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Superchargers and turbochargers

The **power output** of an engine depends basically on the **weight** of mixture which can be burnt in the cylinders in a given time, and the weight of mixture which is drawn into each cylinder on the induction stroke depends on the **temperature** and **pressure** of the mixture in the induction manifold.

On a normally **aspirated** engine the **pressure** in the induction manifold at full throttle is slightly **less** than **atmospheric** pressure because of intake duct losses, and the manifold pressure **decreases** with any increase in **altitude**.

Power output therefore, **decreases** with **altitude**.

In order to **increase** engine **power** for take-off and initial climb, and / or to maintain engine power at high altitude, the manifold pressure must be raised artificially, and this is done by **supercharging**.

Superchargers and turbochargers

Where a supercharger is used to **increase** sea **level power**, rather than to maintain normal power up to a high altitude, the engine will need to be strengthened in order to resist the higher combustion pressure. This is called a **Ground Boosted Supercharger**.

Centrifugal Compressors are used in superchargers on aircraft engines and may be driven by either internal or external means, in some installations a combination of both may be used:

- Externally driven superchargers, known as turbo-superchargers or **turbo-chargers**, are driven by a **turbine** which is rotated by the exhaust gases and compress the air.
- Internally driven superchargers are driven by **gearing** from the engine crankshaft and compress the mixture.

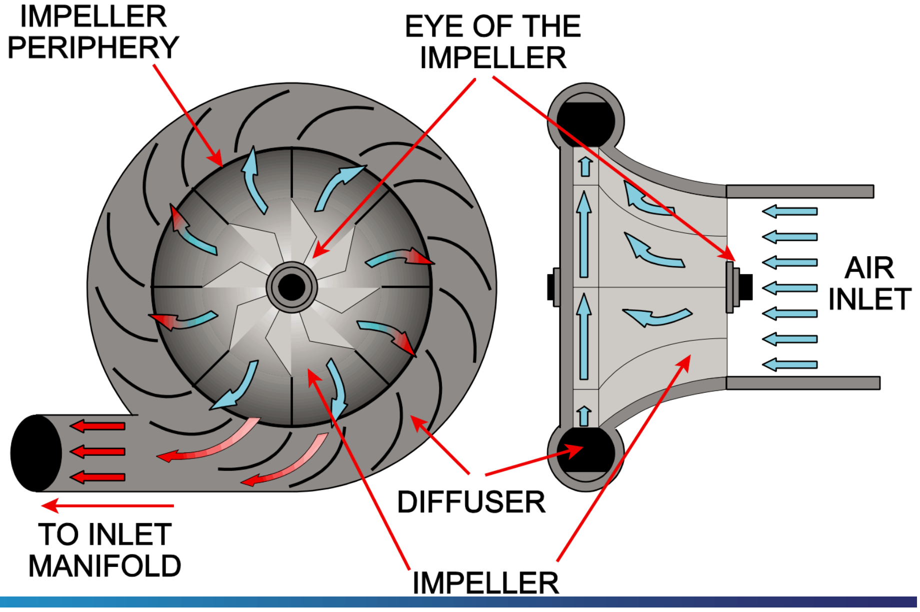
The methods of operation and control of these two types are quite different.

Centrifugal compressors

Centrifugal compressors are used because they are comparatively **light**, are able to run at **high speed**, will handle large quantities of air, and are robust and **reliable**.

A centrifugal compressor is made up of the **impeller** which is rotated and accelerates the air and the **Diffuser** which collects and directs the air into the manifold.

Air is drawn into the impeller as it is rotated. The air is **accelerated** as it flows outwards between the vanes (converting mechanical energy into kinetic energy) and, as the cross-section of its path increases, **pressure increases**.



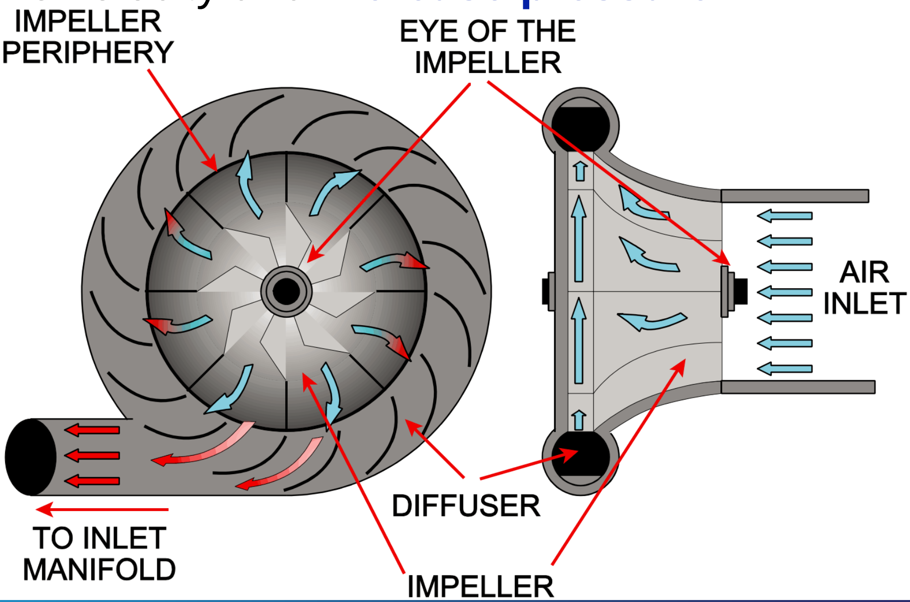
Centrifugal compressors

The pressure gain in the impeller depends on the impeller's **diameter**, speed of **rotation** and the **shape** of the vanes.

Air leaves the impeller with considerable tangential and radial velocity and passes into the diffuser made of a number of vanes fixed between the walls of the supercharger casing. The diffuser vanes are **divergent** passages, which decrease the velocity and **increase pressure**.

Rapidly compressing the air increases its temperature.

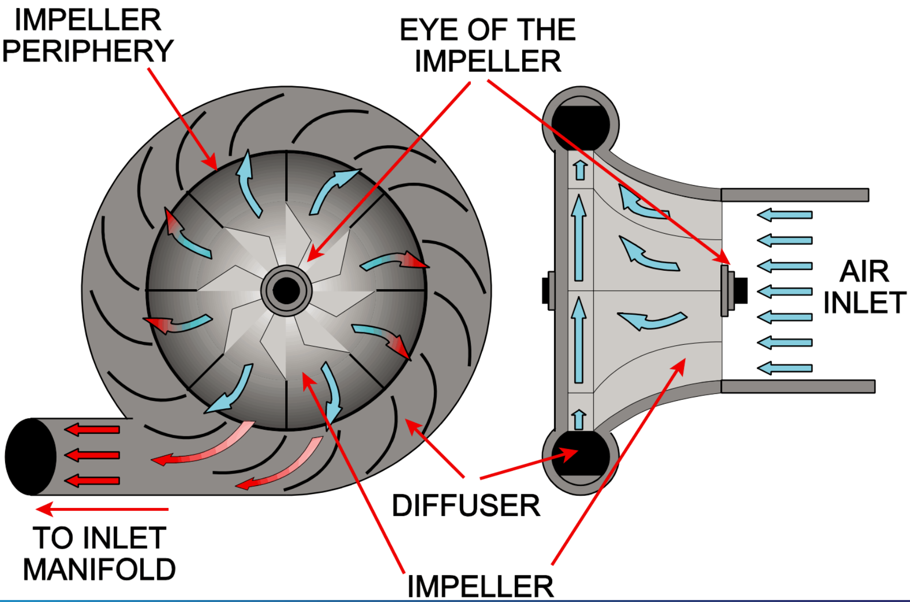
Using an **Inter-Cooler** or **spraying** the fuel into the eye of the impeller, so that **vaporization** will reduce air temperature, can be used to increase the density.



Centrifugal compressors

At a particular **speed** of rotation a centrifugal supercharger increases the pressure of air passing through the impeller in a **definite ratio**.

Physical constraints limit the speed of rotation and size of an impeller, and so limit the pressure rise or Pressure Ratio and consequently, the power output or maximum operating altitude of the engine to which it is fitted.



Centrifugal compressors - Manifold Pressure

Any engine with a supercharger will also be equipped with a **variable pitch** propeller controlled by a constant speed unit. The RPM of the engine is therefore controlled by the propeller pitch lever. To properly set the power and prevent the engine being overboosted the pilot must have an indication of the pressure is allowing into the cylinder with the throttle. This is known as manifold pressure (between the throttle valve and the inlet) and is indicated to the pilot on one of two gauges:

- **Boost Pressure** - the pressure in the induction system relative to sea level standard pressure is called boost pressure, and is indicated by a gauge in the cockpit.
- **Absolute Pressure** - American practice is to use the term Manifold Absolute Pressure (MAP) for measuring the pressure in the induction system.

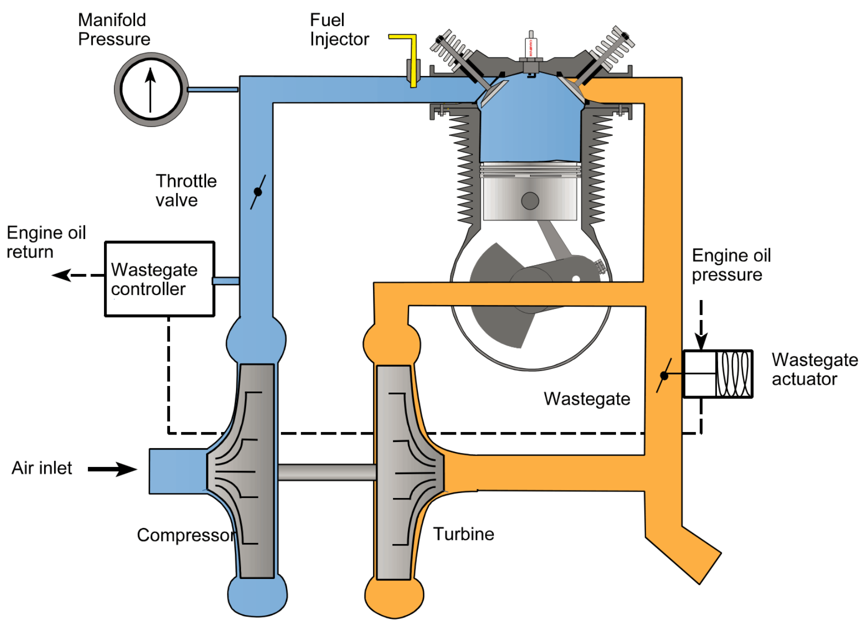
Externally driven superchargers (turbo-chargers)

Externally driven superchargers are powered by the energy of the engine **exhaust gases** and are generally known as turbo-superchargers or **turbo-chargers**.

A turbo-charger consists of a **turbine wheel** and an **impeller** fitted on a common rotor shaft, the bearings are lubricated by oil from the engine.

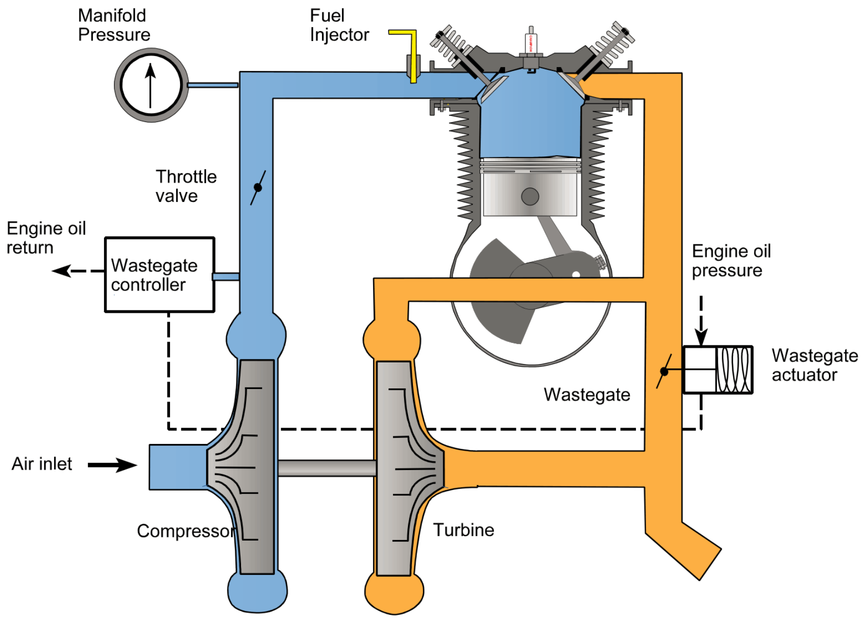
The **turbine** is connected to the **exhaust** system and the **compressor** is connected to the **intake** system.

The turbo-charger is not necessarily an **integral** part of the engine, but may be mounted on the engine or on the fire-proof bulkhead, and shielded from combustible fluid lines in the engine bay.



Externally driven superchargers (turbo-chargers)

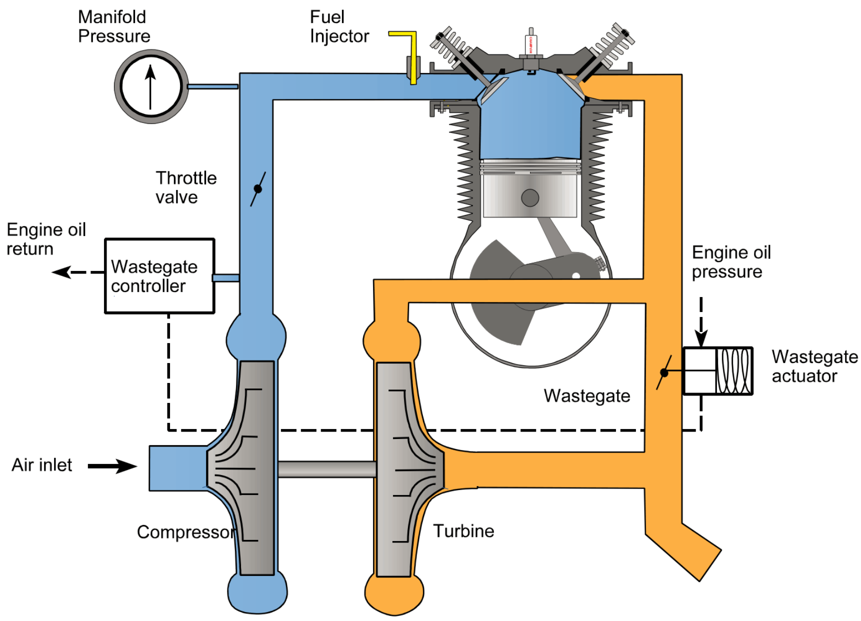
Exhaust gases pass through nozzles and are guided onto vanes on the turbine wheel, causing it to rotate, the gases then pass between the vanes and are exhausted overboard. The **more exhaust gasses** that are diverted over the turbine the **faster** it will go and therefore the faster the impeller will go and the **greater** will be the **pressure ratio** of the **compressor**.



Externally driven superchargers (turbo-chargers)

For any particular power output the turbo-charger must deliver a **constant flow rate** to the engine, and, since the density of air decreases with altitude, the **impeller rotates faster** as the aircraft **climbs** to compensate for the reduction in density and maintain a selected manifold pressure.

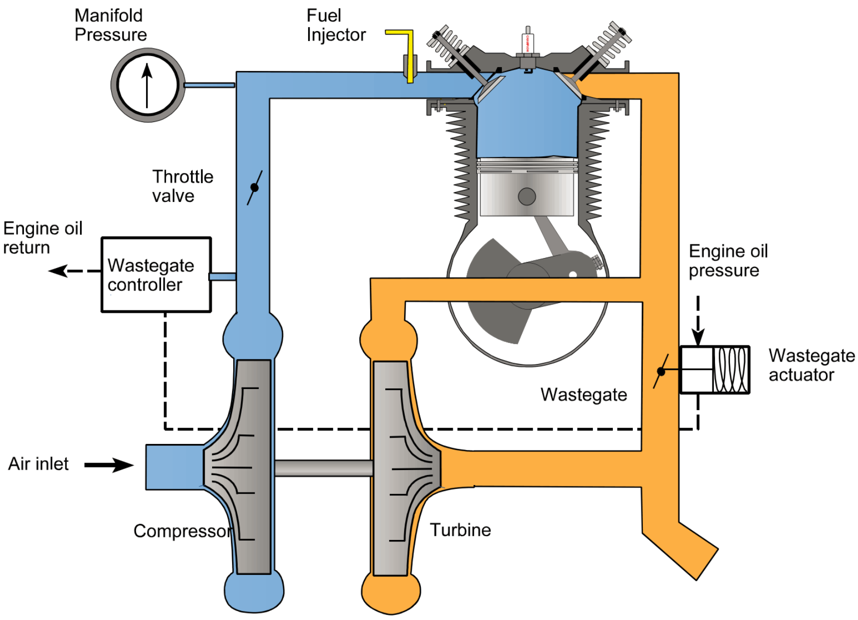
Some form of **control** over compressor output must be provided, and this is done by **varying** the quantity of exhaust gas **passing** to the **turbine** to vary its speed and that of the compressor.



Externally driven superchargers (turbo-chargers)

A turbine by-pass, in the form of an alternative exhaust duct, is fitted with a valve (known as a **waste gate**) which regulates the degree of opening through the by-pass.

When the **waste gate** is fully **open** nearly all the exhaust gases pass directly to **atmosphere**, but as the waste gate **closes** gases are directed to the turbine, and the **maximum rotor speed** is achieved when the waste gate is fully closed, this will happen at what is termed the **critical altitude** for that engine and that turbo-charger (the height above which maximum boost or absolute manifold pressure can no longer be maintained).



The waste gate may be controlled **manually** by the pilot, but in most turbo-charger systems **automatic** controls are fitted to prevent over-boosting the engine.

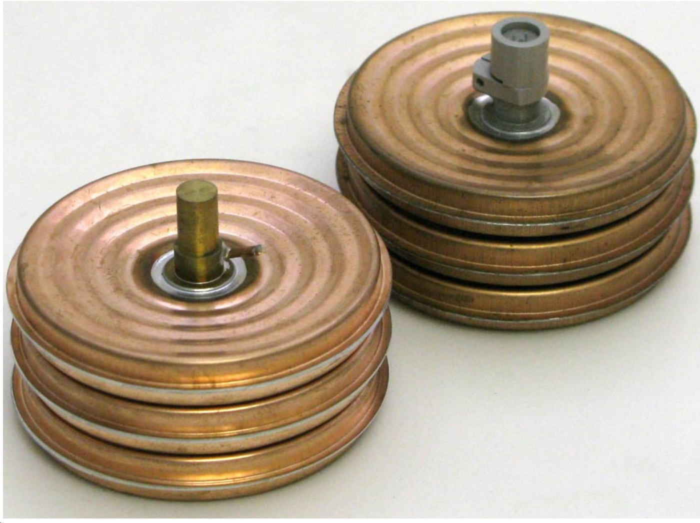
In an automatic control system, the waste gate is mechanically connected to a single acting actuator, the position of which depends on the **opposing forces** of **spring** (open) and **engine oil pressure** (close). Thus oil pressure in the actuator regulates the position of the waste gate according to engine requirements.

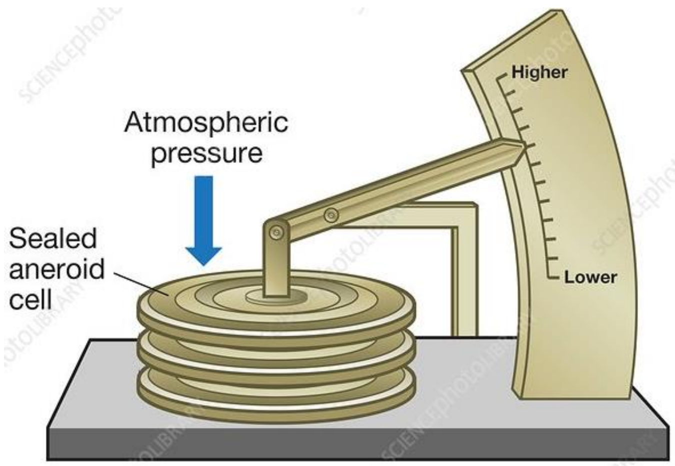
Various types of **controllers** may be used to vary the waste gate actuator oil pressure:

- Absolute Pressure Controller (APC)
- Variable Pressure Controller (VPC)
- Density Controller (DC)
- Differential Pressure Controller (DPC)
- Rate of Change Controller (ROC)
- Pressure Ratio Controller (PRC)

Absolute Pressure Controller

The APC, that prevents the compressor outlet pressure from exceeding a specified maximum, uses an **aneroid capsule** sensitive to compressor outlet pressure to control the oil bleed from the wastegate actuator.

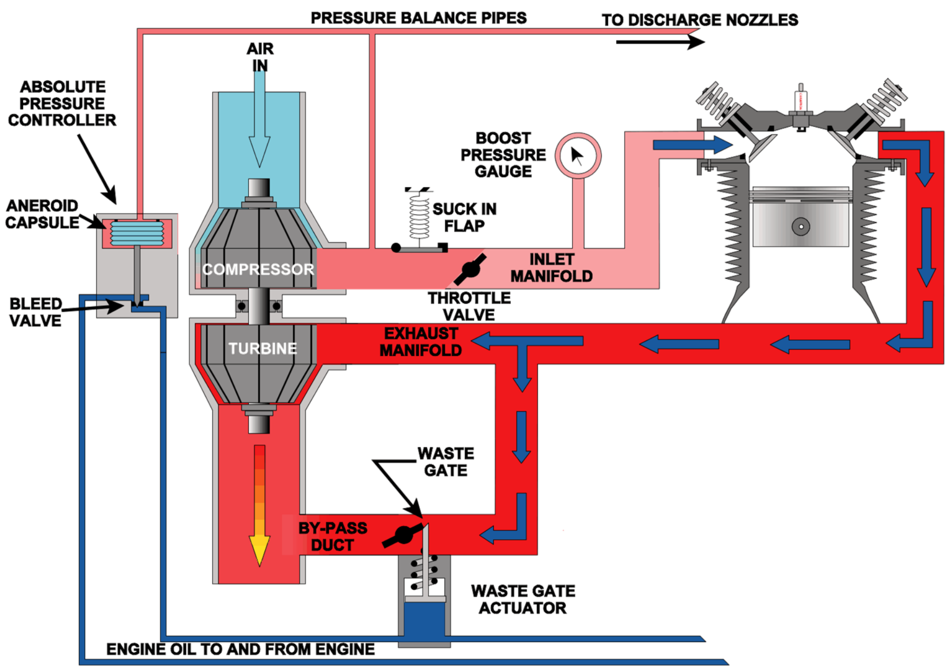




Absolute Pressure Controller

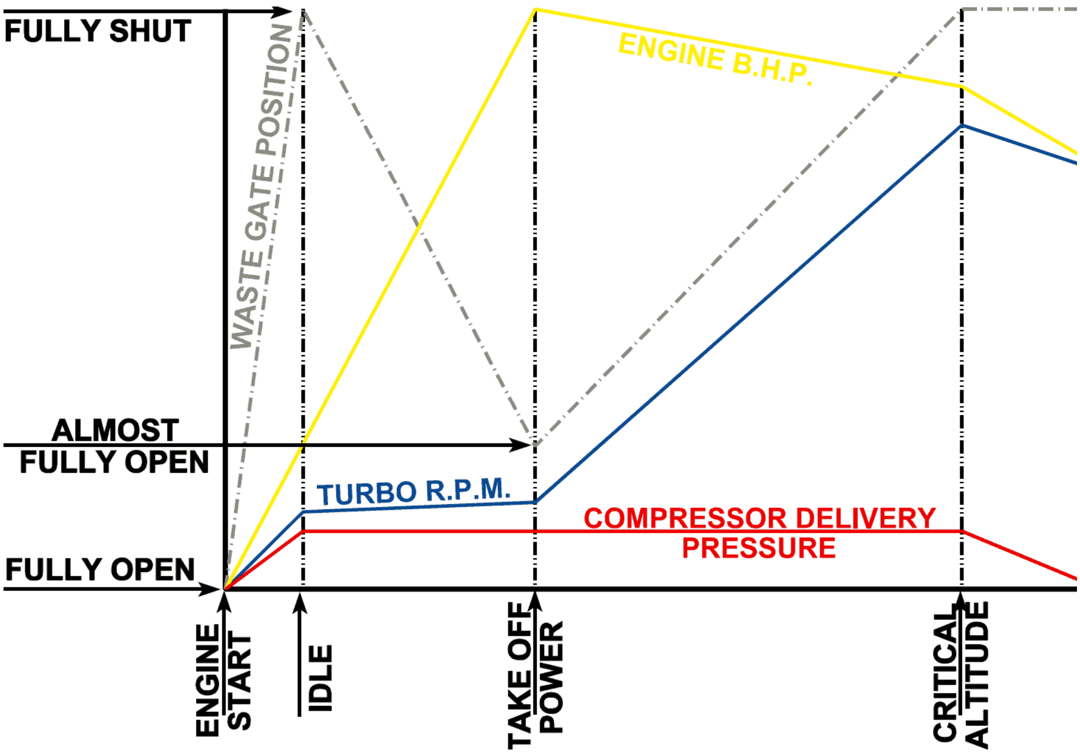
The **throttle** then controls manifold pressure. At low power settings full oil pressure is applied to the waste gate actuator, which closes the waste gate and diverts all exhaust gases through the turbine to maintain the compressor outlet pressure at the designed value.

The **oil** which is used to **move** the piston in the waste gate is taken directly from the engine lubrication system, this oil is also used to **cool** and **lubricate** the turbo-charger bearings.



Absolute Pressure Controller

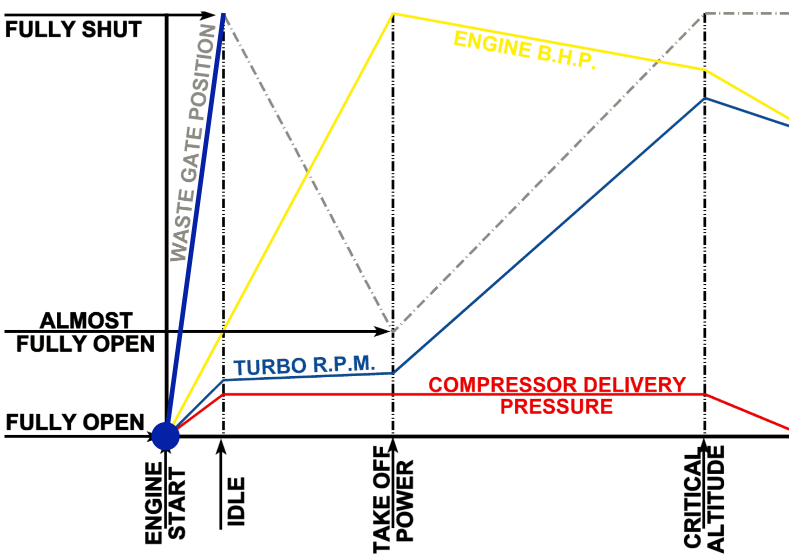
The **position** of the waste gate throughout the running of an engine from start to critical altitude, including engine power output, turbine speed, and the manifold pressure are all shown in the Figure.



Absolute Pressure Controller

Prior to start, the waste gate must be **open** to allow the free flow of exhaust gases to atmosphere, otherwise the engine would be very difficult, to start. This opening is achieved by the spring in the Waste Gate Actuator which forces it fully open.

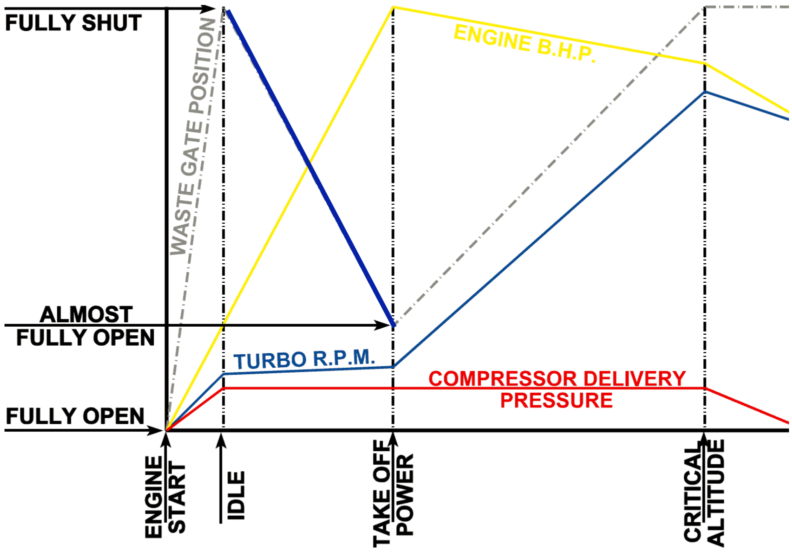
Immediately after start, there is not enough exhaust gas to spin the turbine fast enough to create the required pressure at the outlet of the compressor. The **Aneroid Capsule** will therefore be **expanded**, closing the Bleed Valve in the APC), trapping oil within the waste gate actuator causing its piston to **close** the waste gate fully.



Absolute Pressure Controller

Upon **opening** the **throttle**, sufficient exhaust gas will be produced to turn the turbine at a speed that will enable the compressor to achieve more than the **required pressure** at its outlet. This increased pressure is sensed at the APC and oil is released through the Bleed Valve from within the Waste Gate Actuator, thus allowing its internal spring to start opening the Waste Gate. The waste gate will continue to open as the throttle is opened, until at full throttle at ISA sea level pressure it is **almost** fully open.

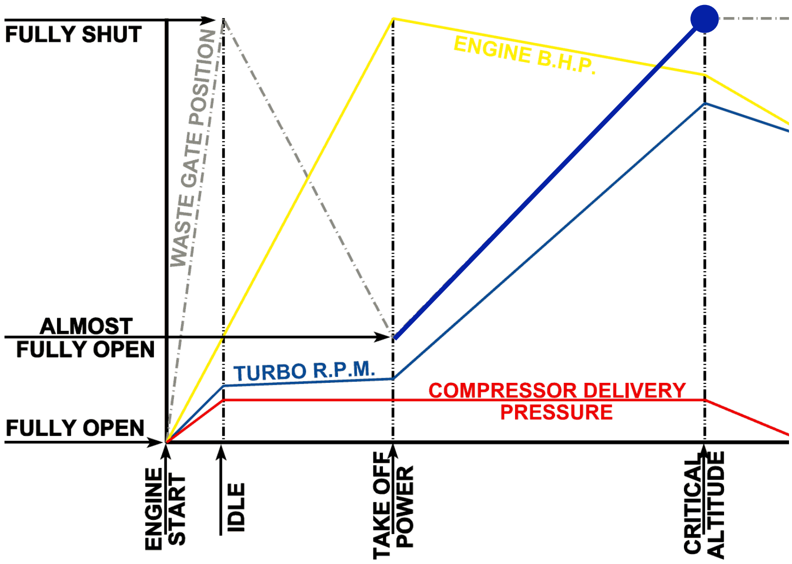
The extra waste gate opening is required to cater for those days when the ambient **pressure** is **greater** than ISA, without the opening there would be no way to maintain the compressor outlet pressure within limits.



Absolute Pressure Controller

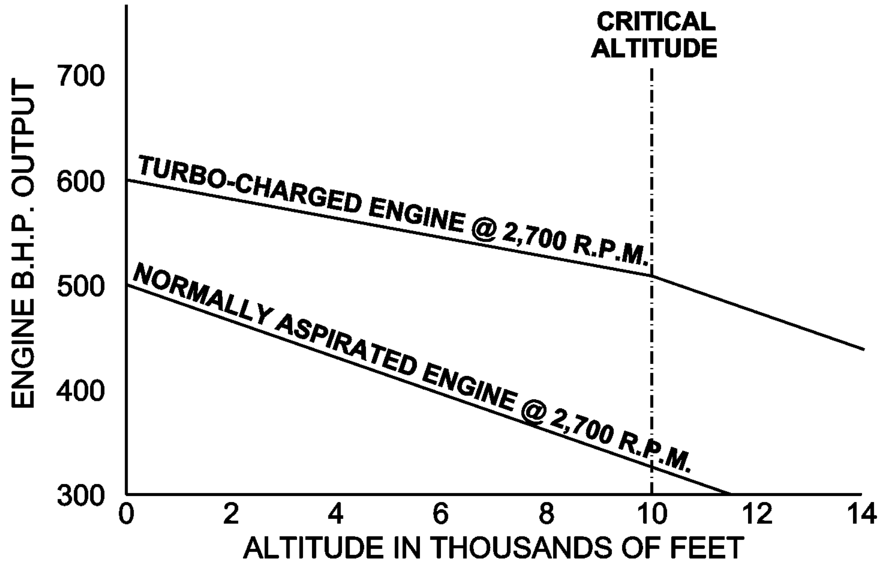
From the moment of take off, and **throughout** the **climb**, the **pressure** at the compressor inlet **falls**, causing its outlet pressure to fall also. This drop in outlet pressure is signaled to the APC, which **closes** the bleed valve trapping oil in the waste gate actuator causing it to progressively close the waste gate.

Eventually the Waste Gate will be fully shut and no more increase in turbine speed is possible, this is termed the **Critical Altitude**.



Absolute Pressure Controller

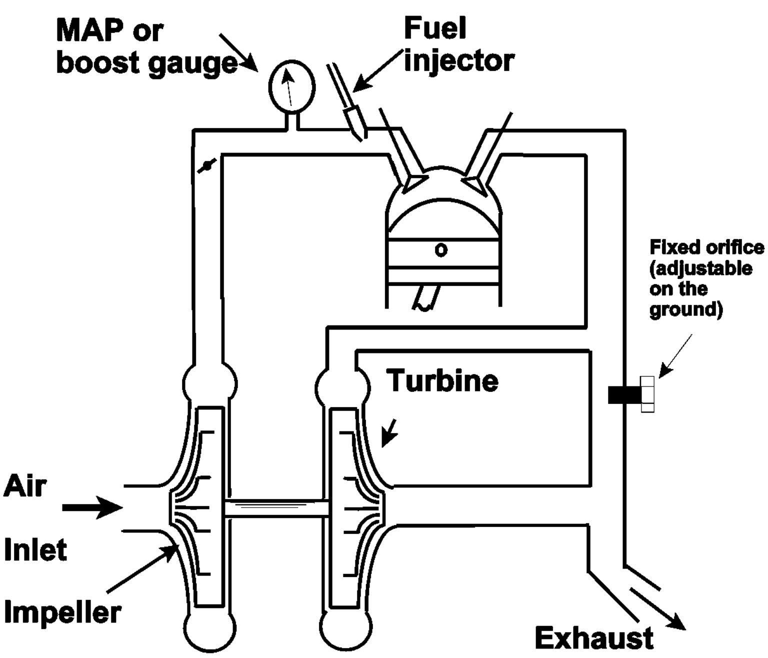
Now the outlet pressure of the compressor will fall and the inlet manifold pressure and engine power output will fall in sympathy. Of course, the engine **power output** will **decrease** with every foot of the climb from the moment of take off, this is typical of a turbo-charged engine, but now, after Critical Altitude, the decrease gets greater, **approximating** that of a **normally aspirated engine**.



Absolute Pressure Controller

The **simplest** form of control is to have a **fixed orifice exhaust** by pass so that a proportion of the exhaust gasses will always drive the turbo, and the manifold pressure is controlled strictly by the throttle valve.

As the **throttle** is **opened** to gain more MAP or Boost, the turbine speed will increase and the throttle input pressure and MAP will also respond to the chain reaction; rapid movement of the throttle will probably cause over boosting with this type of system.

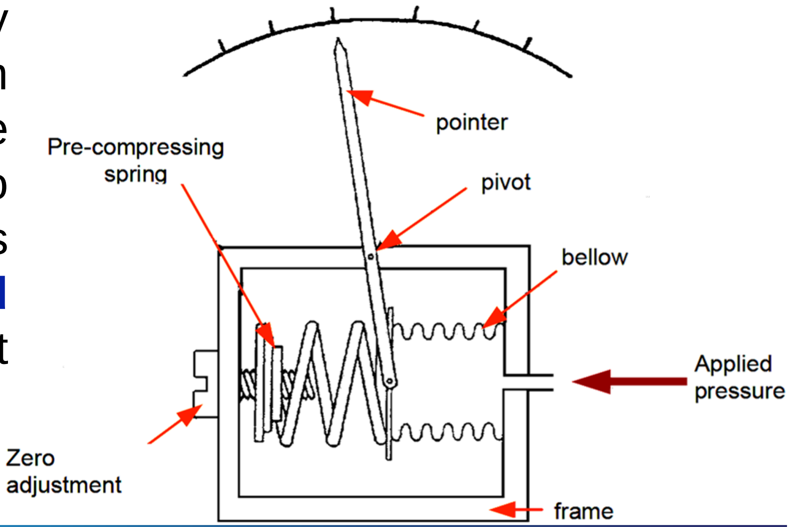


Density and a Differential Pressure

Only fitted to a more sophisticated system the **density controller** limit the Maximum MAP or Boost below the critical altitude when the throttle is opened fully.

The density controller is fitted with two **bellows** sensing compressor outlet pressure and temperature. The bellows are filled with dry nitrogen and allow the pressure to increase as the temperature increases.

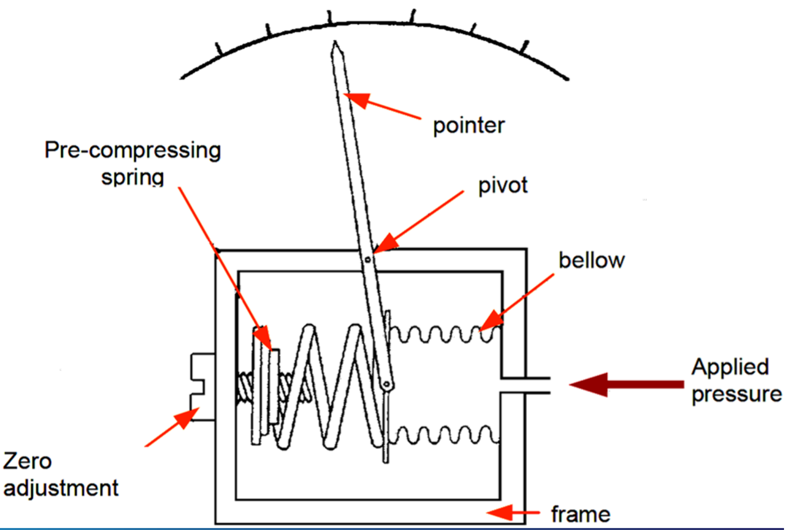
The effect of having a density controller will be that maximum available pressure will increase up to critical altitude and in so doing will **reduce** the normal loss associated with the **increased** charge **temperature** at a constant pressure.



Density and a Differential Pressure Controller

The **Differential Pressure Controller** is used together with the density controller and operates at all positions of the throttle other than the fully open position. To reduce the compressor outlet pressure if a lower MAP is required.

It must be remembered that only one of these two controls will be in use and controlling the waste gate position at any moment in time.



Variable Pressure Controller

The Variable Pressure Controller has a **cam** that will alter the **controller deck pressure** as the throttle position is varied so providing some further compensation for the change of compressor output temperature which would otherwise cause a lowering of the power output at a constant MAP or Boost Pressure. This unit replaces a Density and a Differential Pressure Controller.

On some engines the oil pressure control for the Waste Gate Actuator is managed by **three controllers** all of which use compressor outlet pressure. They are: an Absolute Pressure Controller, a Rate of Change Controller, and a Pressure Ratio Controller.

The APC will control the pressure to a preset level, the R of CC will govern the rate of change of MAP when the **throttle** is **opened rapidly** in order to prevent over boosting, and the PRC will limit the pressure difference across the throttle plate, the PRC is generally effective above the Critical altitude and a typical pressure ratio would be to have a deck pressure limited to 2.2 times the ambient pressure.

Turbochargers

Additional safety features may be built into some systems typically an **Over Boost Warning Light**, and if this boost is exceeded then an Over Boost Relief Valve will open and relieve deck pressure to ambient.

Summing up:

- The pilot moves the **throttle** and so establishes a different pressure drop across the throttle, and also varies the MAP.
- The differential-pressure controller senses the change and re-positions its oil bleed valve.
- The new bleed valve setting will change the oil flow and establish a new pressure on the **waste gate actuator** piston, which in turn will change the position of the waste gate butterfly valve.
- The new waste gate position will change the amount of **exhaust gas** flowing to the turbine.
- This changes the amount of **supercharging** provided (Deck Pressure).
- This new pressure then changes the pressure drop across the throttle valve, and the sequence returns to step 2 and repeats until an **equilibrium** is established.

Turbochargers

The net result of these events is an effect called **throttle sensitivity**, when this operation is compared with the operation of a normally aspirated engine, the turbocharged engine's MAP setting will require frequent resetting particularly if the pilot does not **move** the **throttle** valve **slowly** and wait for the system to seek its stabilization point before making further adjustments to the throttle.

The **differential pressure controller** helps to **reduce unstable** conditions which can be called **Bootstrapping** during part throttle operation.

Turbochargers

Bootstrapping is an indication of **unregulated** power change that results in a continual drift of MAP. It is an **undesirable** cycle of turbocharging events causing the MAP to drift in an attempt to reach a state of equilibrium.

Bootstrapping is sometimes **confused** with **Over Boost**, but it is not detrimental to engine life to the same degree that Over Boost is, and this latter condition can cause serious engine damage.

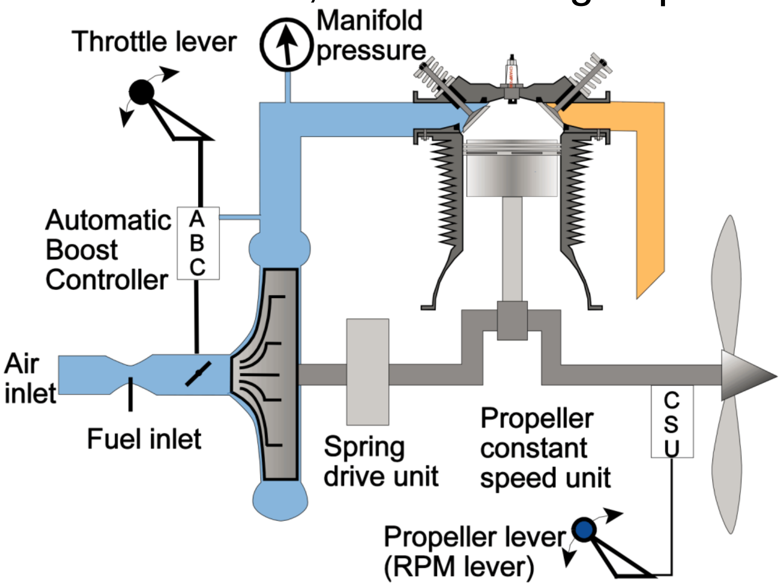
Careful handling of the throttle and selecting a higher RPM prior to increasing the boost when increasing power, and a lower boost prior to reducing the RPM when reducing power will prevent Over Boosting with the possible consequences of high engine loading, detonation and a reduction in engine life.

Internally driven superchargers

Internally driven superchargers are generally used on medium and high-powered piston engines (approximately 250 HP and above) and are fitted downstream of the throttle valve.

In the **past**, the superchargers of high-powered engines have often been driven at **two speeds** in order to save power at low altitudes, the low-speed gearing being used at low altitudes, and the high-speed gearing at high altitudes. In some cases, series to **raise** the overall **compression ratio,** they were fitted with **two impellers** working in series**.**

Current engines usually employ a single impeller driven at a **fixed speed** ratio to the crankshaft (between 6:1 and 12:1).

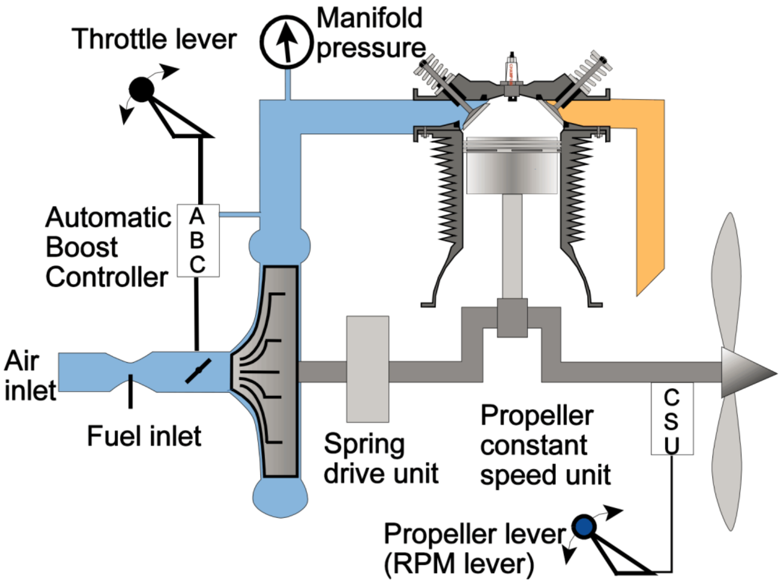


Internally driven superchargers

The **power** developed by the supercharged but otherwise identical engine, at the same speed and manifold pressure, is **less** than that of the normally **aspirated** engine at **sea level**, and this power loss represents the power required to drive the supercharger. However, as height is increased, the power developed by the supercharged engine at constant throttle settings increases as a result of the decreased temperature of the atmosphere.

The **decreased temperature increases** the **density** of the air, and thus a greater weight of air is pumped into the cylinders for the **same manifold pressure**.

Decreased air pressure also causes **less back pressure** on the exhaust, thus improving scavenging of the cylinders.



Full Throttle Height

At **sea level** the throttle valve in the supercharged engine must be **partially closed**, so as to restrict manifold pressure and prevent excessive cylinder pressure, but as the aircraft climbs the throttle valve must be progressively opened (either manually or automatically) to maintain this manifold pressure.

Eventually a **height** is reached where the throttle is **fully open**, and this is known as **Full Throttle Height**, above this height power will fall off as with the **normally aspirated engine**.

Since the effect of the supercharger depends on the speed of rotation of the impeller, **each power setting** will have a different Full Throttle Height according to the **engine speed** and manifold pressure used, the Full Throttle Height at Rated Power settings is known as **Rated Altitude**.

Supercharger controls

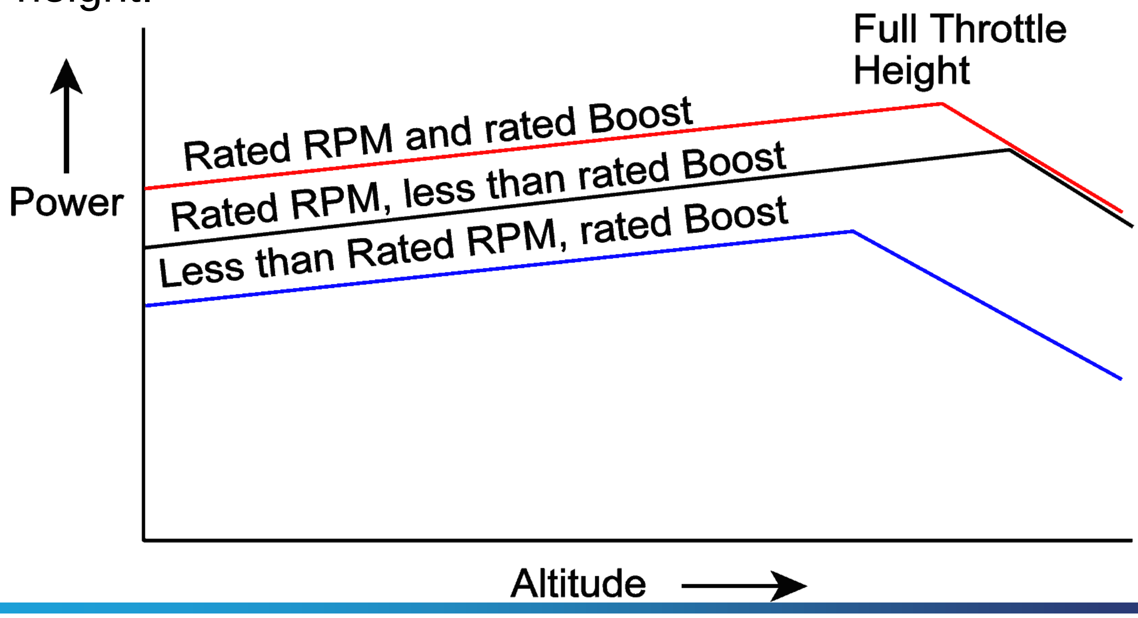
Since a **supercharger** is designed to compress air and provide **sea level pressure**, or greater, in the induction manifold when atmospheric pressure is low, excessive manifold pressures could be produced when atmospheric pressure is high. It is necessary, therefore, to **restrict throttle opening** below **full throttle height**, and, to relieve the work load on the pilot, this is often done automatically. There are two controls that affect the pressure developed by the supercharger.

- **The Throttle Lever** (Power Lever) position, within the limits imposed by full throttle height, determines the boost pressure that is delivered by the supercharger. The throttle is, in effect, a boost selection lever and, together with the propeller control lever, determines the power output of the engine.
- **The Propeller Control Lever** (Pitch Lever). current practice is to install a variable pitch propeller to aircraft engines, where the blade angles can be adjusted in flight between fine and coarse limits, resulting in the rotational speed of the engine increasing or decreasing.

Supercharger controls

The effect of climbing at less than Rated Power by maintaining **Rated RPM** with **less than Rated Boost** selected is to **increase** the Full Throttle height.

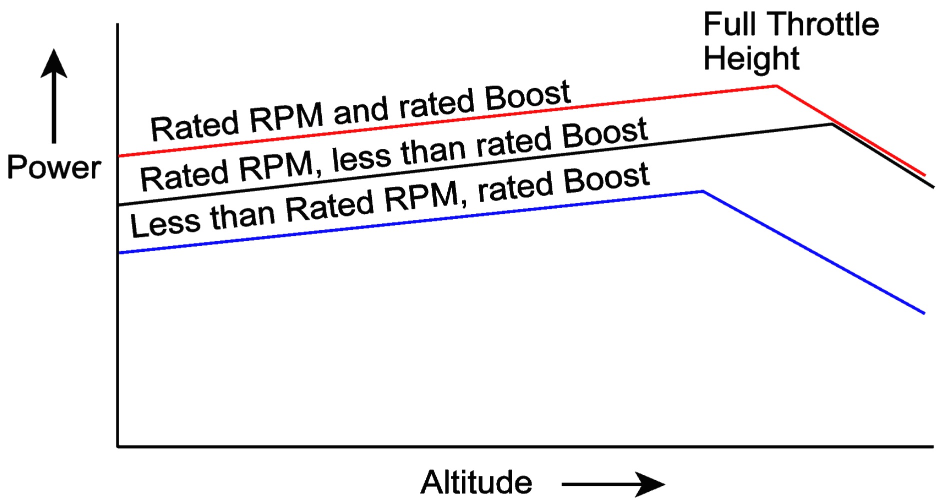
The effect of climbing at less than Rated Power by maintaining **Rated Boost** with **less than Rated RPM** selected is to **decrease** the Full Throttle height.



Supercharger controls

This is because it is necessary to **increase** the **throttle opening** to make up for **reduced compressor output**. The Throttle-valve will open more quickly in the climb to compensate for the slower RPM, or more slowly when the RPM is maintained and the Boost selection is low.

The **propeller control lever** is an engine speed control and, as the impeller is geared to the crankshaft, any change in engine speed will result in a corresponding change in the **speed of rotation** of the **impeller**.



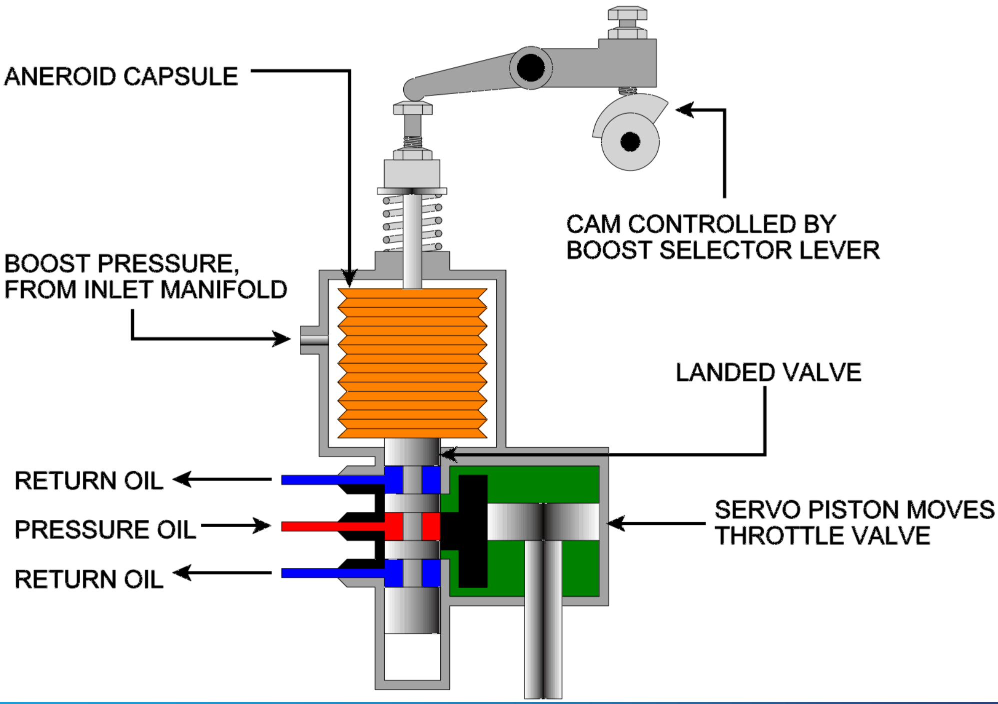
Supercharger controls

At **low altitudes** where the air is more dense, the supercharger produces too much pressure, consequently, to avoid severe detonation and mechanical stresses due to excessively high combustion pressure, the delivery pressure must be restricted by only **partially opening** the **throttle valve**.

As the aircraft climbs, the throttle valve must be progressively opened further to maintain a constant boost pressure.

Supercharger controls

To relieve the pilot of the responsibility of constantly varying the position of the throttle lever during climb or descent, the boost pressure is kept constant automatically by the **Automatic Boost Control** unit (ABC) which is generally attached to the carburetor.



Engine power checks. Reference rpm

When an engine is first installed in an aircraft, a check of its performance is made and a **reference RPM** is established. This RPM is an indication of the engine's power output with the propeller on the fine pitch stop, and it is almost constant, regardless of the airfield altitude or temperature.

A note of the reference RPM would be made and it would be placarded somewhere convenient in the cockpit, e.g. on the relevant RPM gauge. Once the **Reference RPM** has been established it should **not change appreciably**, any change would indicate some form of malfunction.

A new Reference RPM will have to be established every time a **major** engine component, such as a carburetor or a magneto, is changed.

Comparing the turbo-charger and the supercharger

The effect of **altitude** change on turbo-charged and supercharged engines is vastly different; the **power** output of a **turbo-charged** engine **decreases** with increase of altitude, while the output of the engine fitted with an internal **supercharge**r **increases** with increase of altitude. This is due to the variation of exhaust back pressure with each type.

When making comparisons between turbo-chargers and internal superchargers it is inevitable that the question of "**which is best**?" is asked. If it was just a matter of added **performance** at **ground level** for a given cost, then the **turbo-charger** would probably win.

Comparing the turbo-charger and the supercharger

There are other considerations to be taken into account:

- Do we only want the added performance at ground level? Unavoidably with an aircraft the answer must be no, in which case the internal **supercharger**, with its ability to **increase** engine **power** with aircraft **altitude**, must be favorite.
- Do we require that the **response** to throttle opening be **instant**? If the answer to this is yes, then once again the internal **supercharger** wins hands down. The **turbo-charge**r, for all that it is the **cheaper** option, cannot with present day technology respond to rapid throttle opening without suffering from the phenomenon known as **turbo-lag**.

Turbo-lag is the result of the time it takes to **speed up** the **turbine**/compressor after the signal of low compressor output has been sent to the Absolute Pressure Controller (APC) and the waste gate actuator has reacted by closing the waste gate.

Comparing the turbo-charger and the supercharger

SUPERCHARGER	TURBOCHARGER
Internally driven	Externally driven
Rotational speed controlled by RPM	Rotational speed controlled by Waste Gate position
Compresses mixture	Compresses air
ABC senses manifold pressure and controls the throttle	APC senses compressor discharge pressure and controls the waste gate
Compressor discharge pressure same as manifold pressure	Compressor discharge pressure greater than manifold pressure
Throttle controls manifold pressure	Throttle controls manifold pressure
Decreased exhaust back pressure in the climb	Increased exhaust back pressure in the climb