8 Power Augmentation Devices

8.1 General

In normally aspirated engines the throttle sets the manifold pressure, and the manifold pressure will always be lower than the ambient pressure due to losses in the air induction system. For a given throttle setting the manifold pressure, and therefore the power, will decrease as altitude increases, because ambient pressure decreases with altitude, see black dotted line in *fig. PO 8.1.*

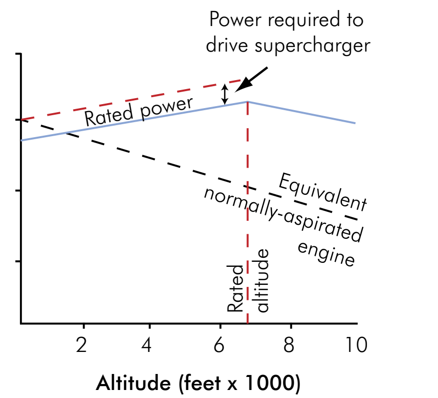

Fig. PO 8.1 Power curves for an altitude boosted single speed supercharger

Power will be increased if the manifold pressure is increased, since more air and hence more fuel can be burned per unit time. The power increases because more chemical energy is released per time unit. An increased manifold pressure can be obtained with turbochargers or superchargers. These units are called power augmentation devices.

A supercharger is an internal centrifugal compressor mechanically driven from the engine crankshaft, usually through a gear train.

A turbocharger is an external centrifugal compressor driven by an exhaust turbine.

Superchargers

A power augmented engine can deliver more power for a given cylinder volume and RPM than a normally aspirated engine, but the engine has to be designed to withstand the higher power. A supercharger requires power from the engine to turn the impeller and compress the air-fuel mixture, but this is more than compensated for by the power gained by the increased air density in the induction system.

An engine where maximum allowed sea level manifold pressure is higher than ISA sea level pressure is called a groundboosted engine.

An engine where max allowed MAP is the same as ISA sea level pressure, but allowed MAP is higher than ambient pressure at altitude is called an altitude boosted engine, *see fig. PO 8.1 and fig. PO 8.2.*

An engine with a single speed geared supercharger is a groundboosted engine. This means that the sea level rated power has been

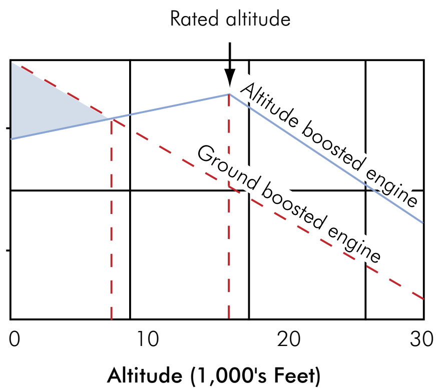

Fig. PO 8.2 Graph showing comparison between ground and altitude boosted engine

increased by the use of the supercharger, but the power decreases as the aircraft gains altitude, *see fig. PO 8.2.* There are a number of ways that sea level power can be maintained at a specified altitude using superchargers.

Turbochargers

The most efficient method of increasing power on modern aircraft engines is, however, by the use of turbochargers. The advantages of a turbocharger is that it has an infinitely variable drive; it utilises the engine exhaust gases, which account for about a third of the energy of the fuel; and utilises an energy source that would usually be wasted. A typical turbocharger installation is shown in *fig. PO 8.3.*

The turbocharger comprises a turbine, driven by the exhaust gasses and a compressor driven by the turbine through a shaft. Controls, which limit the speed of the turbo-charger assembly, prevent over pressurising of the induction manifold. This is done by the matching of the output requirement and the amount of exhaust gasses passing through the turbine. This will control the

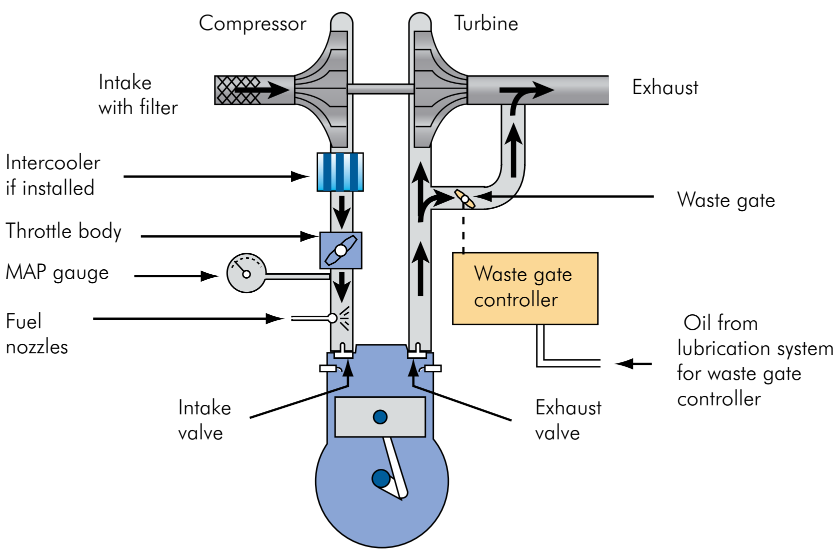

Fig. PO 8.3 Typical turbocharger installation for an injection engine turbine and compressor speed. At sea level rated power can be maintained up to a certain altitude. Maximum altitude at which rated power can be achieved is called the critical altitude, *see fig. PO 8.4.*

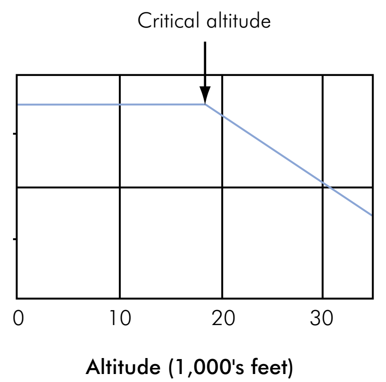

Fig. PO 8.4 Effectiveness of a turbo charged engine

It is usual for turbocharged engines to be ground boosted. There is a critical altitude for every power setting. At the critical altitudes the waste gate is fully closed and maximum turbocharging occurs.

Intercooler

The temperature of the air increases when it is compressed. The discharge air from a supercharger or turbocharger is therefore considerably hotter than the inlet air. If the discharge air is too hot, the temperature of the air/fuel charge may become too high and cause pre-ignition or detonation. The exhaust temperature may also become too high causing damage to the exhaust valves. Many power augmented engines are therefore equipped with an intercooler, *see fig. PO 8.5.*

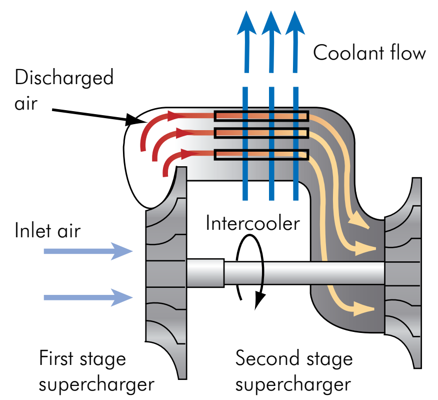

Fig. PO 8.5 Intercooler working principle

The intercooler cools the compressor outlet air. This also increases the density without reducing the pressure. The intercooler is a heat exchanger. It consists of many tubes in parallel. The hot compressor air flows through the tubes, while ambient air passes over the outside surface of the tubes. The ambient air absorbs heat from the hot air in the tubes and the compressor air gets cooled to a suitable temperature.

8.2 Turbocharger Controls

The power increase must be kept under control otherwise it would become excessively high at high turbocharger speeds. The turbocharger speed increases with increasing exhaust gas flow and its speed can be controlled by letting part of the exhaust gases bypass it. Engines with turbochargers therefore have a bypass with a valve called a waste gate. If the exhaust gas flow tends to get too high, the waste gate opens and more of the exhaust gas bypasses the turbine. The wastegate can either be manually or automatically controlled.

Manually Controlled Waste Gate

If the waste gate is manually controlled, it is controlled by the pilot, most often via a knob in the cockpit which is connected by a cable directly to the wastegate. It is imperative that the flight manual instructions are closely followed.

Once again, if wastegate control is purely manual, it is vital to open the wastegate progressively during descent, otherwise the engine may be overboosted when the throttle is opened.

Automatically Controlled Waste Gate

In automatically controlled waste gates, either the pressure delivered by the compressor, the manifold pressure after the throttle valve, or both are used to control the waste gate position in conjunction with engine oil pressure.

Normally a spring tries to drive the waste gate to the full open position and engine oil is used as an actuating medium to drive it to the closed position through an actuator. The oil is piped from the engine oil pump to the actuator, *see fig. PO 8.6.* The oil flow into the actuator is limited by a restrictor. From the actuator the oil flows to a controller and from the controller back to the sump. The controller acts on the principle that increasing air pressure (compressor or manifold) increases the oil flow through it and back to the sump. This reduces the oil

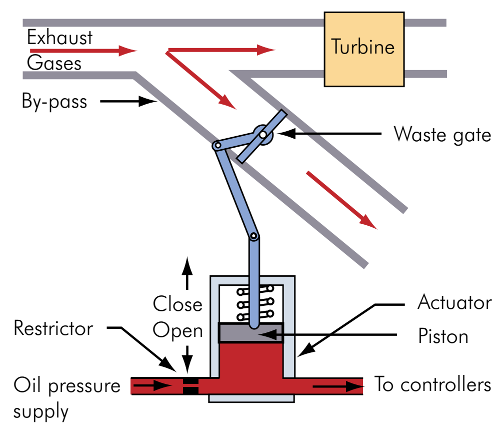

Fig. PO 8.6 Basic control and operation of waste gate

pressure in the actuator causing the waste gate to go more open. A greater amount of the exhaust gases then bypasses the turbine, causing the compressor to deliver less air.

Automatic wastegate control will close the wastegate during climb and open it during descent (Power On condition).

When a low engine power is selected, the wastegate will usually be closed at both low and high altitude. This is because little exhaust gas is available and none can be wasted as the controller attempts to maintain particular discharge conditions from the compressor.

If, whilst flying at high altitude, an automatically controlled wastegate seized closed, or was held closed by a faulty controller, the engine could be overboosted during descent if the throttle was not closed.

There are different types of controllers:

- Absolute pressure controller
- Variable pressure controller
- Dual Control System
- Density controller
- Differential pressure controllers.

Absolute Pressure Controller *(See fig. PO 8.7)*

This is the simplest governing device that allows the compressor delivery pressure to be maintained at a constant value up to the critical altitude. It consists of an aneroid capsule subjected to compressor discharge pressure and an oil bleed valve in the return oil line from the waste gate actuator. The aneroid capsule controls the variable orifice oil bleed valve.

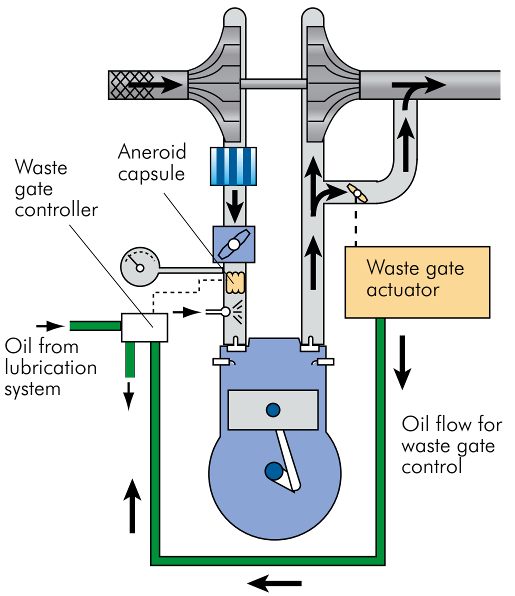

Fig. PO 8.7 Absolute pressure controller

As the throttle is opened towards full power (rated), the turbocharger increases its output until the compressor discharge pressure rises to its maximum permissible value. At that pressure, the aneroid capsule opens the variable orifice bleed valve and oil is bled away from below or to the left of the actuator piston, and spring pressure prevents any further closing of the waste gate. Turbine/compressor RPM and output will be stabilised.

Should manifold pressure (MP) tend to rise above maximum, oil will be bled away from the bottom or left of the actuator piston and spring pressure will open the waste gate to reduce the manifold pressure to the maximum value.

This controller is sometimes called the fixed datum controller.

Variable Pressure Controller *(See fig. PO 8.8)*

Refinement to the absolute controller can be achieved as follows:

An aneroid capsule is subjected to the discharge pressure from the compressor. A cam, operated by a linkage from the throttle lever, applies pressure to the end of the aneroid capsule and the oil restrictor is actuated by the aneroid capsule. Opening the throttle will rotate the cam and an increased pressure will be applied to the aneroid capsule. The effect of this will be that the compressor discharge pressure increases until it is in balance with the increased pressure on the aneroid capsule.

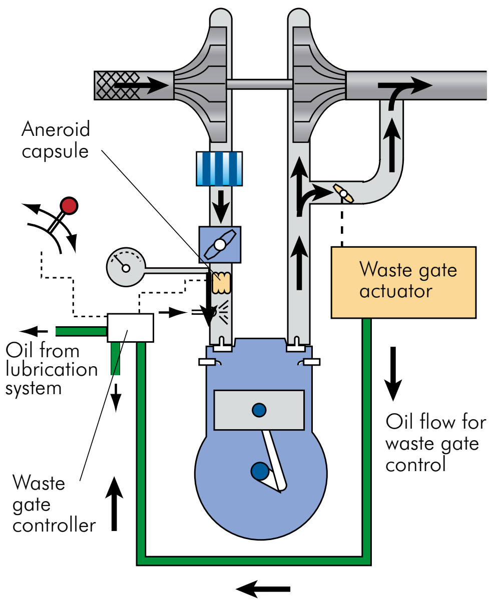

Fig. PO 8.8 Variable pressure controller

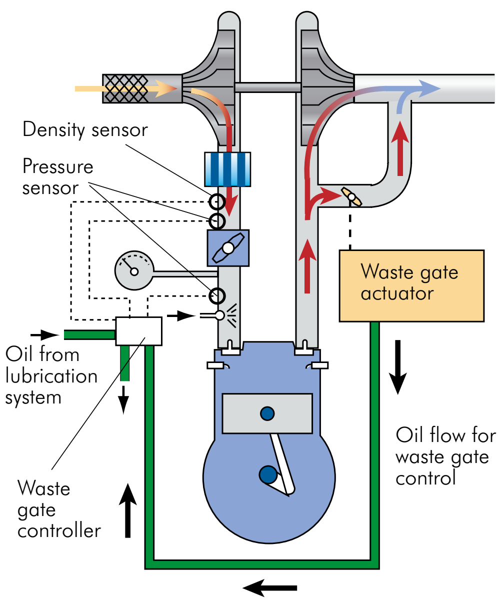

Fig. PO 8.9 Dual control system

Operation of the throttle to select a specific manifold pressure is matched with a suitable waste gate setting. The operation of the waste gate is as before. With the variable pressure controller the discharge pressure is maintained at 1-2 in Hg above manifold pressure. This relatively low differential pressure reduces the load on the turbocharger and the throttle valve.

Dual Control System *(See fig. PO 8.9)*

Ground boosted turbochargers require sophisticated control devices if they are to function safely and efficiently. A dual control system, comprising a density controller and a differential pressure controller are usually included.

- **Density Controller:**
  This controller is the same as the absolute controller mentioned earlier, with exception that the aneroid capsule is filled with dry nitrogen which is temperature sensitive. This means the capsule measures temperature and pressure and is thus measuring density. The density controller limits maximum Manifold Pressure (MP) up to critical altitude only. The aneroid capsule filled with dry nitrogen is subjected to manifold pressure and is sensitive to charge temperature. The capsule acts on the oil restrictor and the waste gate is controlled as before. The density controller prevents overboosting.

- **Differential Pressure Controller:** The differential pressure controller controls the waste gate at all positions of the throttle other than fully open, and responds to the pressure drop across the throttle valve. It is at its most effective, therefore, when the throttle is towards closed. Waste gate position and turbocharger output are related more effectively to engine power requirements. It is most effective in limiting temperature rise due to high manifold pressures, and this reduce the chances of detonation.

8.3 Waste Gate Position

During engine start up the waste gate will be in the open position to avoid excessive manifold pressure. At fully rated power at sea level the waste gate will be approximately full open.

During climb the waste gate will go more and more closed until an altitude is reached where the closed position is necessary to obtain full power. If the aeroplane climbs higher the waste gate will remain closed, but manifold pressure will begin to reduce.

If throttle setting is reduced to reduce power, the waste gate will tend to go more open since less compression is needed.

During descent the waste gate gradually goes more and more open as ambient pressure increases.

8.4 Manifold Pressure Relief Valve

This is a last ditch device that is located in the induction manifold, *see fig. PO 8.8.* This device is a basic poppet type valve that will open if overboosting occurs. It is fitted in some installations to cater for a stuck waste gate or mishandling.

8.5 Manifold Pressure Gauge

Manifold Pressure (MAP) and RPM determines the power and both must be held within the allowable limits. It is therefore necessary that both values are displayed to the pilot. The MAP gauge is graduated in Hg (inches of mercury) and displays the manifold pressure as an absolute pressure, e.g 29.92 at sea level ISA conditions when the engine is not running, *see fig. PO 8.10.* The working principles of a typical gauge is described in the “Instrumentation book”.