

Powertrain Design and Efficiency

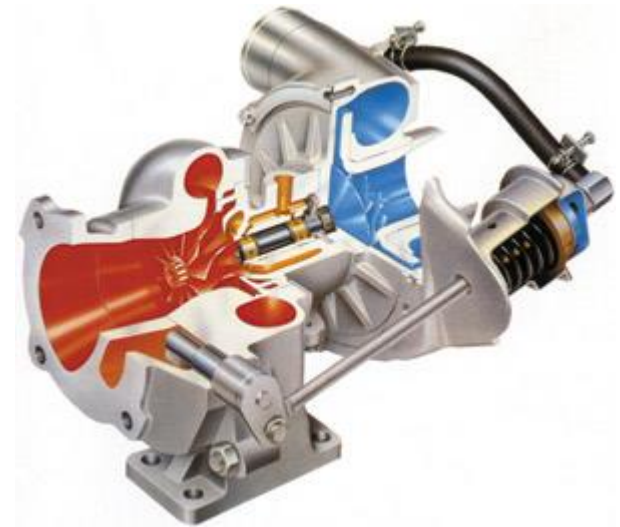
Intercoolers (2) and Boost Control



PRIFYSGOL CYMRU
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Trinity Saint David

- Air/Water Intercoolers
- Density recovery calculations
- Boost Controls

Contents

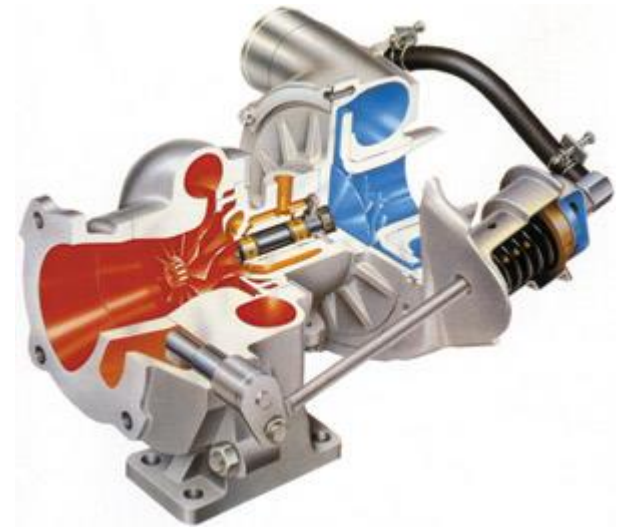




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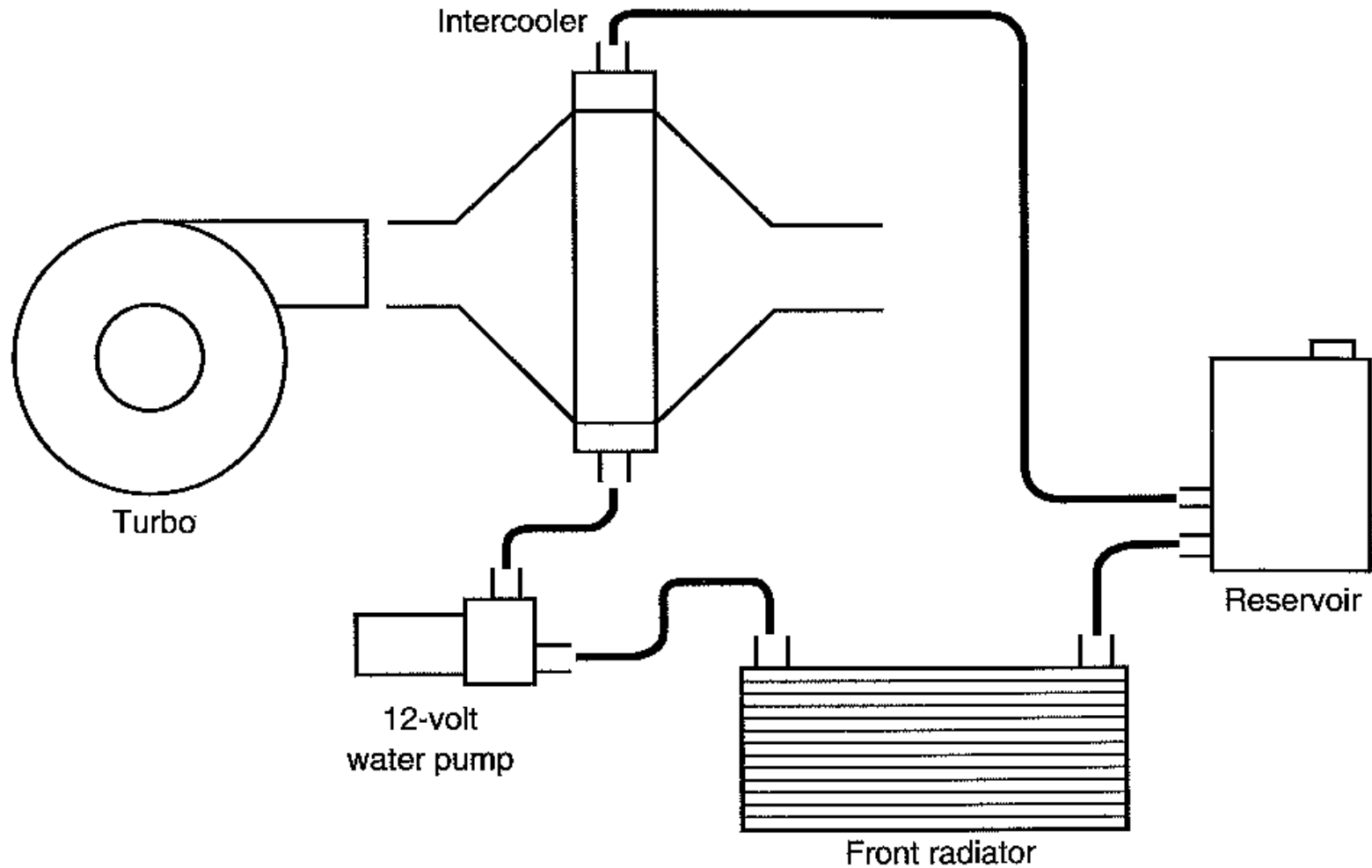


Air/Water Intercoolers

- Useful where space precludes the use of an air/air intercooler
- Water is circulated through a heat exchanger to remove heat from the charge air
- The heat exchange coefficient between water and aluminium (as in an intercooler) is approximately 14 times greater than between air and aluminium
- So the air/water intercooler could potentially have massive benefits compared to air/air systems
- **But** you still need to cool the cooling water!!!



Air/Water Intercoolers



Air/Water Intercoolers

- Cooling water is circulated to a front radiator by a water pump, where it is cooled and returned to the intercooler
- Design of an air/water intercooler system focusses on:
 - Water flow
 - Amount of water in system
 - Removal of heat from water
- Coolant is water with antifreeze as per usual engine cooling systems

Air/Water Intercoolers

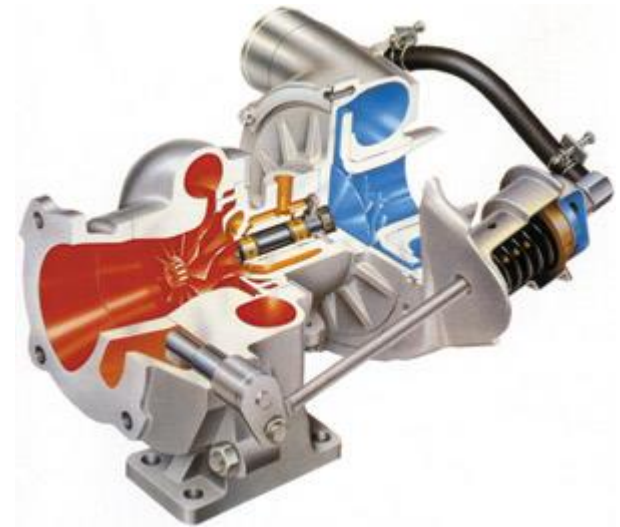
- Reservoir size
 - Typical boost application lasts a few seconds (say 15 maximum)
 - Size reservoir such that water only passes once through intercooler during this 15 seconds
- Pump
 - Usually 12v electrical pump
 - It is normal to run continuously in performance applications
 - This has the unusual effect that, when off boost, the charge air is cooling the cooling water via the intercooler!!!



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Density Recovery

- Intercooler is designed to recover some of the air density lost due to the heating of the charge by the compressor
- Air density is directly proportional to absolute temperature
- Thus we can calculate the density recovered (DR) by fitting an intercooler using:

$$DR = \frac{T_{co}}{T_{io}} - 1$$

where T_{co} = original compressor outlet temp (K)
 T_{io} = outlet temperature with intercooler (K)

Density Recovery

- The result of this calculation gives the proportional increase in charge density (x 100 to give the percentage increase)
- This means that DR% more air molecules will pass into the combustion chamber as a result of the intercooler
- All other things being equal, it would be logical to expect a similar increase in power output
- This is never quite realised in practice, due to pressure losses associated with aerodynamic drag inside the intercooler

Density Recovery

- **Example:** A turbocharger is run with a pressure ratio of 2.32 and the ambient temperature is 27°C. The compressor is 72% efficient
 - Calculate the compressor outlet temperature
 - If a 60% efficient intercooler is fitted, what is the new charge temperature, and how much increase in charge density does this represent?

$$\text{Actual Temp Rise} = \frac{(PR^{0.28} \times T_{in}) - T_{in}}{\eta_c}$$

$$\eta_i = \frac{T_{co} - T_{io}}{T_{co} - T_a}$$

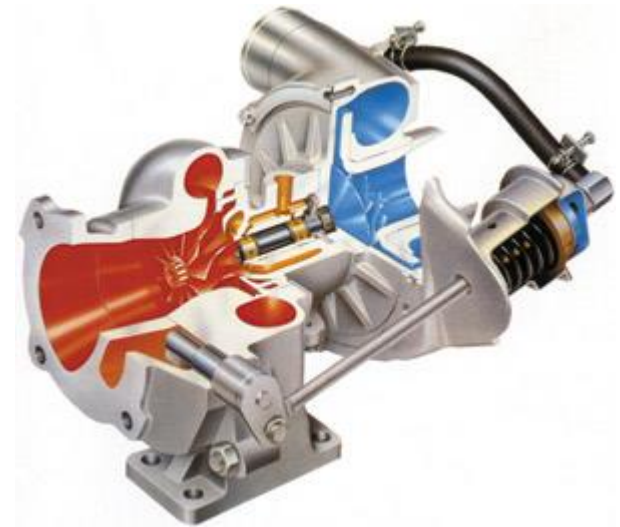
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Boost Controls

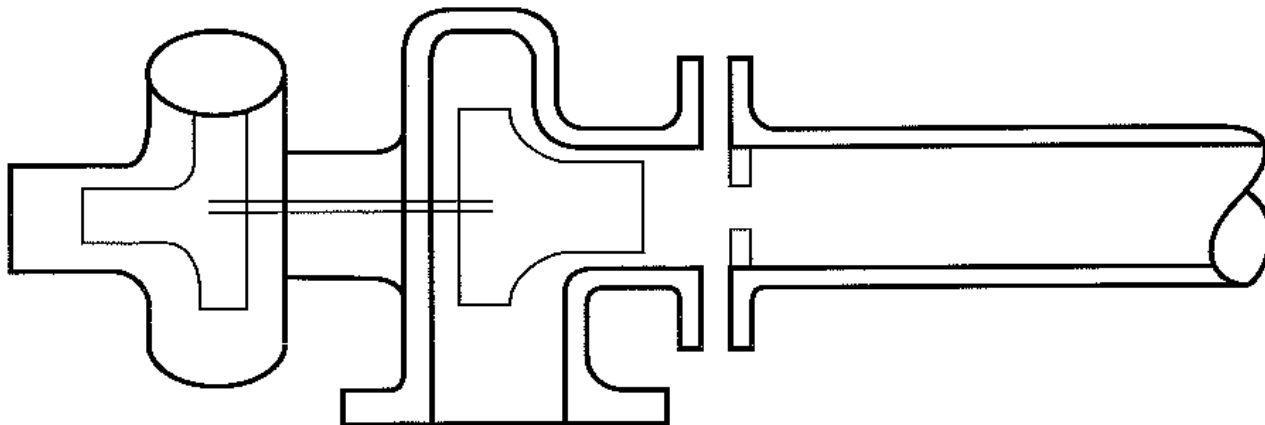
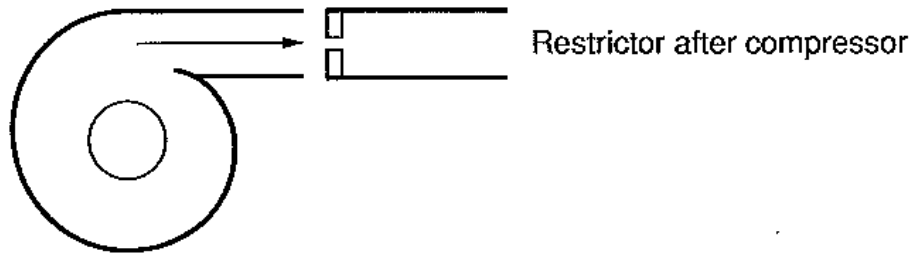
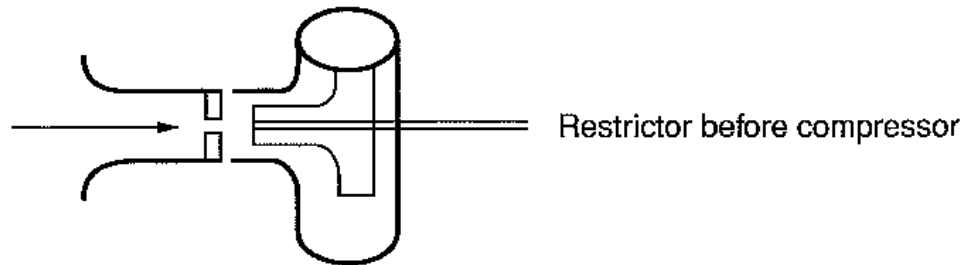
- Turbocharger characteristic means that it increases airflow faster than the ability of the engine to use the increased airflow
- If boost pressures are not controlled, high pressures can cause knock (uncontrolled combustion)
- There are a number of methods for controlling boost pressure

Restrictor

- A restrictor can be placed
 - Upstream of the compressor
 - Downstream of the compressor
 - Downstream of the turbine
- The restrictor acts to limit air flow
- Wherever you place the restrictor, temperatures rise
 - Restricted compressor – boost is made with less air, so effective pressure ratio (and hence temperatures) rise
 - After turbo increases exhaust back pressure and hence combustion chamber temperatures rise
- Fundamental concept of a turbo is to increase air flow, so then adding a restrictor to limit pressures isn't a good idea!



Restrictor



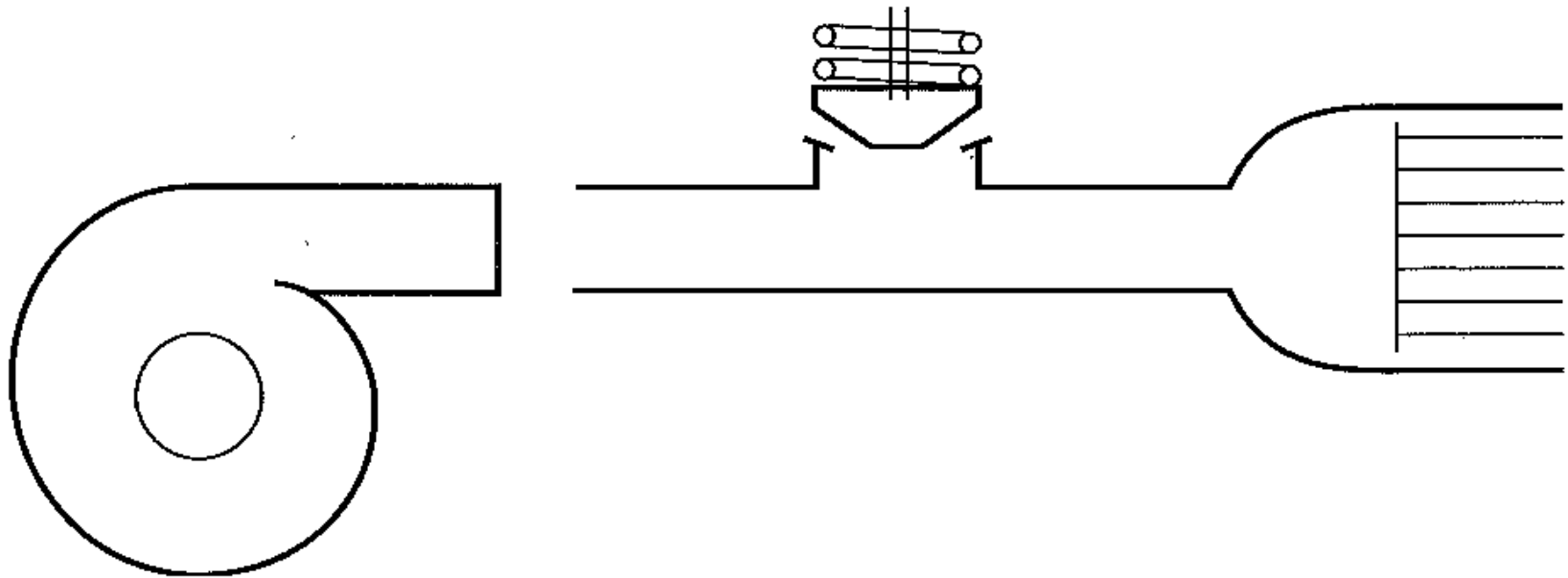
Vent Valve

- Essentially, a vent valve is a sophisticated radiator cap used to control boost pressures.
- Not particularly accurate
- Very noisy
- Often fitted to production cars as an overboost protection device in the event of wastegate failure
- Not suitable in draw-through carburetted systems where the device would vent an air/fuel mixture



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Vent Valve

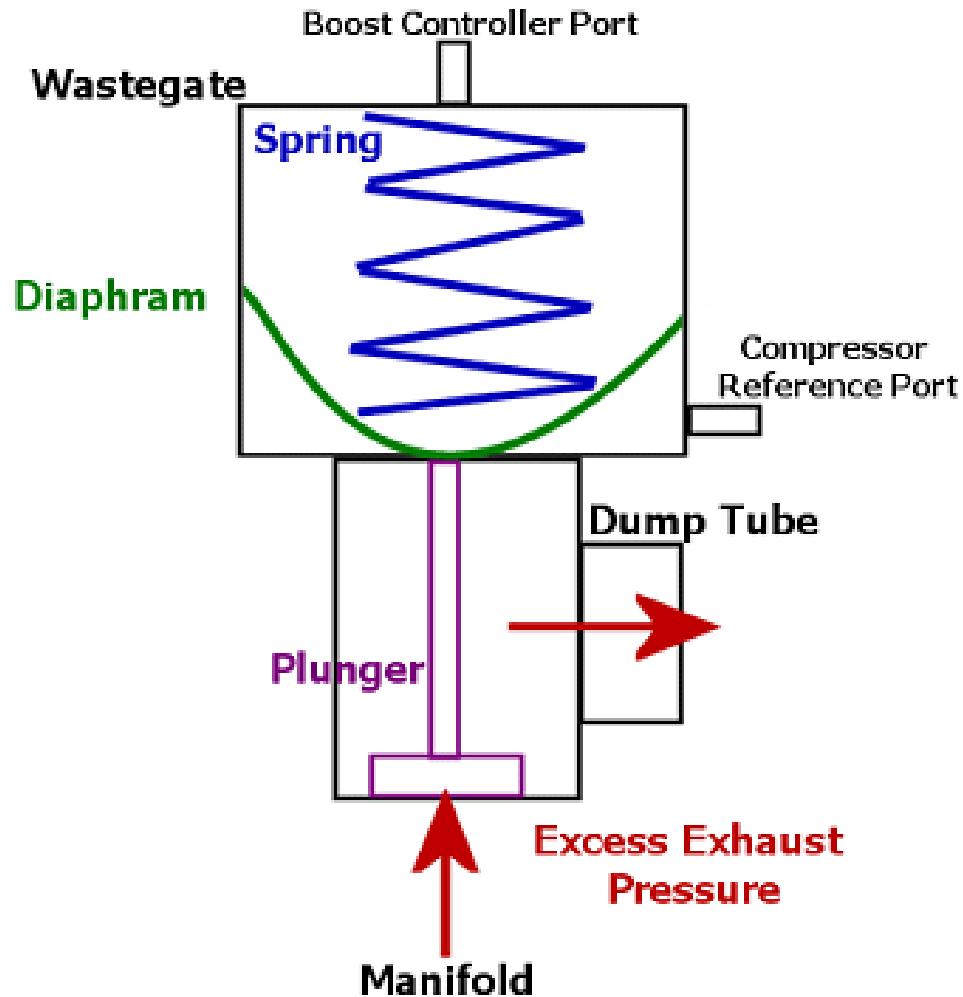


Wastegate

- Bypasses a controlled amount of exhaust gases around the turbine, hence controlling the amount of energy which the turbine extracts from the exhaust gas
- This therefore limits the amount of work the turbine can produce to drive the compressor, limiting the boost which the compressor can generate
- One potential problem is that, for example, a wastegate set to 10psi will *start* to open at a lower pressure, affecting turbine response



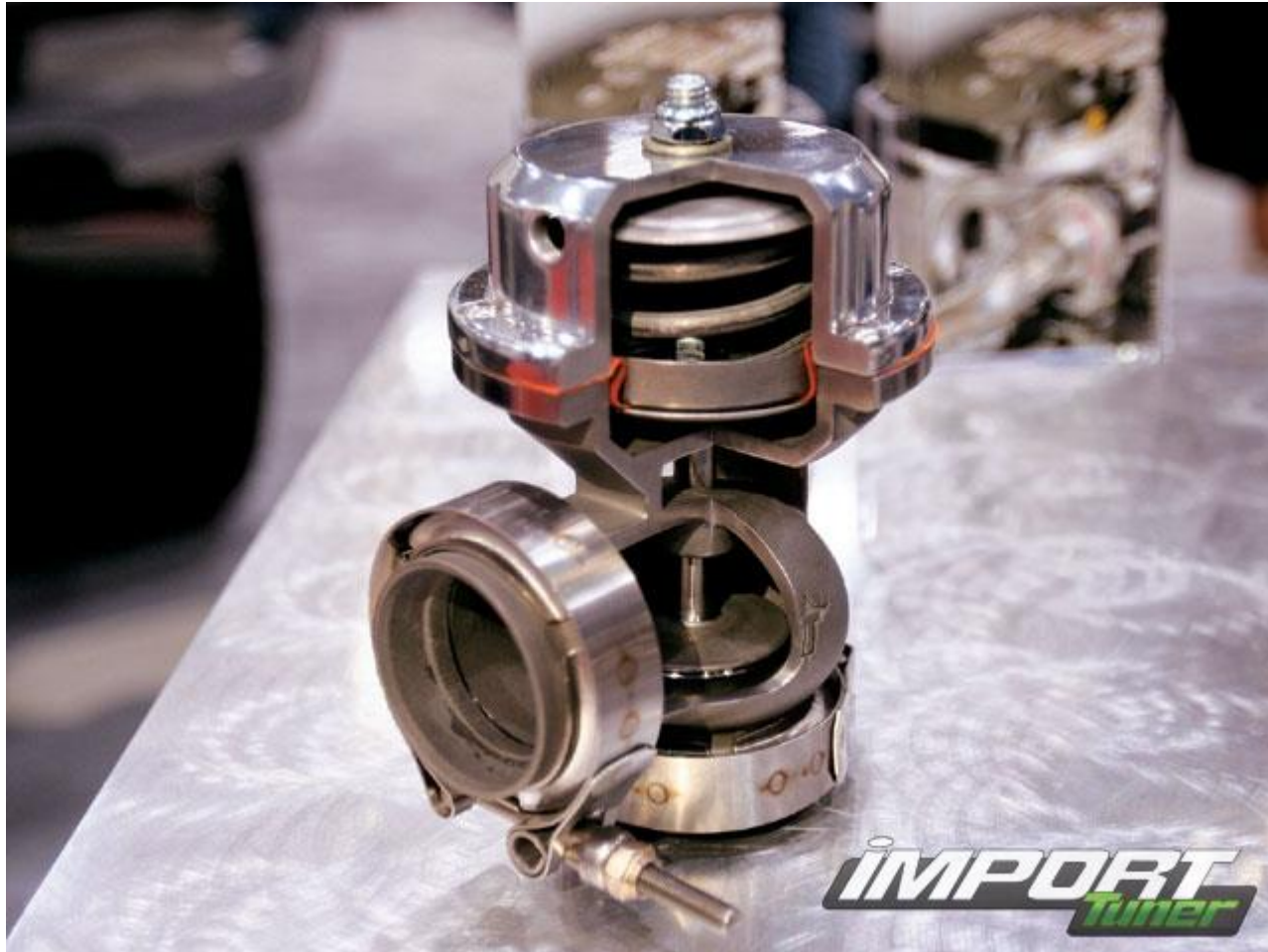
Wastegate





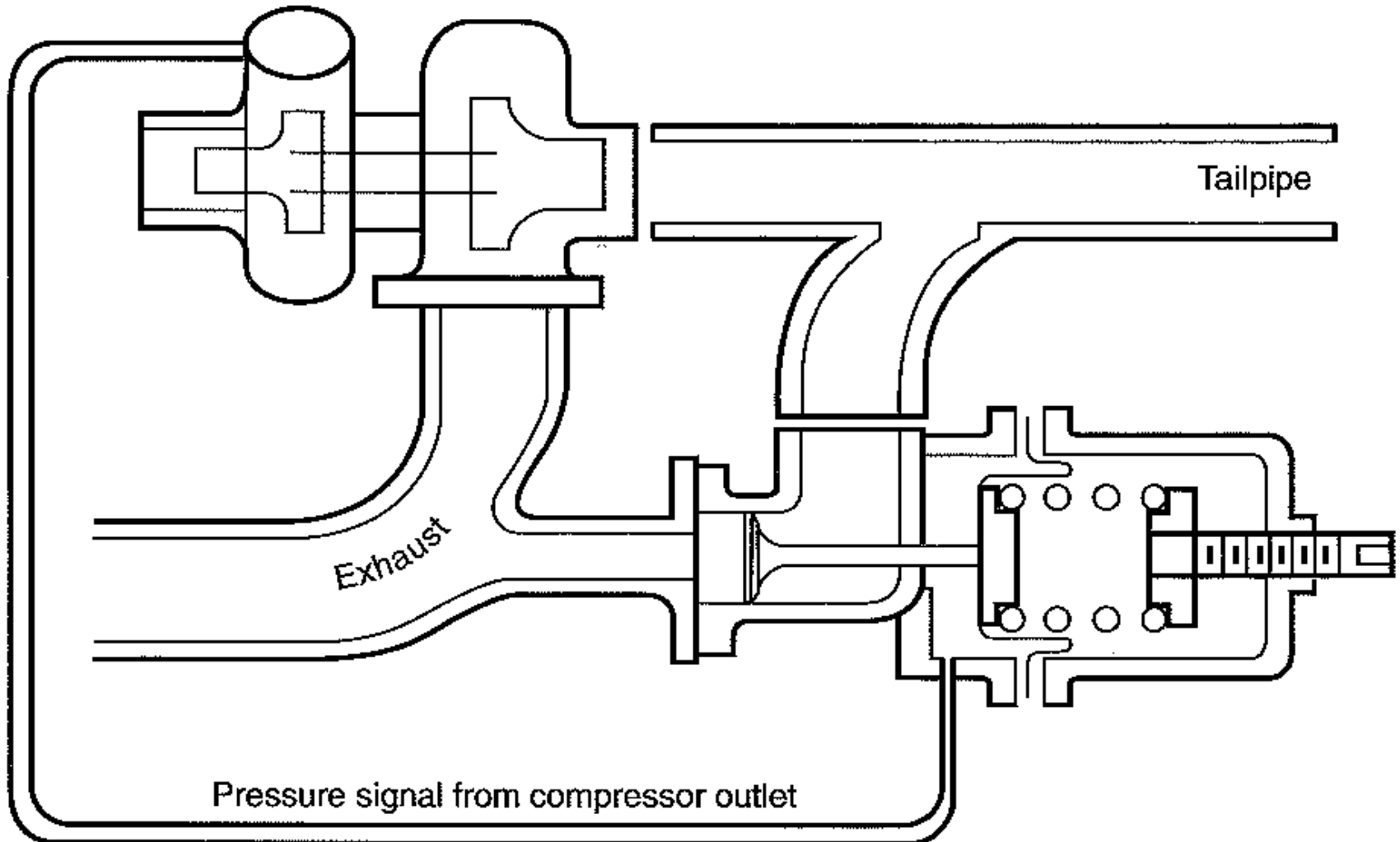
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Wastegate





Wastegate



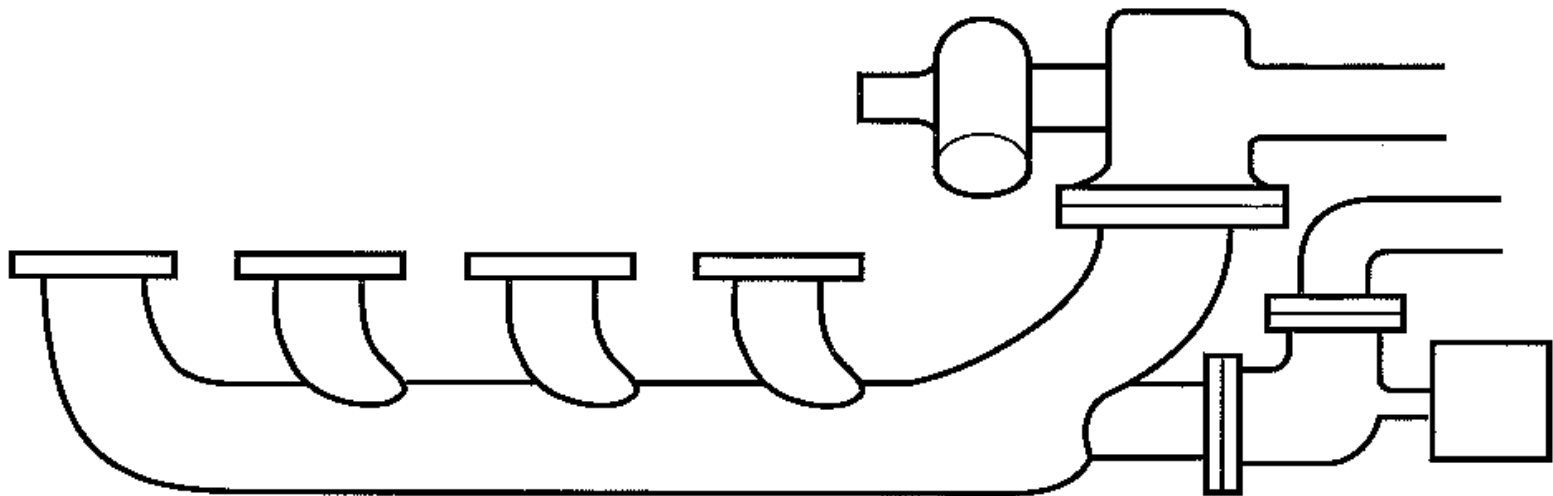
Wastegate

- Two types of wastegate
 - **Integral** – incorporated into the turbocharger itself
 - **Remote** – situated separately at some suitable location
- **Integral** is cheaper to produce but has performance limitations
- **Remote** is highest performance and is commonly employed on race cars



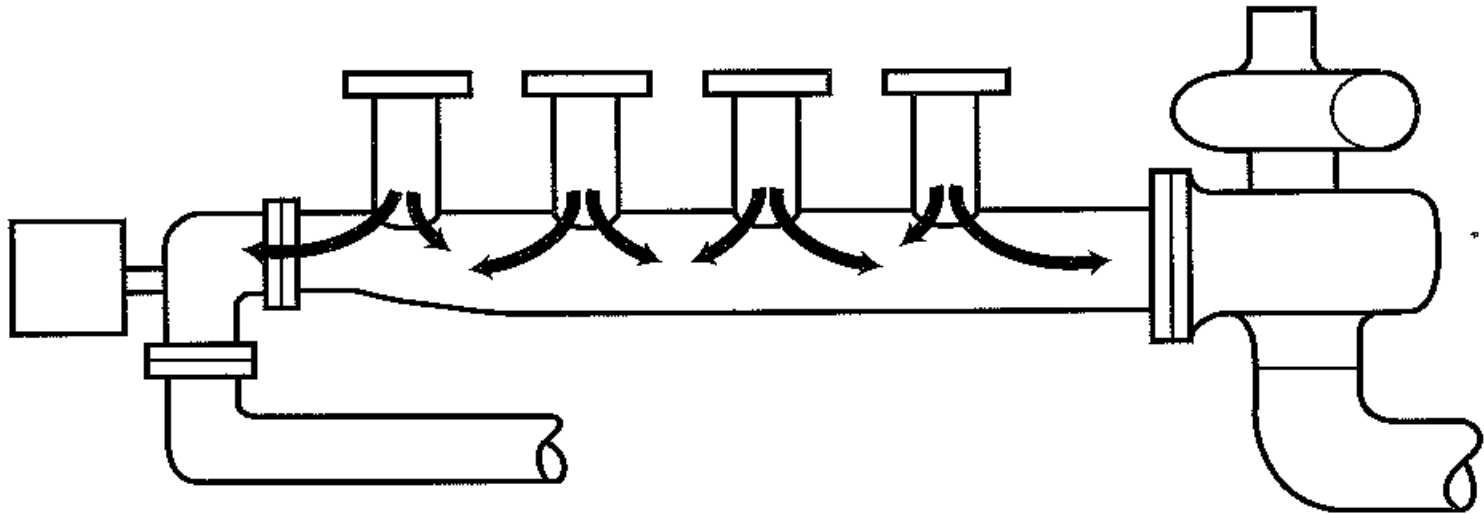
Remote Wastegate

- **Location** of waste-gate bleed off is critical
 - Should draw evenly from all cylinders



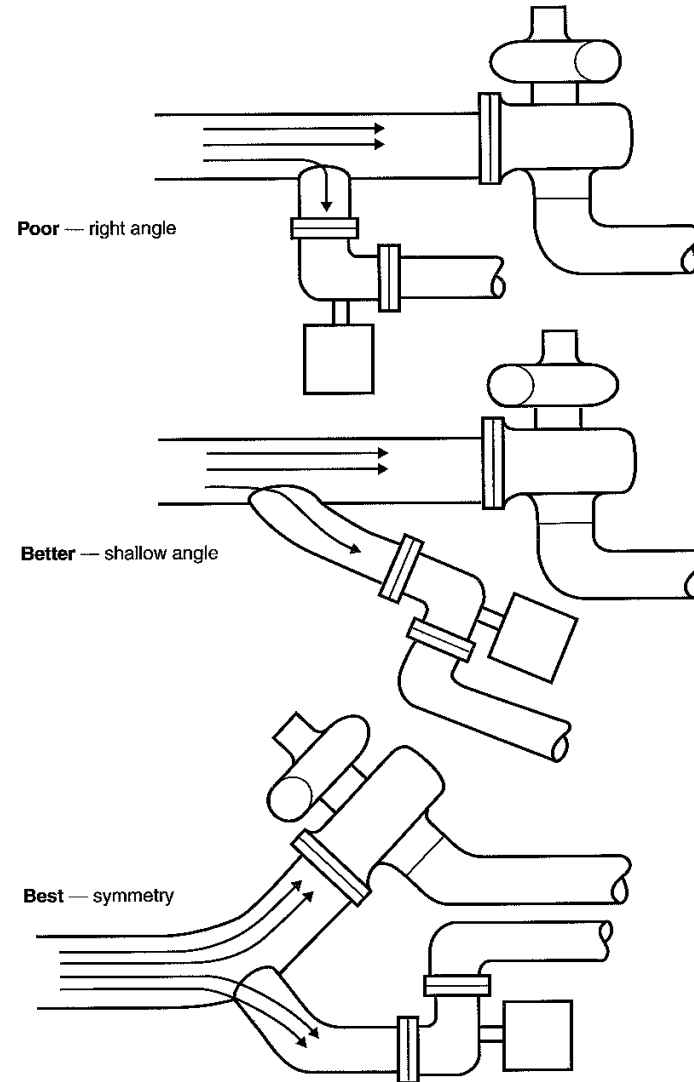
Remote Wastegate

- Poor location – gases have to change direction between turbine or wastegate
- Will affect flow balance from cylinders



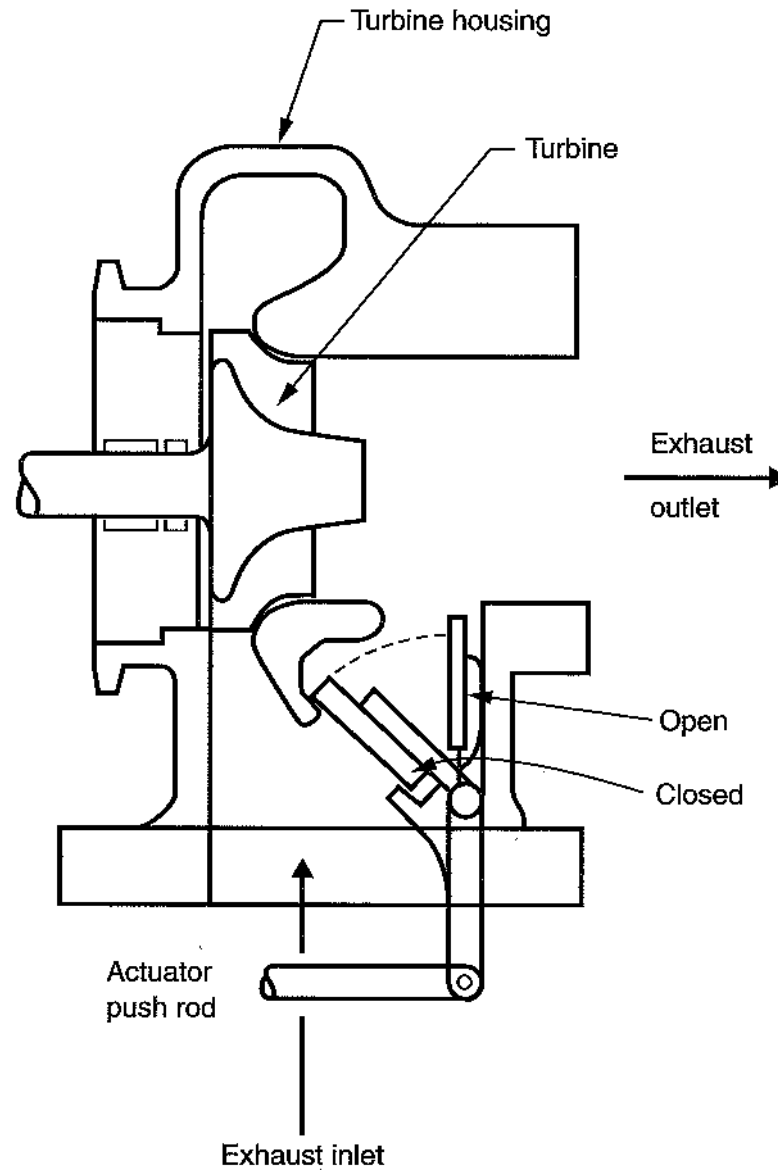


Remote Wastegate



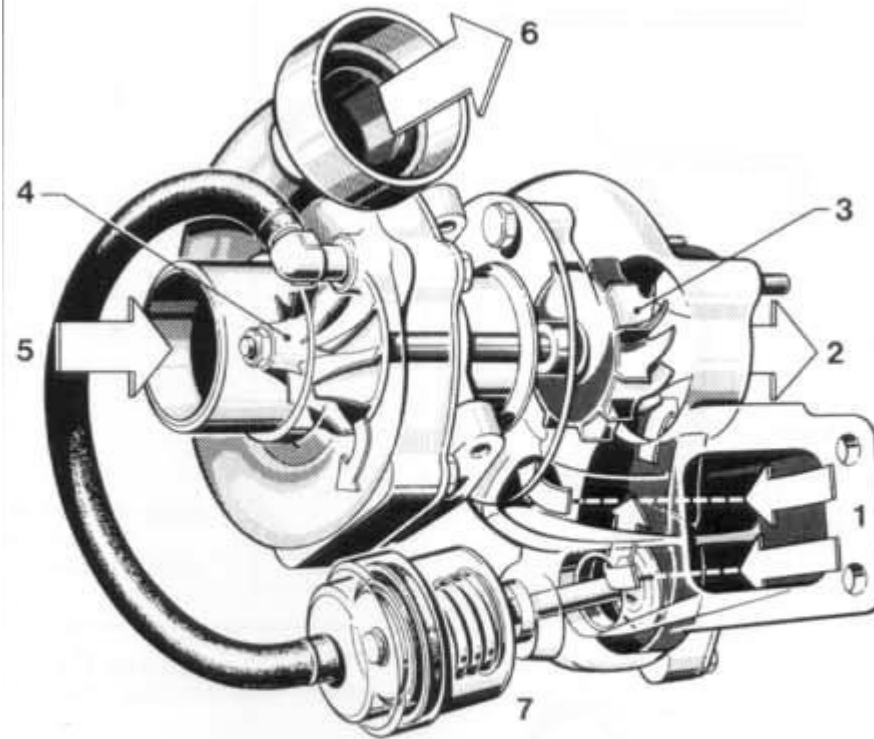


Integral Wastegate





Integral Wastegate



Key 1 Exhaust gases to turbine of turbocharger. 2 Exhaust gas outlet. 3 Turbine wheel. 4 Compressor wheel. 5 Intake air to compressor. 6 Compressed air to engine. 7 Wastegate boost control.

Integral Wastegate

- Integral wastegate vents gases immediately behind turbine wheel creating high turbulence
- This reduces the overall flow through the turbine
- It raises exhaust back pressure
- Reduces performance

