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Review Article

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Flow Control and Thermal Behavior of Bearings Using a Proportional Valve in a Closed-Loop Lubrication System for Turbofan Engines

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ABSTRACT

Effective lubrication and thermal management have become extremely important in modern turbofan engines, under extreme temperatures and high rotational speeds. The bearings in both the cold and hot sections of these engines are subjected to considerable thermal and mechanical stresses and require credible lubrication to reduce wear and avoid early failures [1,2]. Indeed, closed-loop lubrication has become the de facto industry norm in aero-engine designs as it efficiently re-circulates oil, controls heat, and removes contaminants [3]. However, the biggest engineering challenge still lies in the proper optimization of oil distribution, especially across regions where there is a difference in thermal load [4].

Fixed or manually adjusted components have always been a part of the traditional lubrication system. They do not adequately respond to the dynamic conditions of the engine with varying RPM and sudden thermal excursions during operation [5]. New-age systems try to overcome this limitation by adding active flow control devices like proportional valves that control oil delivery to important parts of the system in real-time [6]. These valves offer very precise control of oil flow, ensuring that the bearing temperatures are kept safe, which ultimately improves the durability of the engine and its operational reliability [7].

The study is directed towards the incorporation of oil flow regulation using proportional valves into a closed-loop lubrication system of a small turbofan engine, rated for approximately 4000 N of thrust . The research investigates two most vital bearings in the engine - one in the cold sector and the other in the hot sector. The bearings thermally responds appropriately to oil distribution changes under different flow scenarios. Moreover, the work contributes to the overall advancement in the aerospace arena in thermal management by showing how adaptive lubrication control could elevate efficiency and safety [8-10].

Keywords: Turbofan Engine, Bearing Thermal Management, Lubrication, Proportional Valve

Material and Method

This study is about a closed-circuit lubrication system in a small-class turbofan engine that produces 4000 Newton thrust at nominal performance and reaches 44000 rpm. This lubrication subsystem consists of an oil pump, oil tank (reservoir) heat exchanger, filter, and two proportional valves separated for 2 separate bearings, cold and hot. This two-channel system provides independent control in the lubrication of each bearing group.

MIL-PRF-23699 synthetic ester oil was selected as the lubricant fluid due to its high thermal stability and low volatility properties. Due to the mentioned properties, MIL-PRF-23699 is a type of oil frequently used in aviation applications.The turbofan engine was examined by dividing it into two groups, basically cold section and hot section. While the bearing in the cold section is located in the compressor assembly where it is exposed to moderate thermal loads, the bearing in the hot section is exposed to much higher thermal loads due to its location in the turbine and combustion chamber.

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To evaluate the system performance, a system architecture was designed with parametric simulations and thermal models in MATLAB. Four different valve opening ratios were determined as 25%, 50%, 75% and 100%. The oil flow rate changes according to these opening ratios. In addition, a relationship was established between the engine speed and the pump output, and the effect of changing flow rates on bearing temperatures was examined.

Findings

Overall, this research has highlighted the importance of using proportional valve controlled lubrication system to improve the basic performance of bearings used in turbofan engines. One of the first findings is the critical relationship between valve opening ratio (%) and oil flow rate, as shown in Figure 1. Oil flow rate (L/min) increases directly from 0 to 40 liters with valve opening from 0 to 100%. This shows the reliability of using proportional valves to control the flow of lubrication system, no matter how challenging the engine operating conditions are.

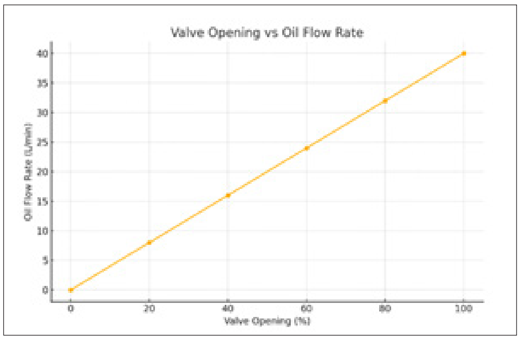

Figure 1: Valve Opening vs Oil Flow Rate

Figure 2 shows the relationship between the pump oil output and engine speed. The pump performance starts at 10 L/min at 10,000 rpm and delivers 30 L/min at 28,000 rpm, while it delivers 40 liters of oil per minute when it reaches 44,000 rpm. This shows that engine performance and pump performance have a linear relationship under normal operating loads, and that when the maximum engine speed is approached, a regulated oil flow is provided by proportional valves.

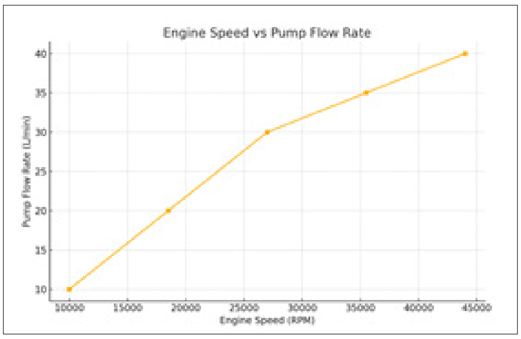

Figure 2: Engine Speed vs Pump Flow Rate

As seen in Figure 3, the oil flow rate is of great importance in regulating the temperatures of the bearings in the cold and hot sections. The temperature of the bearing located in the cold section decreases from 55 °C to 35 °C with the increase in oil flow. In contrast, the temperature of the bearing in the hot section, which is subject to much higher thermal loads, decreases from 100 °C to 65 °C. These results emphasize the thermal gradient between the two sections and indicate that the oil supply of the system is directed more towards the areas where the cooling requirement is greater.

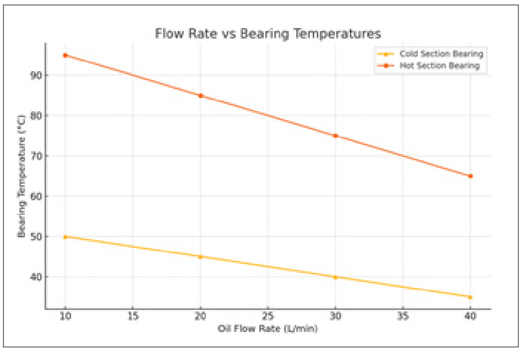

Figure 3: Flow Rate vs Bearing Temperatures

In addition, Table 1 shows the bearing temperatures in relation to the valve openings. For example, with a 50% valve opening, the bearing temperature in the cold section is fixed at 45 °C, while the bearing temperature in the hot section is fixed at 90 °C. Therefore, these results confirm that the system is actively driven in the cooling process as determined by the local thermal requirements.

Table 1: Valve Opening & Temperature Table

Valve Opening (%)	Cold Section Temp (°C)	Hot Section Temp (°C)
25	55	100
50	45	90
75	40	80
100	35	65

Conclusion

The results obtained from this study show that proportional valve controlled lubrication systems affect the thermal performance of bearings to a very serious extent. There is also a linear relationship between the life of the engine and the life of the bearings. Engine OEMs (Original Equipment Manufacturers) who want to produce long-life engines attach great importance to the thermal resistance of bearings in particular. Closed-loop lubrication systems create specialized thermal management systems for different performance requirements by regulating the amount of oil delivered to the bearings.

A significant result obtained is that when the oil flow rate delivered to the bearings reaches the highest levels, the bearing temperatures experience a major decrease from 55°C to 35°C in the cold section and from 100°C to 65°C in the hot section when the valve opening is compared with 25% and 100%. This cooling process reduces the thermal stress on the bearings and increases the reliability of the engine.

Moreover, this study reveals the importance of lubrication systems in reducing the energy consumption of propulsion and control systems in aviation engines. In the future, advanced 3D computational fluid dynamics analysis, testing and validation applications can optimize system performance, provide higher levels of thermal stability, and design safer lubrication systems and engines.

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