to meet the flight goal. The effect of lubrication pattern on bearing performance has been studied during this exercise. The bearings are found to be cooler with respect to engine speed as well as with altitude when working with closed loop system within the operating range.

Introduction

Small turbojet engines are increasingly becoming the choice for powering Unmanned Aerial Vehicles (UAV) worldwide. However, the high rotor speed of such engines in the range of 30000 to 40000 rpm demands an efficient lubrication system to keep the bearing temperature within the acceptable limit. Any malfunction of the lubrication system or its inefficiency to meet the requirement at any operational condition will lead to rotor instability and seizure causing power loss and damage to the engine. The UAVs are generally launched from ground stations or from ship decks with the help of booster rockets and subsequently propelled by the turbo jet engine. This type of booster launching induces high shock loads on the engine and its components and systems. The function of lubrication system and location of oil tank play an important role during the launch period due to high shock as well as launch orientation. Configuring a proper lubrication pattern for high-speed high altitude operation is a challenging task for the designer. While selecting the lubrication system for this type of small gas turbine engines generally there comes the choice of mist lubrication system or close-loop system each having its own merits and demerits. Because of better tribological performance of oil mist lubrication as applied to rolling element bearings, it has obviously become the first choice for this engine [1]. Also the merit of mist system for high-speed rotor systems has made its place in some aerospace applications [2]. But

due to engine behaviour during a typical mission cycle, the lubrication system has developed malfunction beyond certain altitude. One way of addressing the problem is replacing the lubrication system with a close-loop system and carry out the mission within the flight envelope. The present paper evaluates the performance of a mist lubrication system during flight and its limitations and drawbacks while highlighting the performance of a close-loop system at altitude operating conditions. The effect of lubrication pattern on bearing performance has been studied in this exercise. The bearings are found to be cooler with respect to engine speed as well as with altitude when working with closed loop system within the operating range. Alternatively, an attempt may be made to address the problem by modifying the mist system to improve its altitude performance.

Engine Configuration

The turbojet engine under study is a single shaft engine of 4 kN thrust class designed with axial compressor, axial turbine and straight flow annular combustor. The design has been intended for achieving a compact, lightweight, reliable and low cost engine. The schematic layout of a simple turbojet engine is shown in Fig.1. The major components of the engine apart from the core engine are electrical alternator and bridge rectifier, Fuel Control System, Digital Electronic Control Unit (DECU), Lubricating System, Power Control Unit (PCU) and Ignition Unit. The

* Regional Center for Military Airworthiness (Engines), Centre for Military Airworthiness and Certification (CEMILAC) Bangalore-560 093, India, Email : rkmishra_gtre@yahoo.com

Manuscript received on 16 Dec 2008; Paper reviewed, revised and accepted as a Engineering Note on 11 Jan 2010

core engine consists of air intake section, compressor section, diffuser section, combustion section, turbine section, rotor assembly and exhaust section.

Lubrication System Configuration

Mist Lubrication System

In a mist lubrication system, a small quantity of oil mixed with compressed air in the form of mist and is delivered to the bearing locations. This system generally consists of an oil tank, mist generators and piping to carry mist and air for lubrication. The compressed air is drawn from last stage of the engine compressor and supplied to the mist generators. Mist going through the pipes to the front and rear bearings are mixed with second stage compressor air to increase the cooling effect. Fig. 2 shows the scheme of mist lubrication system and location of bearings in the engine.

In the system, two mist generators are used to increase the safety of the system. The mist generated is taken to the front and rear bearings from two separate outlets of the mist chamber of the oil tank. The working of mist generator is shown schematically in Fig. 3.

Heavier particle of the oil settle down in the mist chamber and flow down to the oil compartment of the tank. In this system there is no re-circulation of oil due to mist formation. Mist generator parameters that depend on the flight envelop controls the quantity and quality of mist.

Limitations of Mist Lubrication System

During developmental trials of the engines on ground test bed, high vibration was observed in many engines due to bearing failures. Generally the bearing performance of a gas turbine engine depends on various factors such as oil temperature and viscosity, type of lubrication system, insufficient lubrication, contamination of lubricant and air, thermal conductivity of the backing material to dissipate heat developed in oil film, engine critical speed, rotor thrust load, shaft misalignment and overloading. When the failures were analyzed, a majority of the failures were found to attribute to insufficient lubrication resulting in high temperature of bearing leading to bearing seizure. A number of modifications were incorporated like increasing the diameter of mist jet nozzle, oil change and removal of intermixing cooling air with mist which could make a little improvement in the performance of the bearings.

Further investigations revealed that inadequate oil mist generation and malfunction of its distribution system as the prime factor causing the bearing failure in this mist system. The rate of actual oil mist generation to the front and rear bearings depends on the flight envelope achieved through the different ratings of the engine. Therefore, the mist lubrication system is not reliable at high altitudes due to low ambient air pressure. The complete loss of lubricating oil and lack of re-circulation system prohibits the mist system to operate efficiently at high altitude and also for long duration.

Closed Loop Lubrication System

The closed loop lubrication system uses an oil pump to deliver the oil to the bearing locations. A pressure pump and two scavenge pumps forms a pump assembly, which is mounted on the air intake assembly. The engine shaft through a reduction gear train drives the oil pump. Oil from the pressure pump is supplied to the front bearing and rear bearing. Two scavenge pumps suck oil from the front bearing and rear bearing and the oil is returned to the tank. The oil flow circuit in closed loop lubrication system is shown in Fig. 4.

System Failure Analysis

A minimal amount of information on prior work in the area of evaluation of mist lubrication during flight trial is available in the open literature [3] [4]. This is due in part to the proprietary nature of most studies. Further, the amount of information available in open publications has been limited [5]. The objective of this work is to investigate the operation of a mist lubrication system based on bearing failures. During flight trial of the engine, bearing failure was noticed immediately after the launch. A system failure analysis is carried out to establish the cause of failure and to take corrective measure for improvement of performance for closed lubrication system. The elements of the failure analysis approach are explained in following sub sections.

Symptom

The engine was recovered and flight data was analyzed. The oil pressure differential was found to become zero after few seconds of the launch stopping the lubricant flow to reach the bearing points. When a bearing fails due to oil starvation, its surface usually becomes very shiny. In addition, there may be excessive wear of the bearing surface due to the wiping action of the journal. In the most

severe cases the bearing surface will be smeared or scratched and torn as shown in the Fig. 5. The absence of a sufficient oil film between the bearing and the journal permits metal-to-metal contact, which is also evident from the Fig. 6. The resulting wiping action causes premature bearing fatigue. The friction and wear increases rapidly causing bearing seizure and eventual wiping of babbitt around the whole circumference.

Synthesis and Confirmation

The lubrication system of the engine was isolated and its elements contributing to the failure were listed out. Each element was examined thoroughly with respect to its functionality. Test was carried out on lubrication system simulating the operating conditions and launch attitude [6]. The lubrication system along with its components, viz., oil tank, oil pump, pipes and instrumentations, were mounted on a shaker table with proper attitude. A 10 g shock load for 11 milliseconds was initially applied to the setup as against the actual load of 9.5 g for 200 milliseconds [7] [8]. Oil pressure was measured at three different locations, i.e., at pump inlet, pump outlet and tank outlet. Oil pressure drops to a lower level and fluctuations of large amplitude (0.2 Bar) were noticed in the oil pressure, which confirmed that the incident of bearing failure was due to high shock load experienced by the engine during the launch.

Configuration Change

Due to the location of oil tank, the oil starvation was noticed in the pipelines as well as in bearings during launch. Therefore bringing oil tank close to the oil pump at the air intake assembly, the system was reconfigured. The system test was repeated and no fluctuations were noticed in the oil pressure and negligible amplitude of 0.05 Bar was found as momentary disturbance, which are within acceptable limits. The g-load experiment was also carried out to rule out the possibility of air entrapment in pressure pump suction line during high g-level [9].

Results and Discussion

The flight was launched for high altitude operation with the closed loop lubrication system to analyze the engine performance at different altitudes especially the oil system parameters. But due the failure immediately after launch, no parameters were recorded. The engine was recovered and modified based on experiment results and

system failure analysis. The flight trial was repeated with modified closed loop lubrication system for high altitude operation to analyze the engine performance at different altitudes especially the oil system parameters. The parameters recorded were engine rpm, oil pressure, front and rear bearing temperature, compressor delivery pressure, jet pipe temperature, fuel inlet pressure, and aircraft speed. The flight trial points of the engine with both lubrication systems are shown in Fig.7.

The front bearing temperatures measured during flight trials expressed in terms of altitude and engine speed are shown in Figs. 8 and 9 respectively. Both the figures clearly exhibit the benefit of closed loop lubrication system by bringing down the bearing temperature.

Figure 8 indicates the 9 km operation with the closed loop lubrication system at lower bearing temperature. From Fig.9, it is clear that for the same engine rpm the bearing temperature is lower for closed loop lubrication system in comparison to mist system. The oil flow rate is not significantly affected by altitude pressure fall in close-loop system where as the mist generation falls exponentially as pressure falls [5] [10].

The effect of lubrication pattern on rear bearing temperature is shown in Figs. 10 and 11. The lower bearing temperature has enabled the engine to operate for higher duration as well as for higher altitudes and the engine could fly at 9 km successfully. In any gas turbine engine it is the rear bearing that suffers higher thermal stress and any increase in lubrication flow rate dictated by its pressure drop is always beneficial to it.

The effect of these two lubrication patterns on oil tank pressure has also been studied. In case of mist lubrication system, the oil tank pressure keeps on decreasing with altitude causing a problem to the mist generation leading to starvation in lubrication in bearings. In the closed loop system, this pressure is maintained at a higher level throughout the flight as shown in Fig.12. Higher line resistance in close-loop system results a higher pressure differential and this in turn improves the flow rate and tribological performance.

Conclusion

Small gas turbine engines operate at high rotational speed and their long duration operation in flight envelope

requires an efficient lubrication system. The following conclusions are drawn based on the results obtained during the present exercise are as follows:

- The closed lubrication system supports the long flight duration at higher altitude with low oil consumption.
- Closed loop lubrication system offers a lower bearing temperature compared to that with mist system over the engine rpm and altitudes tested.
- Pressure differential across a close-loop system is found to be better showing better tribological performance.
- Attitude of lubrication system and oil tank position play an important role in engine performance.

Acknowledgement

The authors are very grateful to the Chief Executive (Airworthiness), Center for Military Airworthiness and Certification, Govt. of India, Bangalore for his kind permission to present this technical paper. The authors are very thankful to the Engineers of ETBR&DC, HAL and Scientists of Aeronautical Development Establishment for their immense help, cooperation and valuable suggestions during this investigation.

References

1. Shamim, A. and Kettleborough., "Tribological Performance Evaluation of Oil Mist Lubrication", J. Energy Resource Technology, September 1994, Vol.116, No. 3, pp.224.
2. Heinz, P. Bloch and Abdus Shamim., Oil Mist Lubrication: Practical Applications, Prentice Hall International, 1998.
3. Block, H.P., "Optimized Lubrication of Antifriction Bearings for Centrifugal Pumps", Lubrication Engineering, Vol. 35, No. 7, pp. 381-385, July 1979.
4. Hafner, E.R., "Proper Lubrication - The key to Better Bearing Life", Mechanical Engineering, Vol. 99, No. 10, pp. 32-37, October 1977.
5. Robert F. Handschuh and Wilfredo Morales., "Lubrication System Failure Baseline Testing on an Aerospace Quality Gear Mesh", NASA/TM2000-209954, May 2000.
6. Military Specification: General Specification for Engines, Aircrafts, Turbojet and Turbofan, MIL-E-005007E(AS), 1983.
7. Environmental Conditions and Test Procedures For Airborne Equipment, EUROCAE ED-14D/RTCA DO-160D, July 1997.
8. Department of Defense Test Method Standard for Environmental Engineering Considerations and Laboratory Tests, MIL-STD-810F, January 2000.
9. Mishra, R.K. et al., "Qualification of a Small Turbojet Engine for UAV A Challenge", Journal of Institution of Engineers (India), Aerospace Division, Vol.90, May 2009.
10. Towne, C. A., "Practical Experience with Oil Mist Lubrication, Shell Chemical Company", 37th American Society of Lubrication Engineers, Annual Meeting in Cincinnati, Ohio, May 1982.

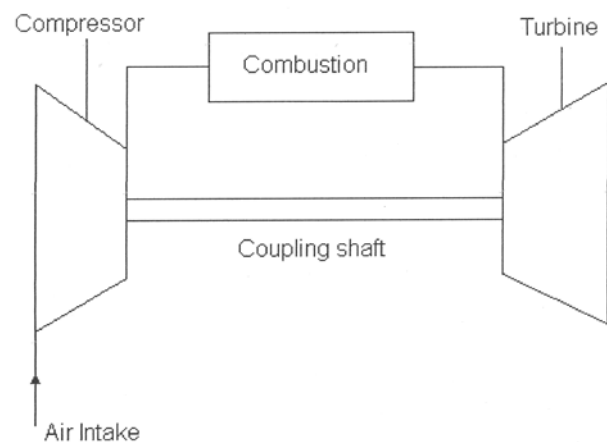


Fig.1 Simple Turbojet Engine layout

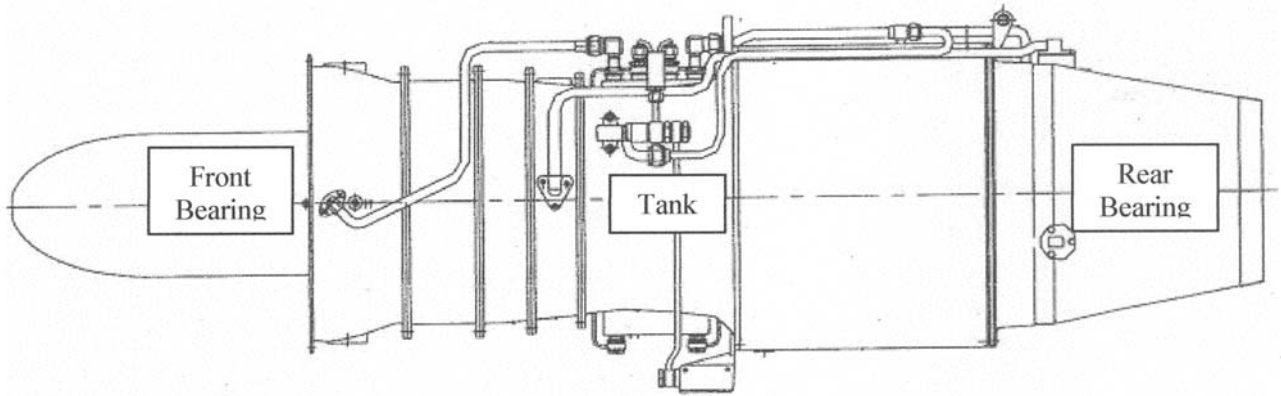


Fig.2 Mist Lubrication System Scheme in Engine

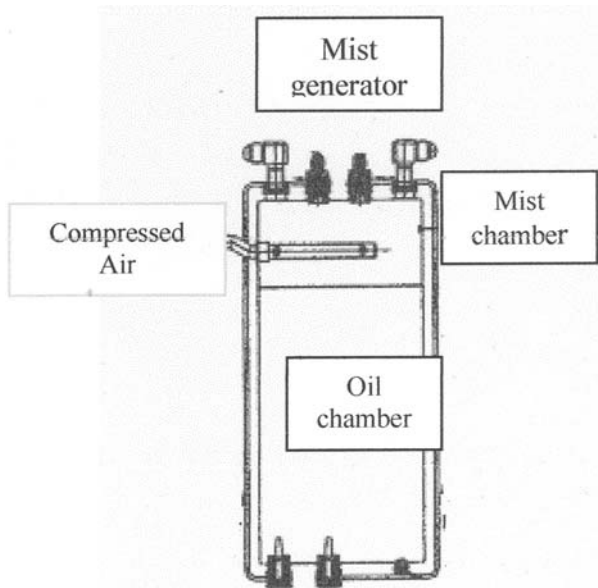


Fig.3 Working of Mist Generator

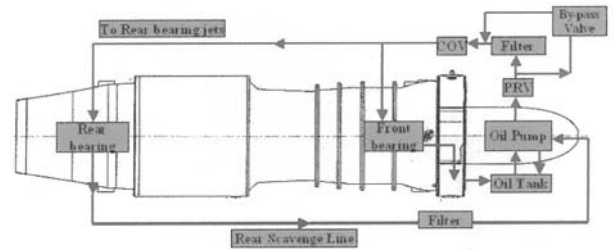


Fig.4 Schematic Closed Loop Lubrication System

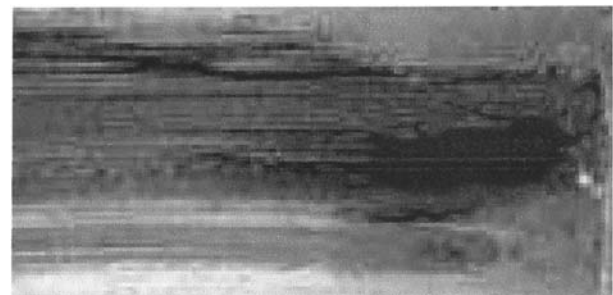


Fig.6 Evidence of Metal-to-Metal Scratch on Bearing

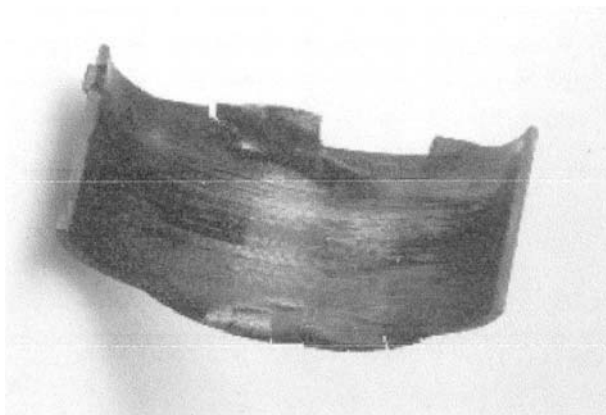


Fig.5 Failure Signatures on Bearing

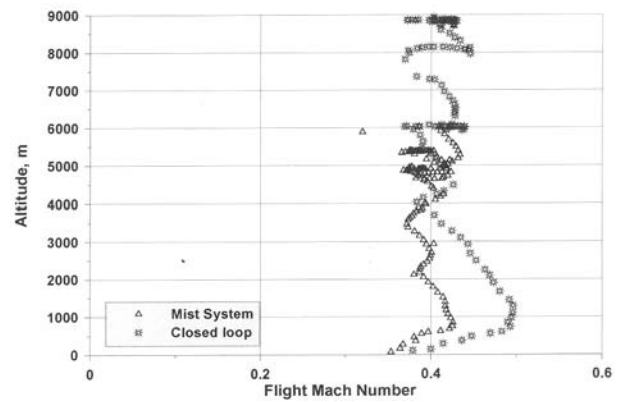


Fig.7 Flight Trial Points

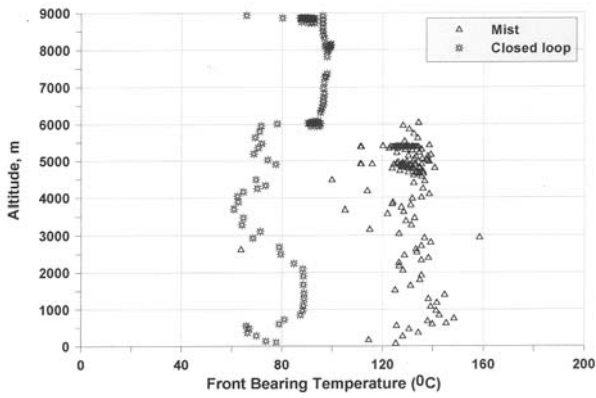


Fig.8 Effect of Lubrication Pattern on Front Bearing Temperature at Different Altitudes

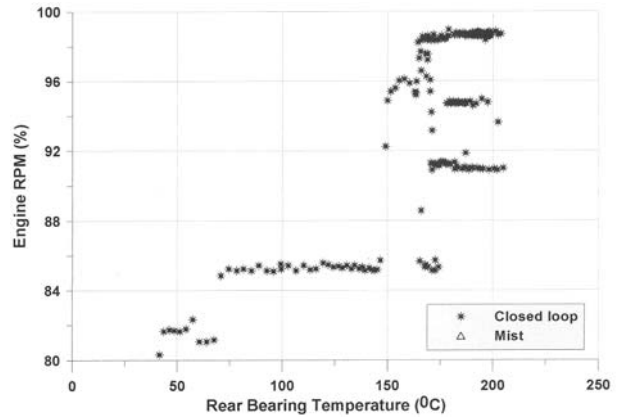


Fig.11 Effect of Lubrication Pattern on Rear Bearing Temperature at Different Engine Speed

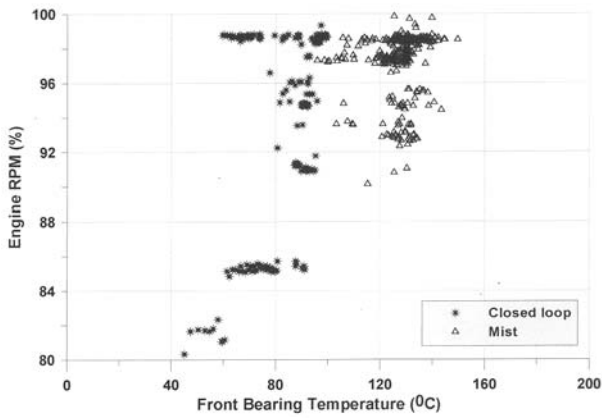


Fig.9 Effect of Lubrication Pattern on Front Bearing Temperature at Different Engine Speed

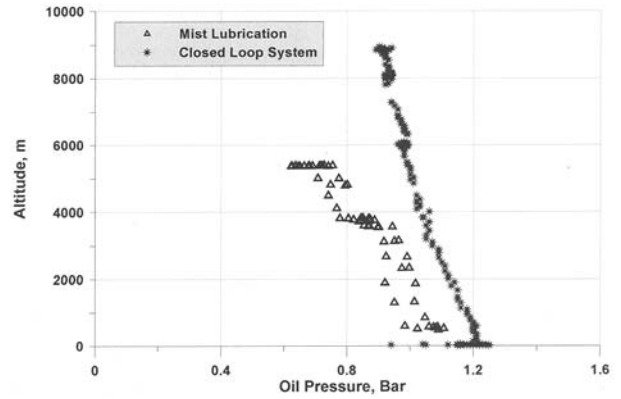


Fig.12 Effect of Lubrication Pattern on Oil Tank Pressure at Different Altitudes

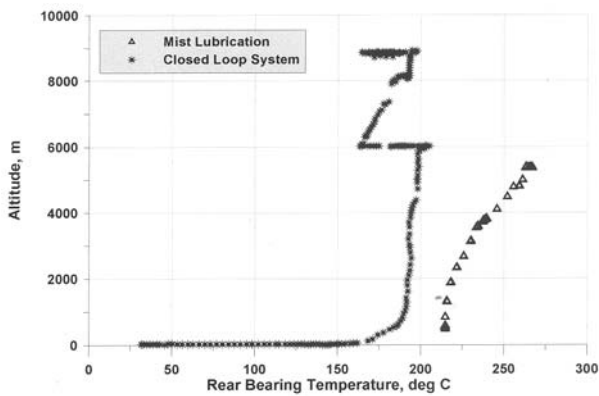


Fig.10 Effect of Lubrication Pattern on Rear Bearing Temperature at Different Altitudes