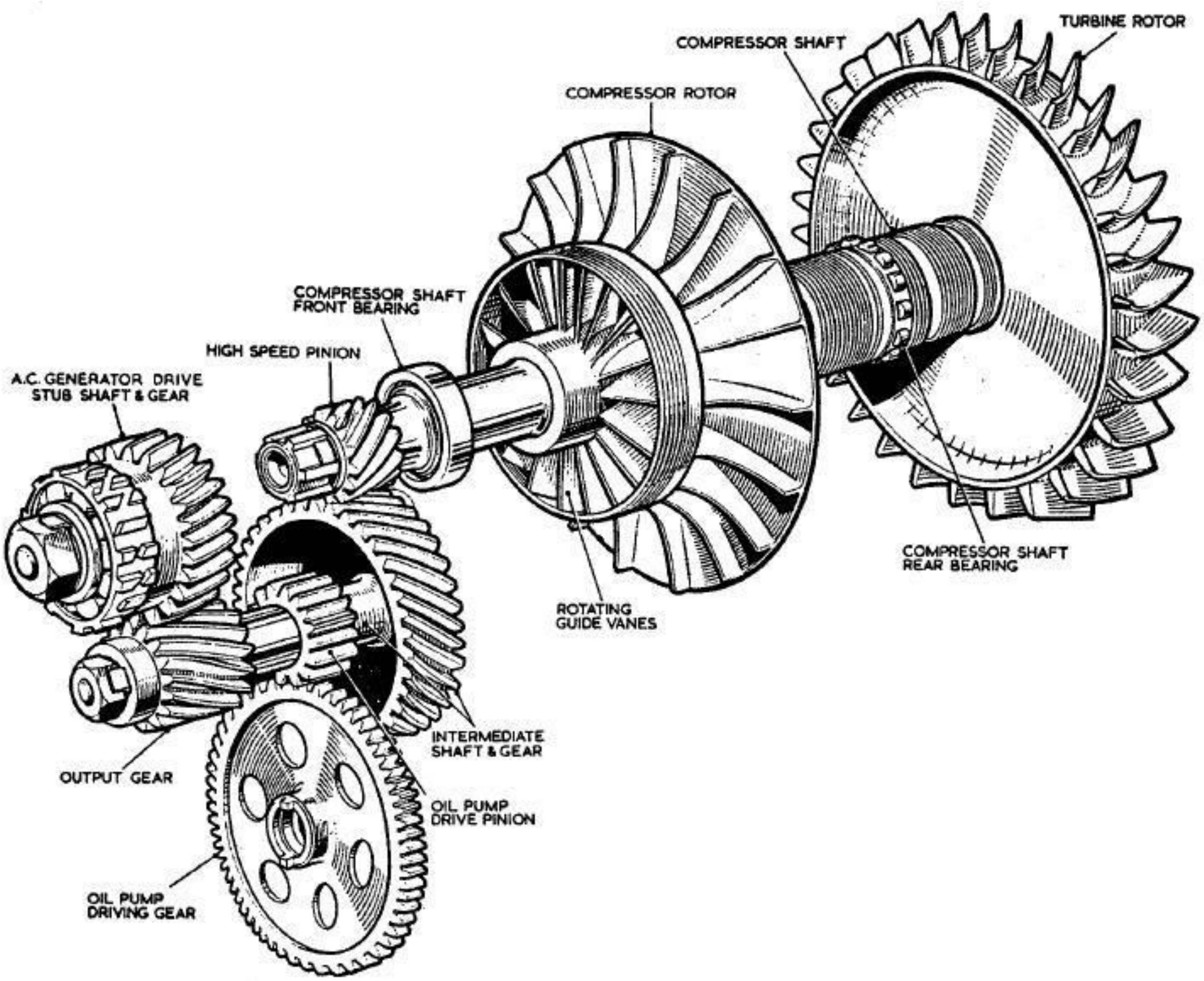
Chapter 4

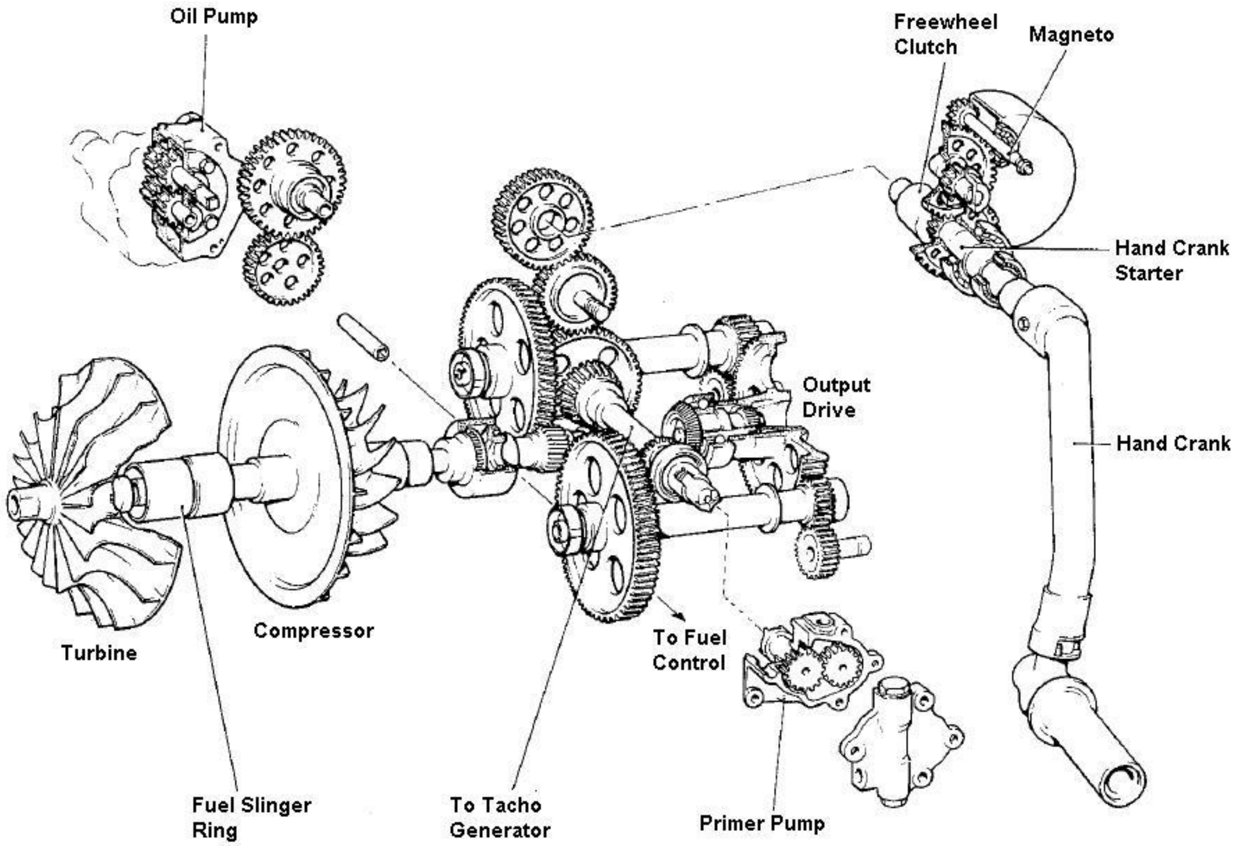
Gearbox, Bearings and Lubrication



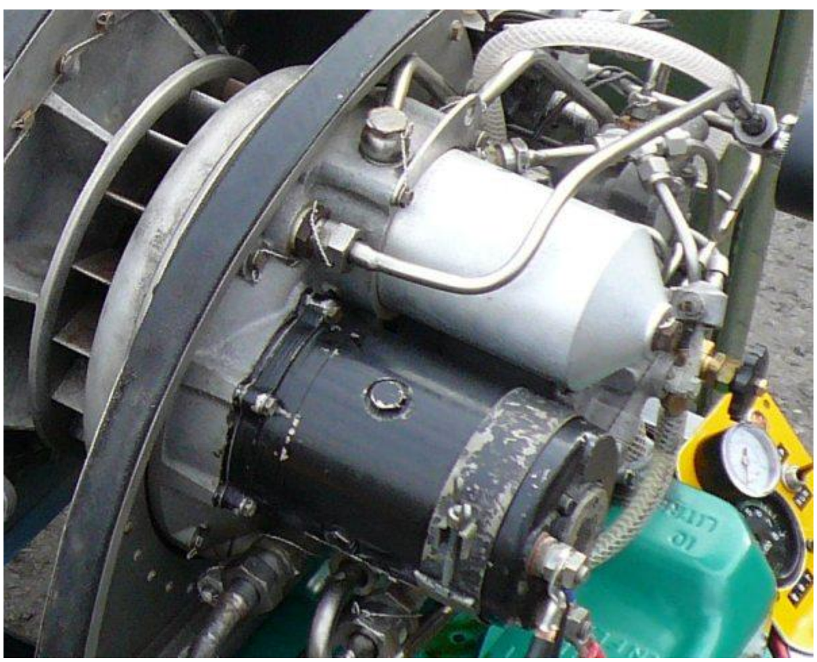
Typical small gas turbine reduction gear train

Small gas turbine engines spin at very high speed in the order of 25,000-85,000 rpm. A reduction gearbox is normally required so that the engine may drive a load at lower speed e.g., Generator, Alternator or Pump. In addition, many small gas turbine engines require accessories such as oil and fuel pumps to be driven via the reduction gearbox.

It is possible to reduce or even remove the need for a load and accessory gearbox if the accessories are to be driven by external electric motors. Simple Turbo-Jet engines are only required to produce thrust and so may not be fitted with a reduction gearbox.



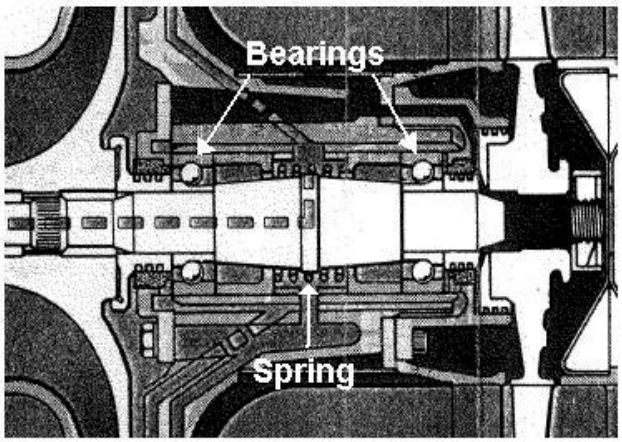
A small gas turbine engine gear train with hand-crank starting



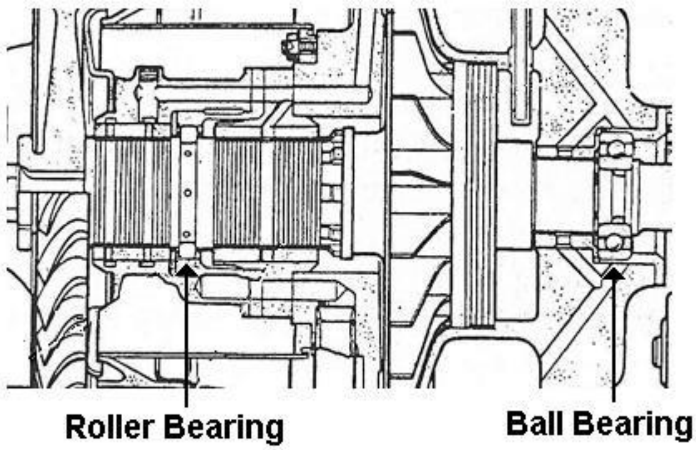
Accessory gearbox Rover 2S100

Main engine bearings

Nearly all gas turbine engines employ ball or needle roller bearings to support the main rotating shaft and other rotating components. Plain bearings are usually found in experimental turbo-charger based units. Small gas turbine engines rotate at extremely high speeds at up to 90,000 rpm, to cope with these speeds special high-speed bearings are used. The method by which the bearings in small gas turbines support the main shaft may be characterized in two ways. -



Spring-Loaded Angular Contact Bearings



Ball Race Bearing and Roller Race Bearing

Preloaded angular-contact bearings

Here two identical ball races are mounted on the engine main shaft and placed at each end close to the compressor and turbine rotors. Between the two bearings a spring is used to hold the outer races apart and preload them. The races are a special type where the regions of contact between the balls and the races are inclined an angle. The bearings prevent both radial movement and axial movement of the shaft, the axial retention is in one direction only per bearing. The two bearings face each other and so prevent axial movement in either direction. The bearing outer races are allowed to move axially and are preloaded by the spring force, this whole assembly is contained in a sleeve. The spring loading has the added advantage that the pre-load is unaffected by temperature. The design of the whole assembly will be carefully chosen so that the bearing system dampens any rotational resonances. On certain designs of engine, the whole assembly will move very slightly back and forth in the sleeve to allow for manufacturing tolerances and wear.

Angular contact ball races will normally tolerate axial forces in one direction only so care must be exercised when removing them from an engine so that the pair of bearings are not mixed up and are refitted with the same orientation.

Spring loaded angular contact bearings are found in many Garrett engines, the Microturbo Saphir and the Plessey Solent GTS. Most miniature turbo-jet engines intended for model aircraft propulsion also adopt this bearing configuration.

Ball and needle bearing systems.

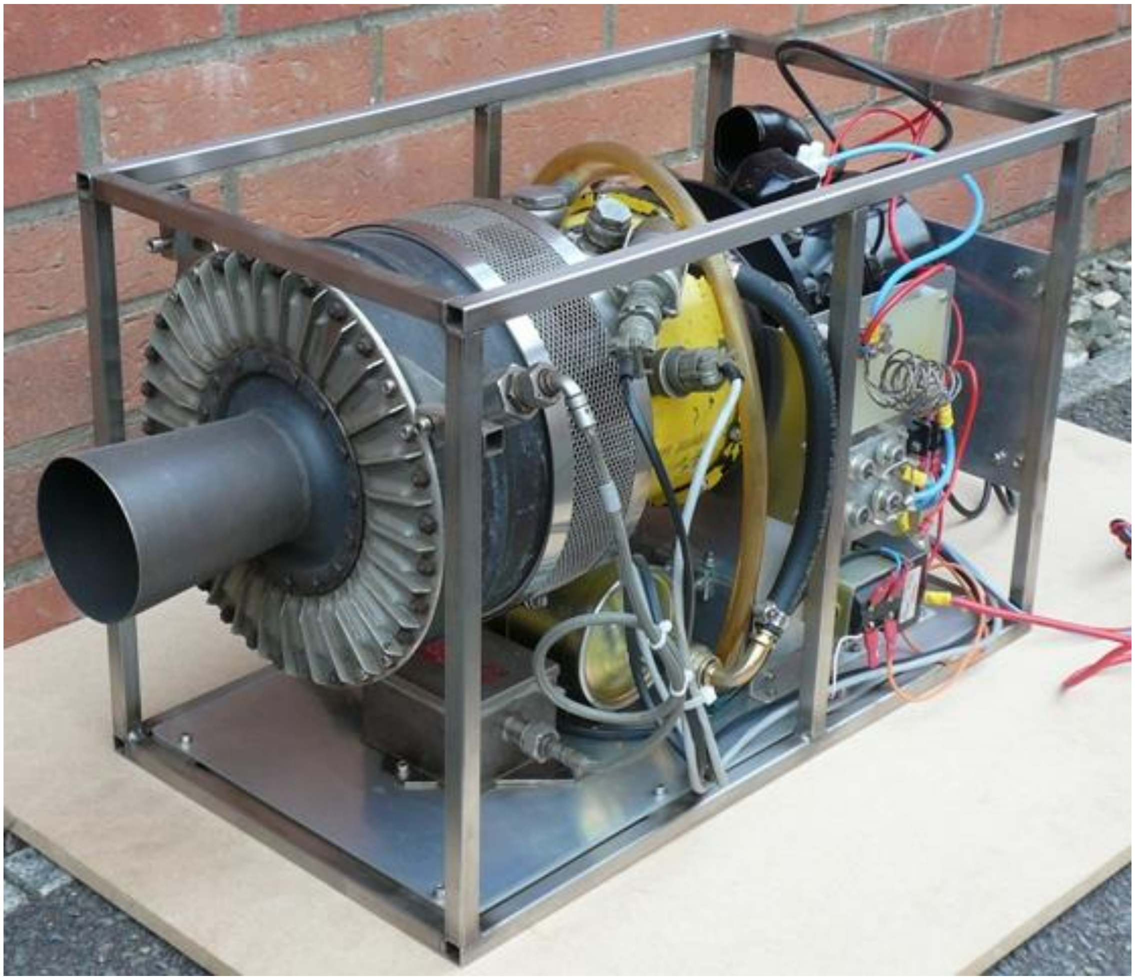
A second bearing configuration commonly used in small gas turbine engines consists of a ball race and a needle roller bearing. A ball race capable of accepting an axial-load is placed at one end of the main rotating shaft assembly (usually the compressor end) and a needle roller bearing is fitted at the other end. The ball bearing maintains the axial position of the shaft and the roller bearings allows for a small axial movement that will be created by the differential thermal expansion between the shaft and the engine structure. The carriers for the bearings may be allowed to "Float" or may be "Sprung" in such a way as to dampen various resonances, the oil supply is also used to dampen some bearing systems.

The Rover 1S60 gas turbine engine adopts a ball race and needle roller configuration. In larger gas turbines where the main shaft is carried in three or more bearings, the engines adopt a combination of ball and roller bearings to allow for thermal expansion.

Several in-line shafts may be coupled together with splines and carried on independent bearings systems to isolate balance and resonance issues. Separating shaft systems with splined couplings also allows for assembly, disassembly and for a modular engine construction.

Lubrication

Most small gas turbines lubricate themselves with a circulating oil system, a few designs notably the Saurer GT15 actually use the fuel as a lubricant. Gas turbine lubricating oil is generally of a thinner viscosity to that of automotive types, automotive types should never be put into gas turbines. Various specifications are laid down for gas turbine oils, most modern oils are synthetic but mineral based oils are also used. When choosing an oil type for a particular engine, the manufactures recommendations should be checked as to which is most suitable. The ambient operating temperature can influence which oil should be used, small gas turbines are often specified able to accept more than one viscosity of oil.



Fuel-lubricated gas turbine (Saurer GT15)

Synthetic turbine oils-

Brand	US MIL	Joint Services	Nato	Viscosity (100)
Aeroshell 390	MIL-L-7808	OX7		3.4
Aeroshell 500	MIL-L-23699	OX27	O156	5.1
Aeroshell 555		OX26	O160	5.4
Aeroshell 560	MIL-L-23699	OX27	O154	5.2
Aeroshell 750		OX38	O149	7.5
Mobil JetII	MIL-L-23699			5.1
Mobil 254	MIL-L-23699			5.3
BP 2380	MIL-L-23699			5

Mineral turbine oil-

Aeroshell 2	MIL-L6081	OM10	0133	10.5 (37)

Warning: ***Always use the correct turbine engine lubricating oil as recommended by the manufacturer. Do not mix mineral and synthetic oils!***

Warning: ***Gas turbine lubricating oils are hazardous substances, avoid prolonged exposure to oil and wear protective gloves when handling oil.***

Oil systems

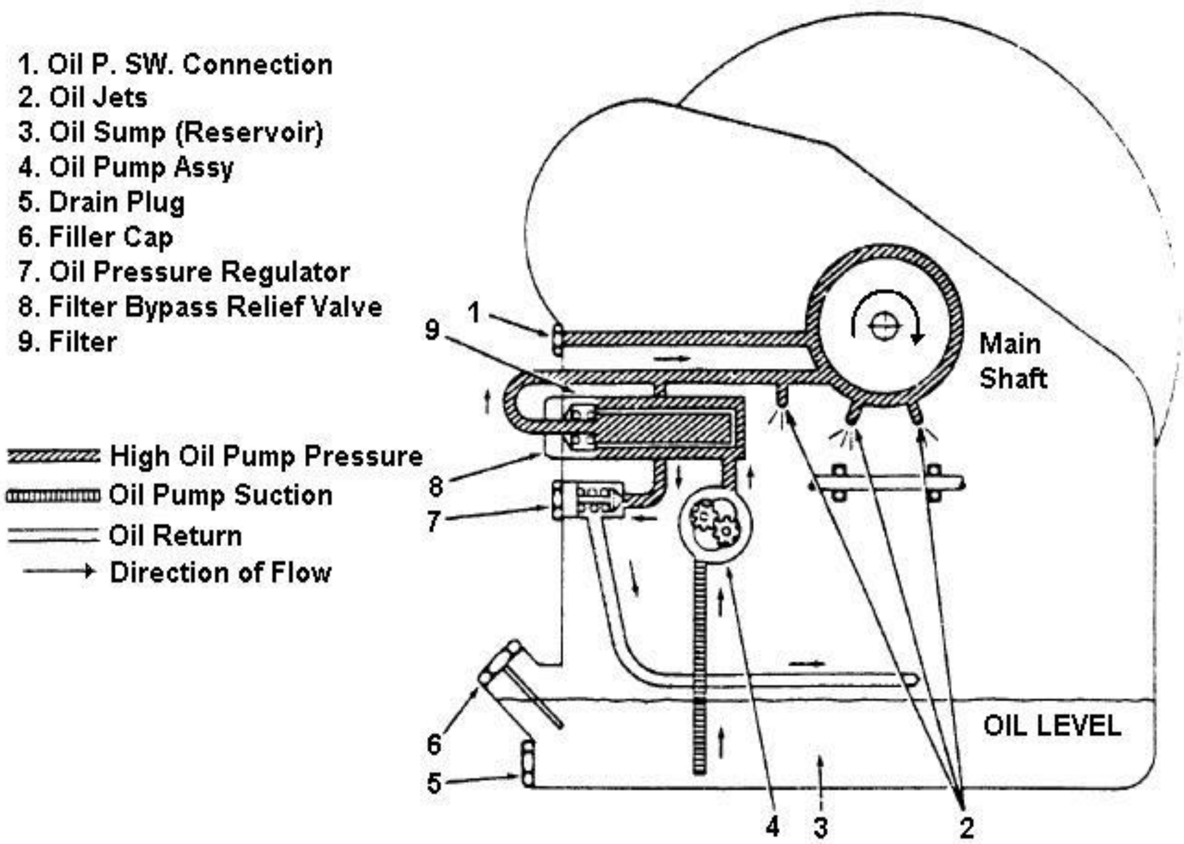
The main shaft bearings in a small gas turbine engine run at very high speeds, for this reason lubrication is very important to ensure a reasonable life expectancy. The high-speed bearings in a small gas turbine are normally lubricated by jets or orifices that meter quantities of oil directly on to the ball races as they rotate. These jets are often very fine (Less than 1mm OD) and so effective filtration of the oil is important, the bearings themselves are also be relatively small and sensitive to particles foreign matter.

The quantity of oil fed to the high-speed bearings must be kept within certain limits, if excessive oil is supplied to them, it has a detrimental effect on the bearing performance. The bearing is rotating at very high speed, the bearing cage will also be turning very fast, too much oil can restrict its movement and cause the balls to "Skid" instead of "Roll" between the races. The dynamics of the lubrication systems in small engines can be tricky to perfect.

Complete gas turbine oil systems fall into two basic categories, a dry sump system and a wet sump system. The wet and dry sump oil systems are similar to that which can be applied to piston engines.

Typical wet sump oil system

Oil is stored in a cavity that forms part of the main engine gearbox casing. The oil is drawn through a scavenge filter and into a pump mounted close by. Oil pumps normally consist of a gear pump or a Gerotor/Trochoid type, in most cases the pump is driven at a relatively slow speed (3000-4000 rpm) via a train of gears from the engine compressor shaft. The oil system is fitted with a pressure relief valve that regulates the oil pressure within prescribed limits and protects the pump form excessive pressures. An electrical pressure switch is often fitted to warn of low oil pressure, or a transmitter and electrical indicator combination may also be used.



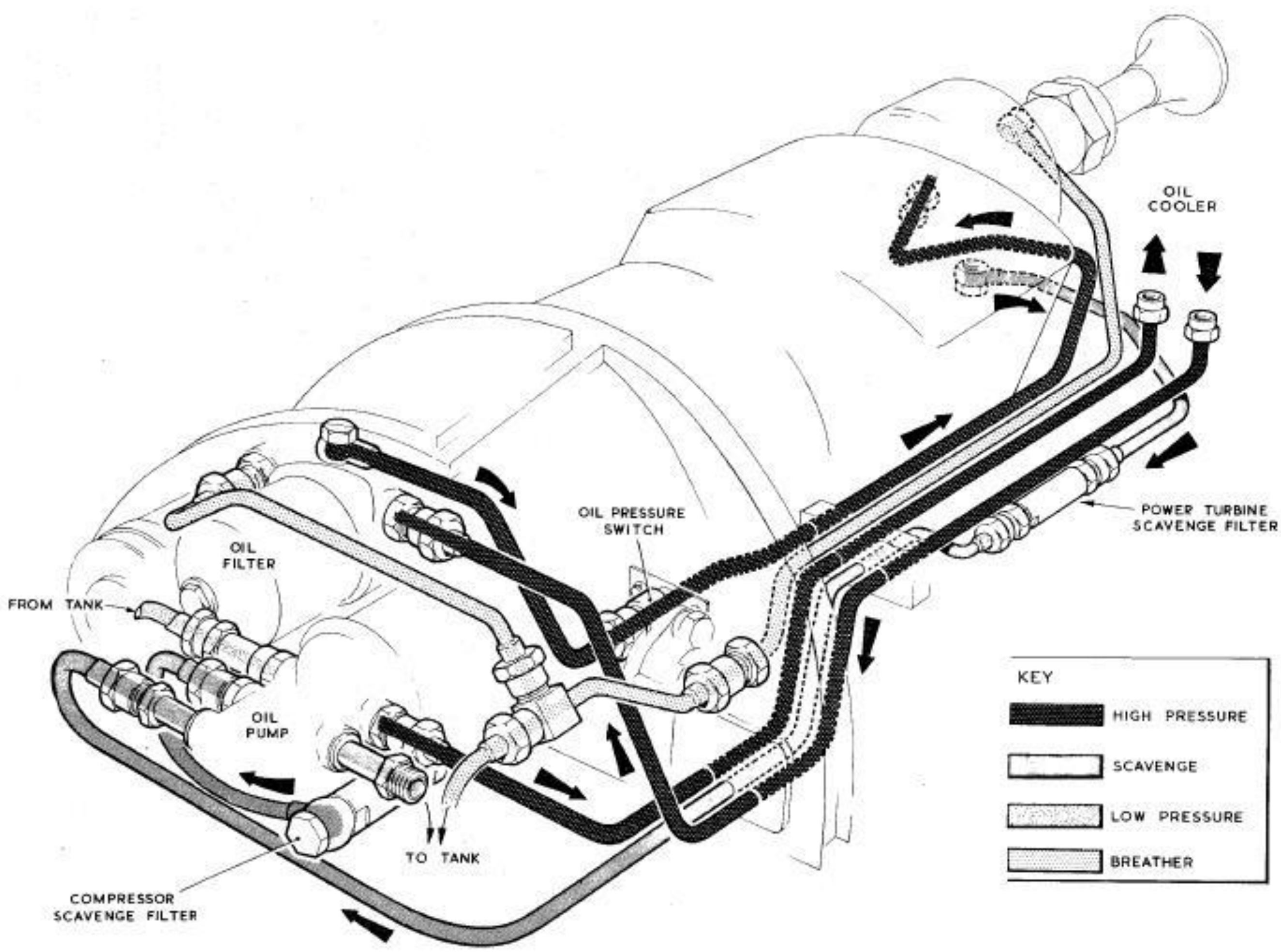
A small gas turbine engine fitted with a "Wet sump" lubrication system

The oil from the pump is then fed to a filter before distribution around the engine. Oil filters may consist of fine mesh types or a removable paper element type similar to automotive types. Any loss of oil pressure in a gas turbine engine is very critical and so some systems employ a bypass valve that opens should the filter become blocked. Oil from the filter is then distributed to the main engine high-speed components such as bearings and the high-speed gears. The slower rotating components inside the gearbox are splash lubricated by oil emanating from the high-speed components. The oil eventually drains under gravity into the sump cavity ready for re-circulation.

The advantage of a wet sump gas turbine is simplicity, a scavenge pump or pumps are not normally required, the oil simply drains into the sump at the bottom of the engine. The Rover 1S60 gas turbine engine employs this principal and so does the Garrett GTP30 engine. An oil cooler radiator device is sometimes fitted to the oil pressure feed, or the sump may be finned like a heat sink to aid the heat dissipation from the oil.

Dry-sump oil system

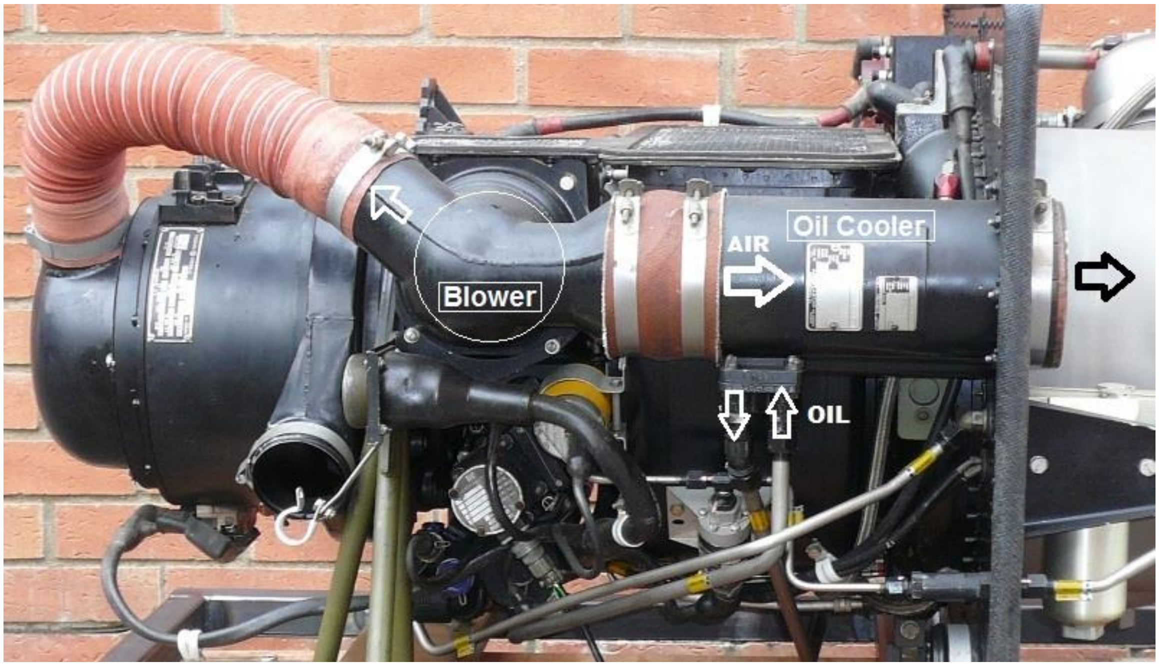
The dry sump oil system is the most commonplace gas turbine oil system. Oil is stored in a separate oil tank or reservoir that is mounted close to or the engine. Oil is drawn from the tank through a suction filter and into a pump that pressurizes it and then via another fine filter the oil is fed to the engine. A second pump of greater capacity to that of the pressure pump scavenges oil back from the engine bearings and gearbox, the oil is then returned to the tank. The increased return capacity is to ensure effective scavenging the oil becomes foamy and aerated and so occupies a greater volume. An oil cooler radiator may also be fitted in the return or supply line from the tank.



Dry-sump oil system

Many small gas turbine engines including the Microturbo Saphir, Lucas GTS/APU, Man Turbo 6012, Artouste and Palouste all employ a dry sump oil system. In a Palouste engine, two oil tanks are cast into the air intake assembly which helps cool the oil. Warm oil contained in the tanks placed near air intake region, have the added advantage of reducing the likelihood of ice formation in the air intakes in airborne installations.

Oil coolers



Oil cooler radiator fed from engine-driven blower

A great deal of heat is generated in small gas turbine engines, a portion of this heat is picked up by the circulating oil and needs to be dissipated. Oil coolers normally consist of a radiator type device that is cooled by airflow blown over it. The airflow may be provided in a number of ways. A motor driven or engine driven blower is used to cool the radiator, or the radiator is placed in the air intake of the engine where it is cooled by the ingested air. Another technique is to use compressor air bled from the engine. A jet of high-pressure air is ejected into a venturi that draws additional ambient air through it. The total airflow from the venturi is then passed through the oil cooler radiator.

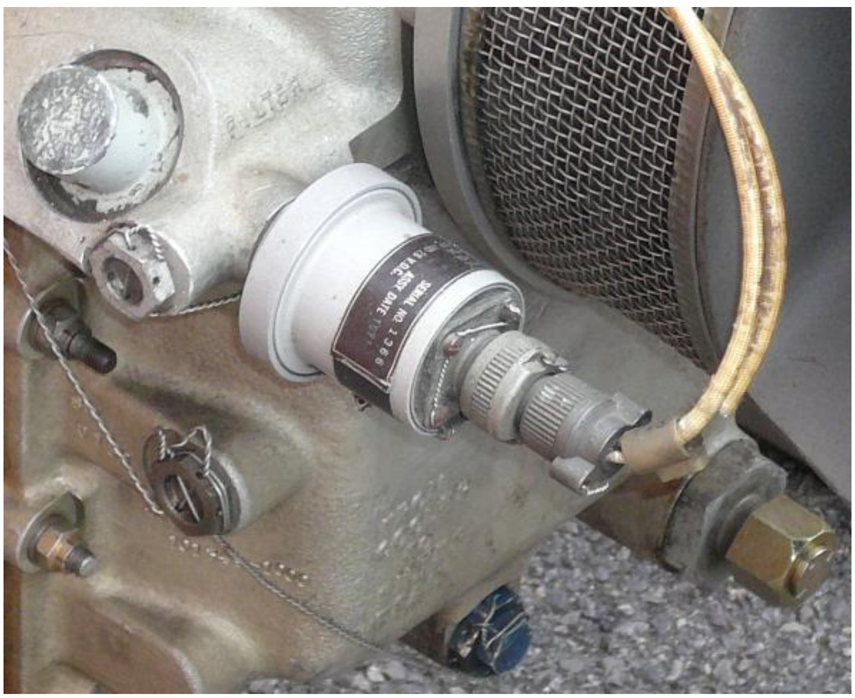
Rover 1S60 models that are employed to drive a fire pump make use of a special water/oil inter-cooler to reduce the temperature of the circulating oil.

Oil reservoirs

Oil tanks and reservoirs may often contain baffles or meshes. The returning oil may carry significant air in the form of bubbles and may have become foamy. A mesh structure will help the re-constitution of the oil as it drains into the reservoir. The reservoir is required to be vented to atmosphere or back into the gearbox cavity of the engine to equalize any built-up pressure.

Oil pressure switch

An electrical oil pressure switch is often placed in the oil circulation system so that falling pressure and hence failure of the oil system may be detected, and the engine shut down automatically.



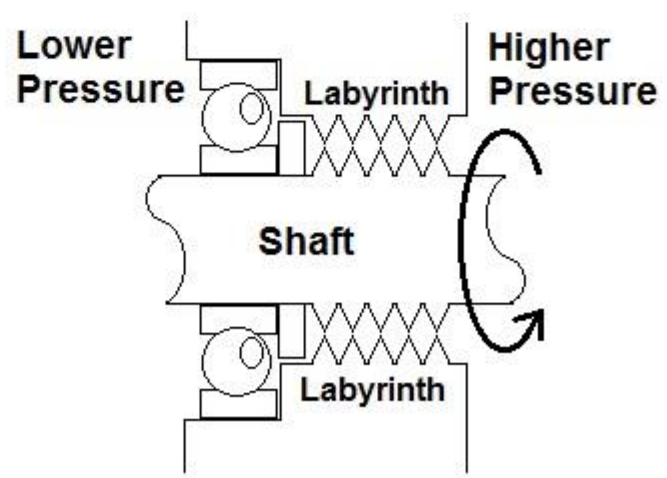
Oil pressure switch

Rotating seals

Inside small gas turbine engines there is a requirement to create rotating seals to prevent the unwanted passage of oil, fuel or air between various parts and assemblies. There are two main types that may be found inside a small gas turbine: The Labyrinth Seal and the Carbon Face Seal.

Labyrinth seals

A labyrinth seal consists of a rotating shaft or drum that has fine circular grooves cut into it. The shaft then rotates inside a similar cylinder that may also have grooves cut around its inside circumference. To ensure fluid such as oil or fuel does not pass from one end to the other of the seal, it is arranged that one side of the seal is pressurized with compressor air. The resulting pressure drop across the seal prevents the passage of fluid in the upstream direction. A relatively small pressure drop is required to make the seal function, the balance of pressures though out the engine is important to ensure the pressure drop occurs in the correct direction and the passage of gas flows do not disturb the balance. A disadvantage of labyrinth seals is that when the engine is stationary no pressure drop exists across them and some leakage of fluid or oil may take place over a period, particularly if the oil reservoir is located above the axis line of the engine shaft.



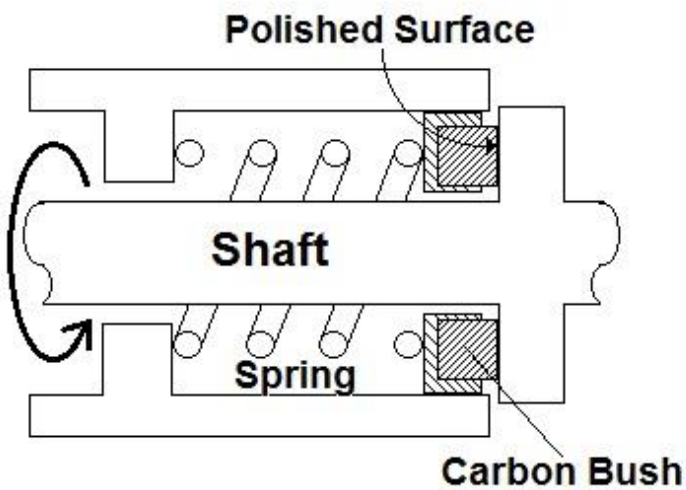
Labyrinth seal

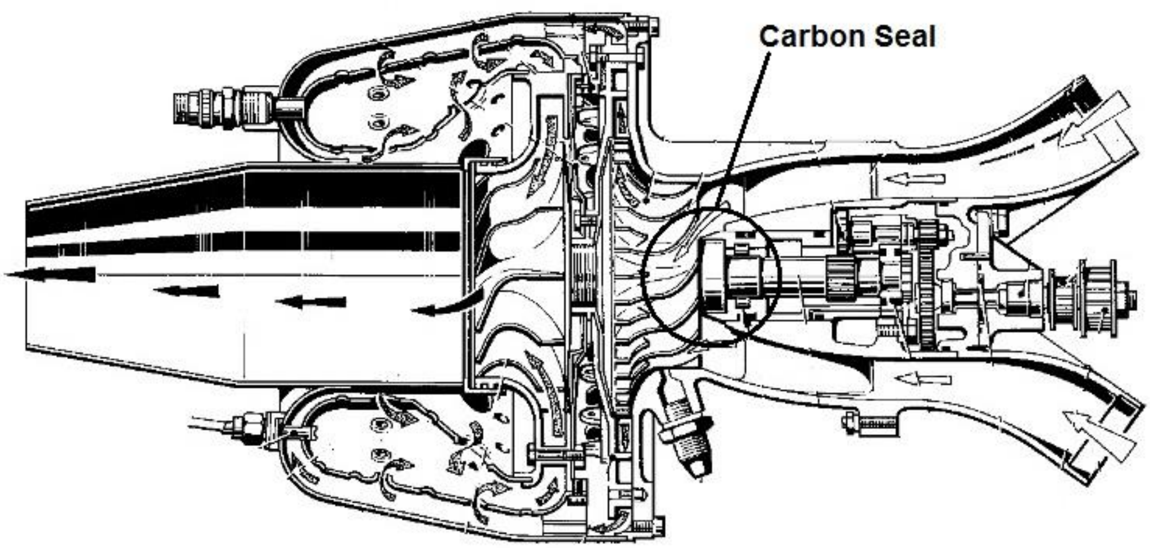
Carbon face seals

A type of seal that provides a positive sealing between moving components in a gas turbine engine is the carbon face seal. A carbon face seal consists of a polished steel disc that rotates with the shaft, a spring-loaded bush made of carbon runs up against the disc.
The carbon bush contacts the disc and "Runs-its self in" creating a close running interface that seals the bush to the shaft. The spring-loaded bush may float slightly and it forms part of a piston arrangement running in a close fitting housing. Traces or fuel or oil reaching the seal will act as lubricant creating a low friction interface.

Carbon seals must be "run-in" after engine assembly or overhaul, a procedure for this is detailed in the engine overhaul manual. Great care is needed when handling carbon face seals, the carbon material is very hard and brittle and can be chipped or broken easily. If a carbon seal is to be re-used (Not likely to be recommended by the manufacturer) then it must be taken care off and protected against contact with components other than the metal face seal itself.

Carbon seals are commonplace in small gas turbine engines but are generally very specialized items in other fields. Carbon face seals may sometimes be found in such technologies as vacuum pumps and air conditioning compressors.





Carbon seals

Carbon shaft seal (turbine wheel removed-Plessey Solent MK101)

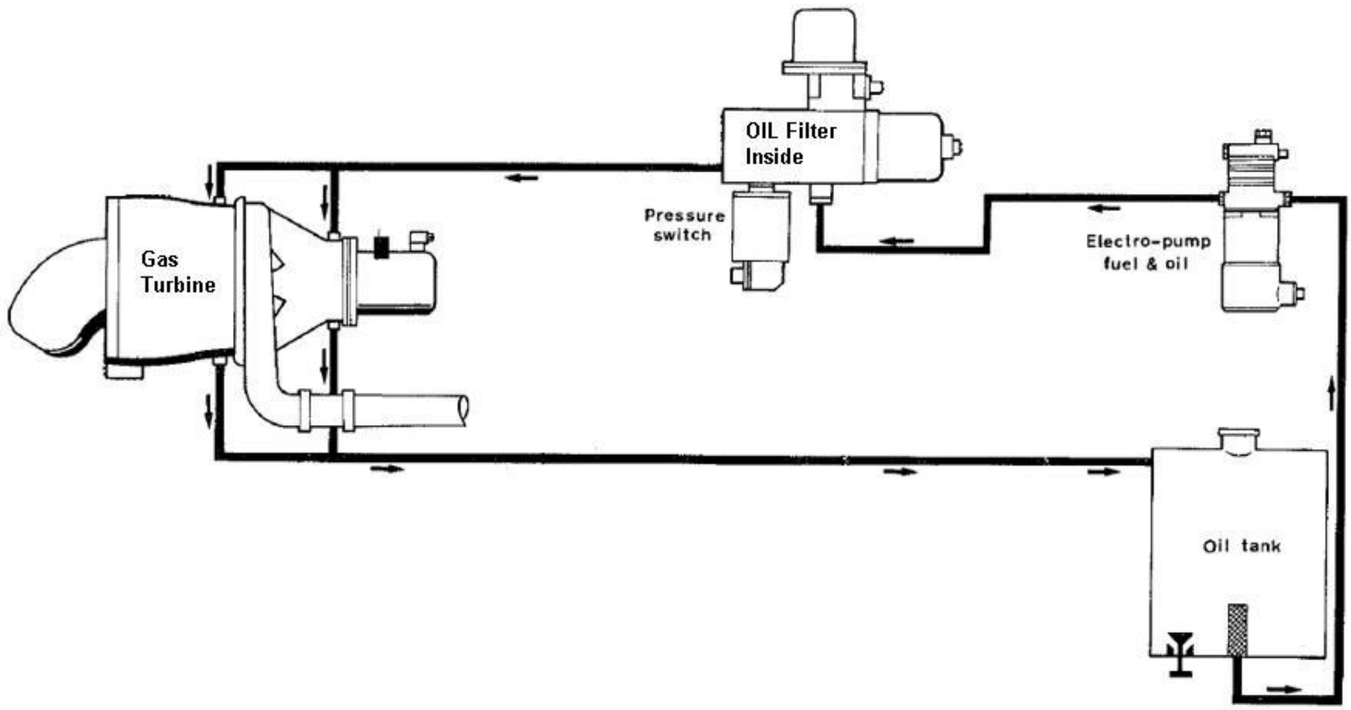
Oil damped bearing carrier system

A common bearing support arrangement found in many British built engines is known as a "Squeeze film damped bearing". The bearing carrier surrounding the outer race forms a piston assembly that acts as a sleeve. The sleeve is carried in a cylindrical mounting and seals are placed around it. A small gap exists between the sleeve and the cylinder walls, this area is pressurized with lubricating oil and a small radial movement is allowed. The sleeve is mounted at one end by a series of fingers that act as leaf springs that allow for the radial movement but otherwise hold the assembly rigidly in place and prevent it from rotating. This arrangement augments smooth running and dampens the rotating assembly preventing excessive resonances and vibration at the critical rotational speeds.

Bearing carrier mounted as oil-damped sprung piston

Microturbo Saphir

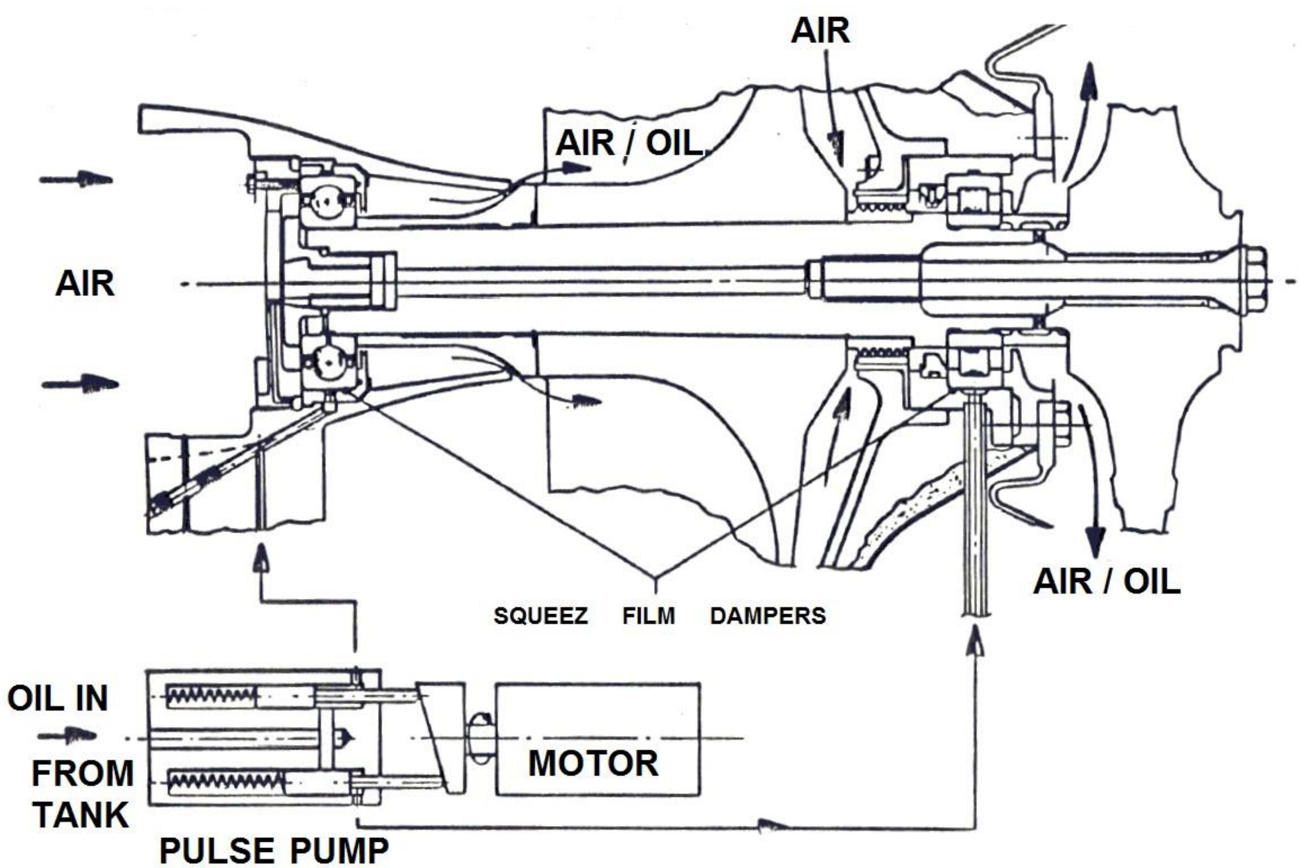
The Microturbo Saphir APU uses an electric motor driven pump to circulated oil around the engine. The pump shares the same motor with the fuel pump, and so if failure occurs of the motor, the engine will safely shut down. This arrangement greatly simplifies the mechanical design of the engine reduction gearbox as no accessory drives are needed except that of the starter. The pump (In this case a gear pump) is fitted with a pressure relief valve that sets the pressure of the oil delivery to the engine. A separate housing (Shared with the fuel metering valve) carries a small oil pressure filter and pressure switch.



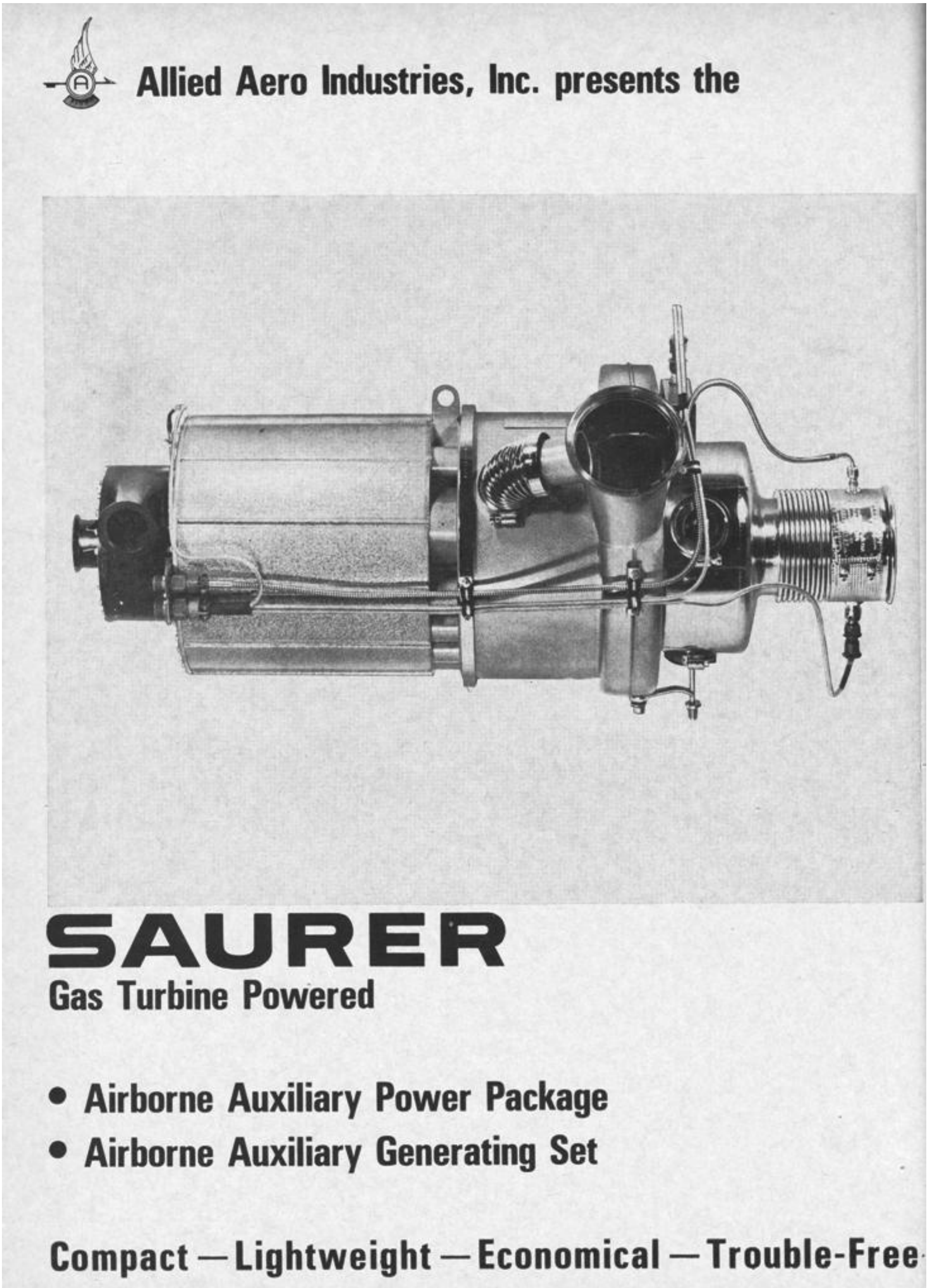
Gas turbine lubricating oil flow circulated by a motor driven pump

NPT301

The NPT301 turbo-jet engine that was briefly manufactured in the late 1980s employed a small reciprocating oil pump to supply oil to the engine bearings. The reciprocating type pump was operated by an electrical motor and with a pulsating action delivered small-metered quantities of oil to the bearing system. There was no return system, the oil was simply lost to the engine gas stream and so could be described as a total-loss oil system.



NPT301 turbojet oil system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