GAS TURBINE ENGINE LUBRICATION SYSTEMS

Executive Summary

The purpose of having a lubrication system in aircraft is to reduce friction in the bearings of turbine engines. The oil pressure, oil temperature and continuous flow of oil in the bearings are controlled by a lubrication system in the gas turbine engines. Significant developments in the lubrication process in aircraft engines are noticed over the years. Evolution in the gas turbine engines and developments in recent years regarding this context is analyzed in the report. The study has highlighted past and present practices in the gas turbine lubrication system. Different types of lubrication system such as pressure relief lubrication system, full flow lubrication system, and Wet-sump and Dry sump lubrication systems are identified by the researcher. It is identified that each of these systems has different operational capabilities which are compared and evaluated in the study.

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Introduction

Military and commercial aircraft of the aviation industry are mostly powered with gas-turbine engines. The safe and reliable operations of gas turbine engine operations are depended on the functions of their lubrication systems. The functions involve lubrication of rotor bearings, cooling of the bearings in turbine sections, removing contaminants from lubricants, sealing of carbon-bearing seals and so on. The systems have specific operational capabilities that ensure safe flight which is outlined in the report along with related issues of the lubrication system of today's gas turbine engines are also analyzed. Information regarding various lubrication system used in past and present are given. The report sheds light on the difference in the lubrication system between the past and present aircraft and evaluates them. The operational capabilities of different lubrication system are also discussed in the report.

Investigation

Different Gas Turbine Engine Lubrication Systems: Past and Present

Evolution of the Gas Turbine Lubrication Systems

The jet age and the requirements for enhanced and improved aircraft engine lubricants began in the year 1930 with the working of Frank Whittle of the Royal Air Force College in England. The introduction of lubricant and the importance of it emerged in the year 1937 when Frank gave a successful demonstration of the experimental turbine engine (Aydin *et al.* 2015). It gave rise to a tremendous rise in the development program and research for high-performance oils.

Before and during World War II, there was independent development of fluids in Germany and United States that were as lubricants to be used in commercial and military aircraft. It even forms the basis of many lubricants to be used in the aviation industry in the present day. This leads to the development of castor oil application as a lubrication system to be used excluding its gumming tendencies. This leads to the development of several triesters and diester oils that were used in the year 1944. The Naval Research Laboratories by then have developed synthetic ester oils and work on improving its properties to be used as a lubricant were done by Air Force Materials Laboratory and Naval Research Laboratory (Buffi *et al.* 2017).

There is a need for developing the existing lubricant system and in order to achieve this, it is necessary to understand the impact of fluid performance at the estimated modern turbine engine operating conditions. The present-day commercial jet planes and aircraft have high speed and require high-temperature resistant fluids. This has led to the development of high-temperature liquid lubricant alternative to those that have been used for the past 35 years. This involves processes such as designing of engines to substitute for the shortcomings, use of inerted lubrication systems and use of micro fog once-through systems.

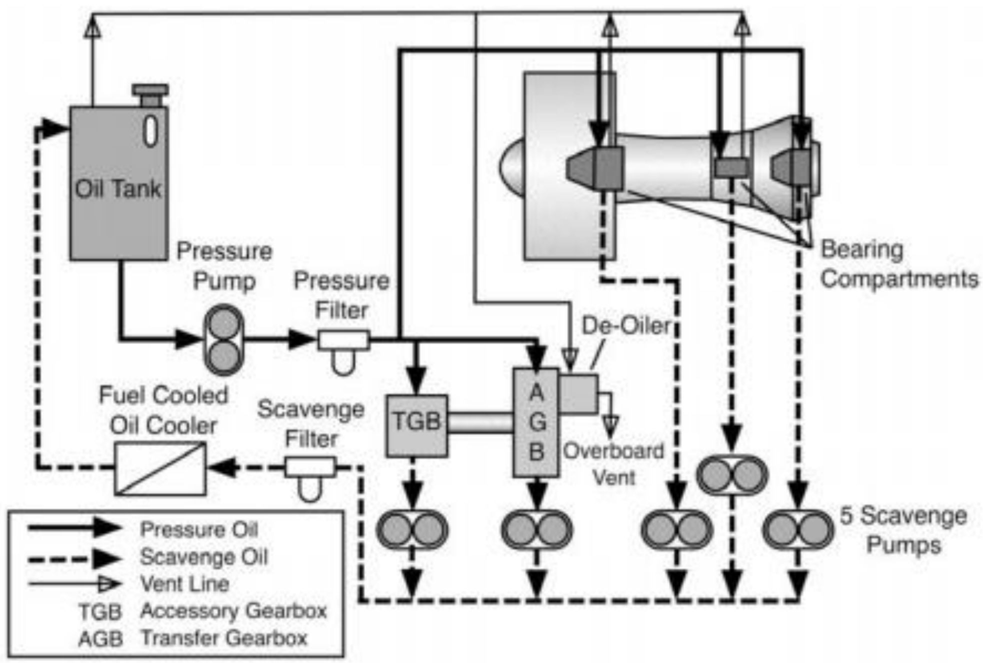


Figure 1: A Typical gas turbine engine lubrication system

(Source: Aydin *et al.* 2015**)**

Development over the Past Gas Turbine Lubrication Systems

Inerted Lubrication System

In the traditional Gas Turbine Lubrication System, the breakdown or decomposition of the lubricant is processed through oxidation. Chiaramonti *et al.* (2014) cited the disadvantage of this process is that the diester formulations have a temperature resistance range up to 177°C. However, in the absence of or limited oxidation, the oils give thermal stability up to 302°C. This gives rise to the modern inerted lubrication system concept that suggests that on restricting oxygen in the jet engine or commercial aircraft similar to those in the inert-gas-blanketed system, the lubricant achieves the required stability more than that the substantial amounts of oxygen.

The feasibility of such a concept is demonstrated and examined with the help of using five different lubricants within a nitrogen gas inerted system. It was used in simulating a Mach 3 aircraft gas turbine engine carrying full-scale mechanical components. Oils operated smoothly in this experiment lasting for 10 hours and it involved a mix of ester, synthetic paraffinic fluid, perfluorinated polymeric oil, and a C-ether fluid (El-Sayed, 2017).

Micro for Once-Through Systems

It has been studied and put to practice that an oil-mist injected through the lubrication system decreases the engine bearing frictional heat. It does the process by eliminating circulating oil at a great speed. According to Lefebvre and McDonell (2017), it also allows a higher bearing operating temperature as thermal degradation is of less importance. Oil-mist system also has lower weight and complexities due to which they are not prone to accidental leaks and plugging of jets.

Present lubrication systems:

Present inventions in the lubrication system of gas turbine engines are mainly focused on an efficient oil system in the aircraft. The use of a greater number of bearings and moving parts in these engines increased the complexity in its lubrication systems. Inefficient lubricant system in those engines is one of the main reasons behind the performance. Compared to piston engines, the gas turbine engines have less number of moving parts and it also rotates in only one direction.

Achieving smooth operation in the bearing chambers, uninterrupted oil flow, and controlling oil temperature is the main purpose of this oil system. Presently, the following types of lubrication systems are used in gas turbine engines:

Oil Systems:

An aerobatic oil system for a gas turbine engine ensures a continuous supply of oil through the bearing chambers. Şöhret *et al.* (2015) commented current gas turbine engines use a separate unit that is part of the engine intake or the external gearbox as oil system for aircraft. Especially for large frame turbines, a single oil supply line is used whose efficiency can determine the overall performance of an aircraft. The oil supply line lubricants as well as cool the bearing chambers during flight conditions. For instance- during start and shut down, auxiliary oil pump component of the oil system supplies oil in the engines. After start-up, once the speed of an aircraft becomes more than 2850 rpm, control is transferred to the main oil pump component. Due to the rotation of shafts, the oil supply to bearings is necessary to give an oil wedge. Moreover, the oil system also maintains the oil temperature in the bearings at a required level (Tatar and Aras, 2017). The key components of the gas turbine engine oil system are as follows:

- Main and Auxiliary oil pump
- Emergency oil pump
- Jacking oil pump
- Oil tank

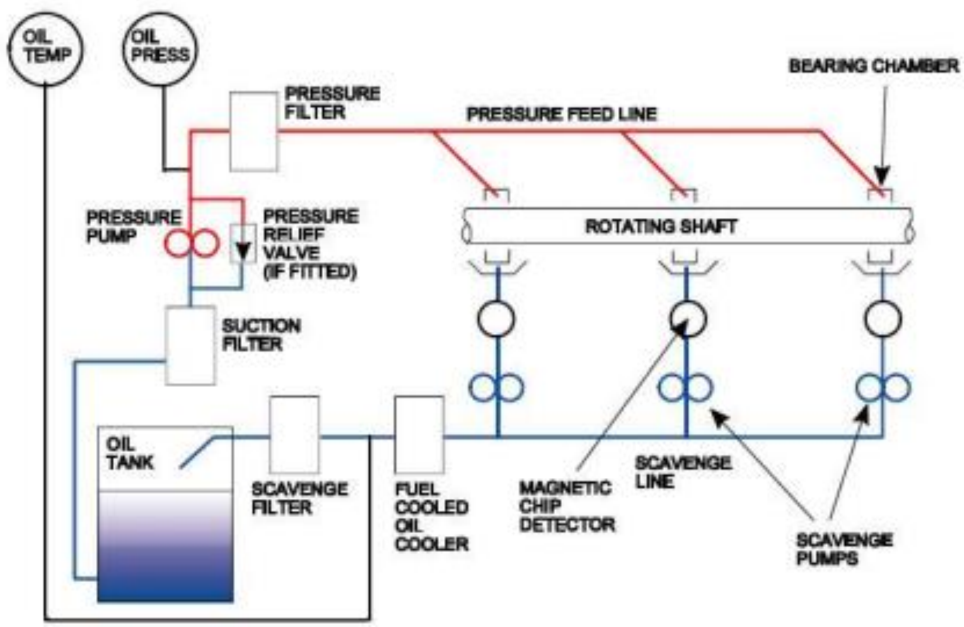


Figure 2: A gas turbine oil system

(Source: citeseerx.ist.psu.edu, 2018)

Pressure relief valve lubrication system:

The pressure relief valve lubrication system is a widely used gas turbine lubrication system in the modern aviation industry. Using a spring-loaded valve the system controls the oil flow through the bearing chambers. Wheeler and Bozhko (2014) stated, especially when the aircraft takes high speed, it is necessary to limit oil flow at a required level which is done by this lubrication system. Thus it controls oil pressure during any engine considerations using a specific pressure limit.

Apart from the lubricating task, the system works as a hydraulic medium that considers the ambient temperature and pressure in the turbine engines. With the help of this system, the pilot is able to find a minimum torque pressure so that the aircraft is capable of operating on any conditions.

Full flow lubrication system

It is noticed that a full flow system is most suitable for the operations of short duration flight such as missiles, target drones and so on. In large turbofan type engines, the full flow lubrication systems are used along with the pressure relief system to maximize the capability of lubrication operations. It ensures a smaller volume of oil passing through the system as compared to pressure relief lubrication system (Khonsari and Booser, 2017). Normally, the full flow lubrications systems do not require any pressure relief valve. Instead, the full flow lubricating system uses various filter elements while oil is passed through the oil pumps. Any types of interruption in the oil flow through engines are detected and warned with an alert system in this gas turbine lubrication system.

Comparison and Evaluation

Operational Capabilities of Different Lubrication Systems

Aircraft manufacturers in the current aviation industry are using various types of lubrication system each of which has specific operational capabilities as discussed below:

Pressure relief valve lubrication system

The pressure relied on valves are mainly used in today's lubrication system to control the flow of engine oil to the bearing chambers. Engine designers and manufacturers restrict the value of oil pressure which is suitable for all conditions that gas turbine engine may encounter. Engine designers generally use a spring loaded valve that controls the pressure and temperature of the oil (Lokesh *et al.* 2015). Apart from that, the operation of the pressure relief valve involves an accurate indication of torque pressure. The accurate torque pressure indicates that the engine is capable to operate in any engine conditions. Moreover, the pressure relief lubrication system control oil flow through external oil pipes and internal drillings using a pitch control mechanism. Using the torque meter pump the system is capable of boosting engine oil pressure in a greater figure.

The above operational capabilities of the Pressure Relief Valve Lubrication System ensures that it has a low maintenance cost and is hygienic (Yilmaz and Atmanli, 2017). It takes minimum time to flush and test operations. This lubrication system helps in mitigating surges and increases the longevity of the pipeline. It can manage high-pressure applications efficiently and has an adjustable closing speed along with utilisation of compressed air. It is noticed, that, the pressure relief lubrication system is a widely used lubrication system in the commercial aircraft because of its positive oil control capabilities.

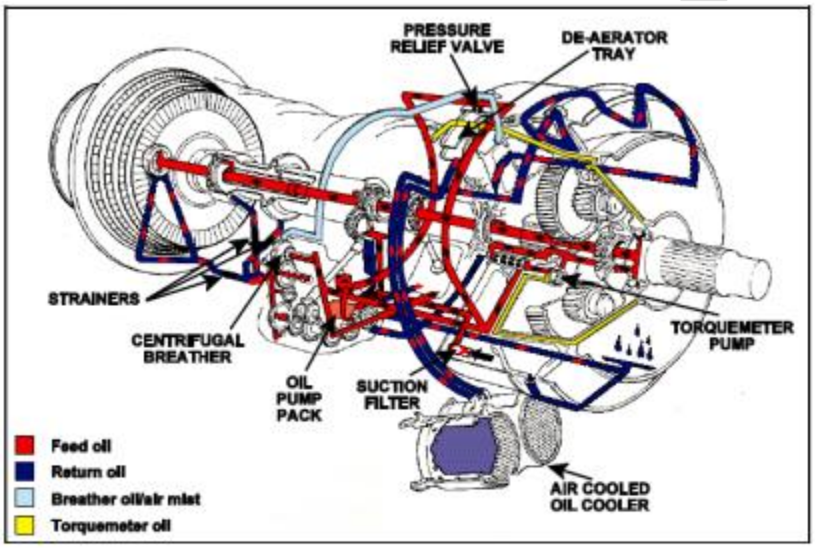


Figure 3: Pressure relief valve lubrication system

(Source: citeseerx.ist.psu.edu, 2018)

Full flow lubrication system

The operational capabilities of the full flow lubrication system involve controlling the oil flow throughout an engine's entire speed range. Harrison (2017) mentioned the system allows the oil pressure pumps to supply oil feed jets directly without using a pressure relief valve. Therefore, scavenge pumps and smaller pressure can be achieved with the help of full flow lubrication system. The main reason behind this capability is that the less volume of oil is passed through engines compared to pressure relief valve lubrication system. The system also involves an oil differentiation pressure switch which is capable of giving warnings on filter blockages in the oil tank. Similar to pressure relief valve the full flow lubrication is system is also able to measure oil temperature, pressure and provides warning against malfunctions in oil systems (Furfari, 2016).

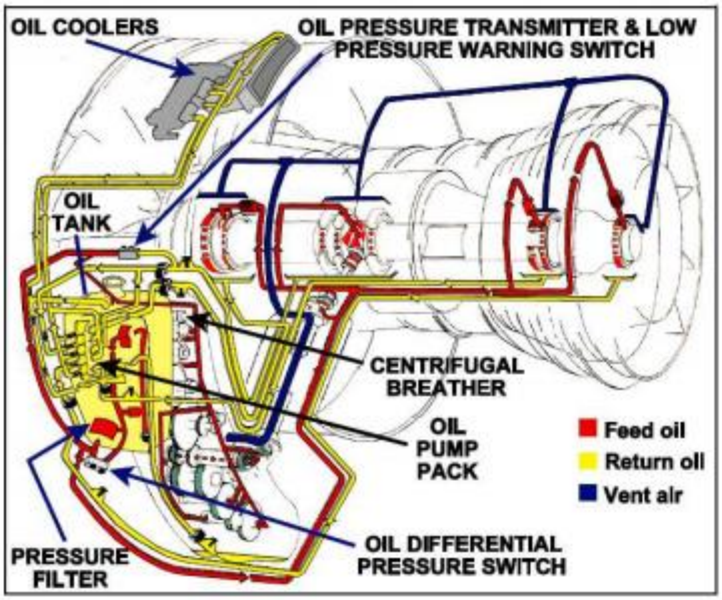


Figure 4: the Full flow lubrication system

(Source: citeseerx.ist.psu.edu, 2018)

Wet-Sump system and Dry-Sump system

The lubrication system in today's gas turbine engines is using Wet-Sump or dry-dump system or a combination of both for lubrication of oil. The wait dump system store lubricating oil in the engine whereas, the dry sump system utilizes the external tank mounted in gas turbine engines. The main operations of the wet-sump system control the supply of oil in the oil system. The gearbox of wet-sump systems allows a space for heat expansion and foaming when oil level fills the casings (Lobo *et al.* 2015). The dry-sump system is more common than the wet-sump system that controls oil supply in the engines. Dry-sump lubrication systems mainly use an oil tank mounted in the airframe that mainly holds the oil supply. Using this oil tank, the dry-sump system is capable of managing larger and cooler oil capacity as compared to the wet-sump system. Ability to control oil temperature to ensure cooler oil flow is also included in the dry-sump system.

Operational capabilities of the Oil systems

The main functionality of the oil system of gas turbine engines is cooling the bearings by circulating oil and carries the heat away from the bearings. In gas turbine engines, the exhaust turbine engines are the critical lubricating point and high temperature is generally presented in these points (Aydin *et al.* 2015). The operations of oil system are mostly focused on controlling the oil temperature in exhaust turbine engines. Providing cool oil flow through the engines, the oil system ensures less quantity of oil to run the engines. Components of the oil system such as oil tank, oil pump, valves have a different type of operational capabilities listed below:

Oil tank

Oil tank the most important part of an oil system that ensures proper lubrication process in the gas turbine engines. Today's high-performance jets powered with gas turbine engines are requiring pressurized oil tanks that assure positive lubrication in various flight conditions. Operational capabilities of oil tanks include preventing excessive air pressure within bearing chambers and the gearbox. In order to achieve that, engine designers make the interior of the tanks by venting it with the atmosphere. Mainly the oil mists are vented to the gearbox and it is made sure that it passes through the centrifugal before reaching the atmosphere (Chiaramonti *et al.* 2014). In this process, the centrifugal breather minimizes the loss of oil from the oil tanks of gas turbine engines. As mentioned above, the oil tanks mostly used along with the full dry-sump lubrication system and ensure a larger oil capacity for the gas turbine engines.

Oil Pumps

The functionality of Oil pump is quite similar to oil tanks; it controls oil supply under pressure only some specific engine points where lubrication is required. In most cases, oil pumps in a gas turbine engine consist of both pressure supply component and a scavenging component. As cited by Lefebvre and McDonell (2017), the scavenge component has a greater capacity for oil pumping compared to pressure supply component. However, few oil pumps are only capable of pressure supply or scavenge. The operational capabilities of oil pumps are largely depended on the type of engine in the aircraft. For instance- centrifugal-flow engines generally have shorter rotor shaft and very few bearings compared to axial flow engines. For this reason, axial-flow engines require highly efficient oil pumps which are capable of both oil supply and scavenge. ***[Refer to Appendix 1 & 2]***

Conclusion

The report has provided an investigating on different types of lubrication systems used in gas turbine engines. It is found that the present gas turbine enabled commercial and military aircraft mainly uses pressure relief valve lubrication system to achieve uninterrupted supply of oil through the engine bearings. Comparing the previous and present practices, it is noticed then, the gas turbine engines have enhanced lubrication system than previously used piston engines. Currently used gas turbine engines facilitates a separate oil system that involves oil tanks, oil pumps and valves each of which has different operational capabilities. As discussed in the report, few aircraft also uses Wet-Sump and Dry-sump lubrication system. It is identified that Dry-sump lubrication system has greater oil capacity and better cooling system compared Wet-sump. Moreover, the full flow lubrication system is often used in the gas turbine engines mostly in short duration flights. Full flow lubrication systems are found as highly capable of controlling oil pressure in various flight situations. Continuous innovation in the aviation industry is being noticed which evolved the use of lubrication system in gas turbine engines.

References

Aydin, H., Turan, O., Karakoc, T.H. and Midilli, A., 2015. Exergetic sustainability indicators as a tool in commercial aircraft: a case study for a turbofan engine. *International journal of green energy*, *12*(1), pp.28-40.

Buffy, M., Valera-Medina, A., Marsh, R., Pugh, D., Giles, A., Runyon, J. and Chiaramonti, D., 2017. Emissions characterization tests for hydrotreated renewable jet fuel from used cooking oil and its blends. Applied Energy, 201(2), pp.84-93.

Chiaramonti, D., Prussi, M., Buffi, M. and Tacconi, D., 2014. Sustainable bio kerosene: Process routes and industrial demonstration activities in aviation biofuels. *Applied Energy*, 136(2), pp.767-774.

El-Sayed, A.F., 2017. *Aircraft propulsion and gas turbine engines*. Taylor & Frrancis: CRC Press.

Lefebvre, A.H. and McDonell, V.G., 2017. *Atomization and sprays*. Taylor & Francis: CRC press.

Şöhret, Y., Açıkkalp, E., Hepbasli, A. and Karakoc, T.H., 2015. Advanced exergy analysis of an aircraft gas turbine engine: splitting exergy destructions into parts. *Energy*, 90(2), pp.1219-1228.

Tatar, V. and Aras, H., 2017. An investigation into an anti-ice static vane of a gas turbine engine. *Applied Thermal Engineering*, 110(2), pp.1039-1050.

Wheeler, P. and Bozhko, S., 2014. The More Electric Aircraft: Technology and challenges. *IEEE Electrification Magazine*, *2*(4), pp.6-12.

Khonsari, M.M. and Booser, E.R., 2017. *Applied tribology: bearing design and lubrication*. Hoboken: John Wiley & Sons.

Lokesh, K., Sethi, V., Nikolaidis, T., Goodger, E. and Nalianda, D., 2015. Life cycle greenhouse gas analysis of biojet fuels with a technical investigation into their impact on jet engine performance. *Biomass and Bioenergy*, 77(2), pp.26-44.

Yilmaz, N. and Atmanli, A., 2017. Sustainable alternative fuels in aviation. *Energy*, 140(2), pp.1378-1386.

Harrison, A., 2017. Designing for Service in a Complex Product Service System-Civil Aerospace Gas Turbine Case Study. In *Advances in Through-life Engineering Services*, 2(1), pp. 57-81.

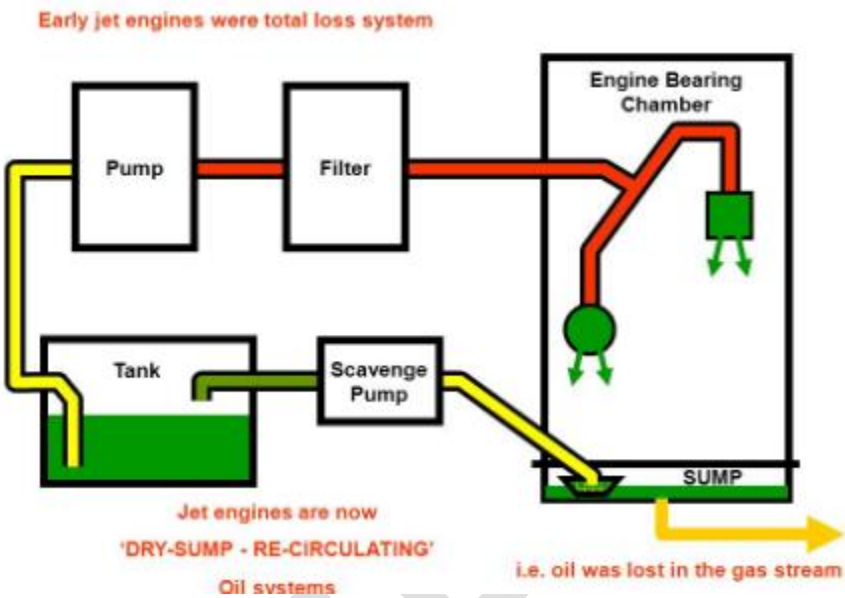
Furfari, S., 2016. Energy efficiency of engines and appliances for transport on land, water, and in the air. *Ambio*, *45*(1), pp.63-68.

Lobo, P., Christie, S., Khandelwal, B., Blakey, S.G. and Raper, D.W., 2015. Evaluation of non-volatile particulate matter emission characteristics of an aircraft auxiliary power unit with varying alternative jet fuel blend ratios. *Energy & Fuels*, *29*(11), pp.7705-7711.

Citeseerx.ist.psu.edu (2018) *Gas Turbine Engines Lubrication System Design* http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.1013.8640&rep=rep1&type=pdf

Appendices

Appendix 1: the Early lubrication system



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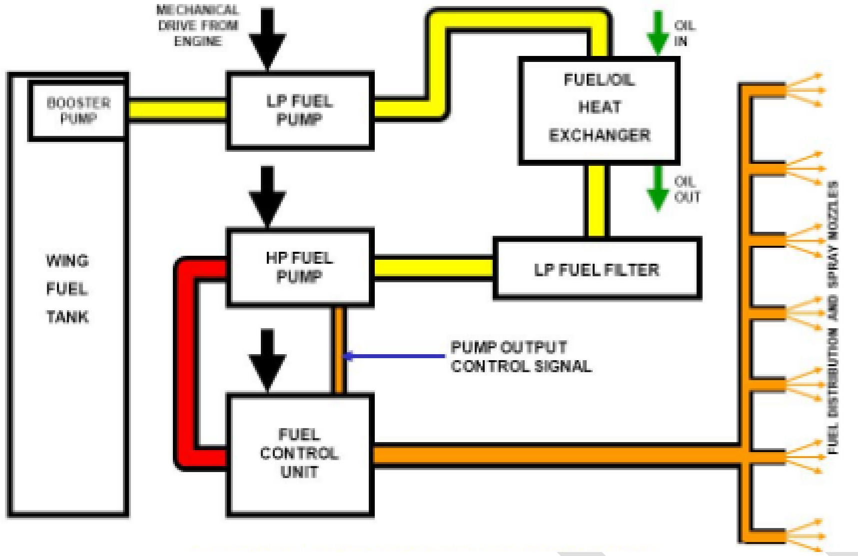
Appendix 2: Modern Lubrication Systems



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