

Engine Design and Efficiency

Introduction to Turbocharging

Contents



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- History of turbocharging
- Basic Principles
- Turbocharger system
- Anatomy of a turbo



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History of turbocharging



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- The turbo is almost as old as the IC engine itself!
- 1885, 1896: Gottlieb Daimler and Rudolf Diesel experimented with pre-compressing combustion air.
- 1925: Alfred Büchi (Swiss engineer) developed the first successful exhaust gas turbocharger. He achieved a 40% power increase.
- The first turbocharger applications were large marine engines.
- 1962/3: Chevrolet Corvair Monza and the Oldsmobile Jetfire were the first turbo'd passenger cars. Suffered from poor reliability.

History of turbocharging



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- 1973: Oil crisis leads to increased application of turbocharging to commercial vehicles.
- Early 1970's: Turbochargers increasingly used in motorsport. Turbo F1 cars etc. Many manufacturers had a flagship petrol-driven model with a turbo
 - High performance
 - Poor economy
 - Turbo lag (poor drivability)
- 1978: Mercedes Benz 300SD – turbo-diesel
- 1981: VW Golf Turbodiesel
 - Increased efficiency
 - Improved drivability
 - Reduced emissions
- 2014 Turbo's back in F1!

History of turbocharging



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- Present day:
 - Pretty much all diesel cars are turbocharged
 - Diesels have a significant market share
 - Would this be possible without the turbocharger?
 - Increasing use of turbochargers in petrol cars
 - Improve efficiency and reduce emissions
 - Use exhaust gas energy
 - Improve performance



VAG 2.5litre Turbo Diesel

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Basic Principles



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$$P = \frac{MEP \times A \times L \times n \times N}{120}$$

- We want to increase power levels
- Ideally we want to do this for free!!!
- There are a number of ways we can do this – let's consider the formula for engine power:

MEP = mean effective pressure

A = bore cross sectional area

L = stroke

N = engine rpm

n = number of cylinders

Basic Principles



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$$P = \frac{MEP \times A \times L \times n \times N}{120}$$

■ Increase swept volume

- More air available in a larger combustion chamber
- More fuel can be burnt
- Increase number of cylinders (n)
- Increase cylinder volumes (A, L)
- Bigger, heavier engines
- No advantage in terms of specific fuel consumption or emissions

Basic Principles



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$$P = \frac{MEP \times A \times L \times n \times N}{120}$$

■ Increase engine speed (N)

- i.e. increase number of power strokes per unit time
- Mechanical stability limits
- Combustion limits
- Increased frictional losses
- Increased pumping losses
- Overall reduction in engine efficiency

Basic Principles



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$$P = \frac{MEP \times A \times L \times n \times N}{120}$$

■ Increase pressure (MEP)

- Same swept volume and engine speed as before
- Combustion air is pre-compressed before it reaches the cylinders
- Ingested volume is the same, but air is denser, so mass of air in each cylinder is higher
- Higher Volumetric Efficiency
- Power boost without significant weight increase
- Higher power to weight ratio

Basic Principles



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- This pre-compression of incoming air can be achieved by a turbocharger
- This is essentially a turbine driven by the exhaust gases which powers a mechanical compressor in the intake system
- There is no mechanical coupling to the engine
- Waste energy in the exhaust gases is extracted by the turbo and used to drive the compressor
- Regrettably, it isn't entirely free, as the turbocharger increases the power losses in the exhaust system
- A boost of 6-7 psi can give a 30-40% increase in power (for a 50% increase in pressure above ambient)

Basic Principles



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- Continuing the theme that there's no such thing as a free lunch.....
 - Compressing the incoming air heats it up
 - This can lead to knocking, where the mixture pre-ignites before the spark plug fires
 - Higher octane fuel or reduced mechanical compression ratios can alleviate these issues

Basic Principles



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- However, compared with a naturally aspirated engine of the same power output, the turbo engine:
 - Has improved fuel consumption as some of the normally wasted exhaust gas energy is recovered by the turbo
 - Has a lower volume for the same power output, and so has lower frictional and thermal losses
 - Has a much higher power to weight ratio
 - Requires a smaller installation space
 - Has an improved torque curve
 - Has improved performance at high altitude
 - Is less noisy (as it has less surface area) and the turbo itself has a silencing effect

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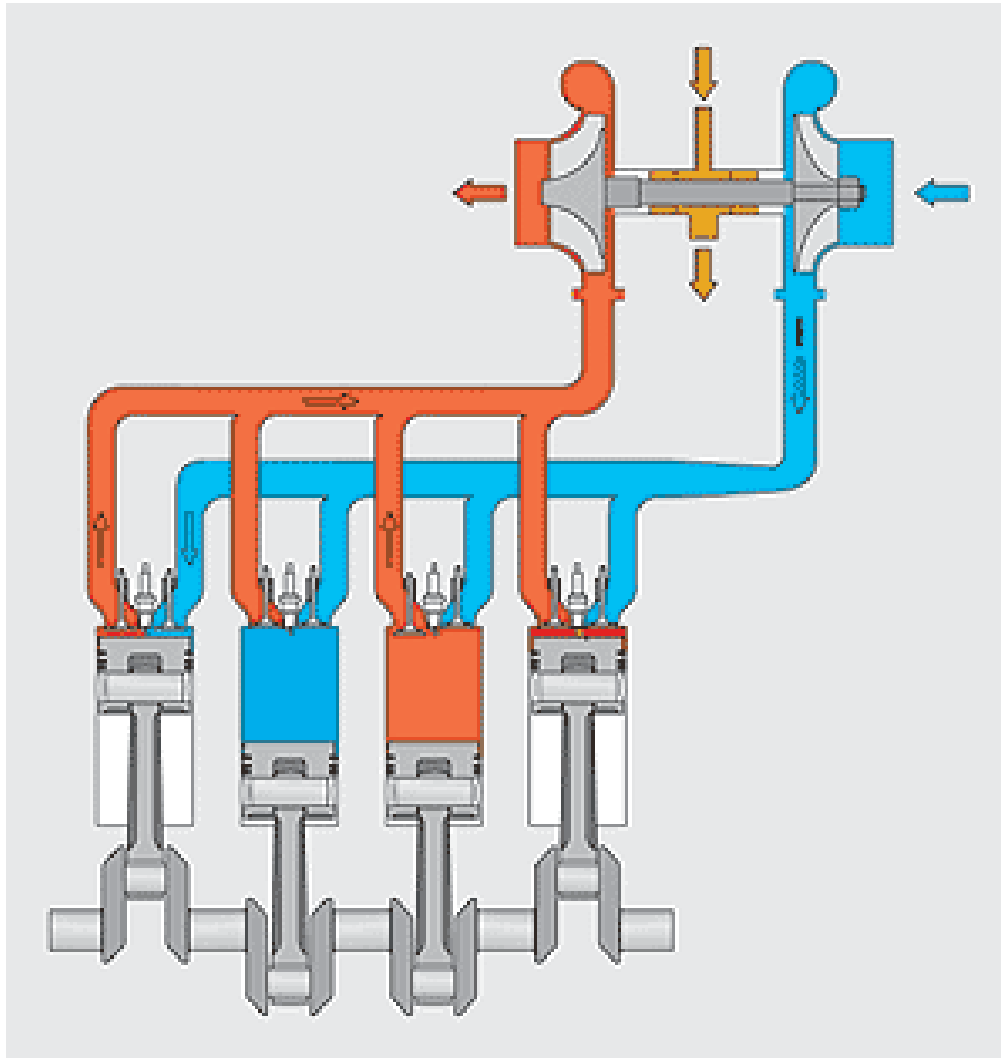
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Turbo System



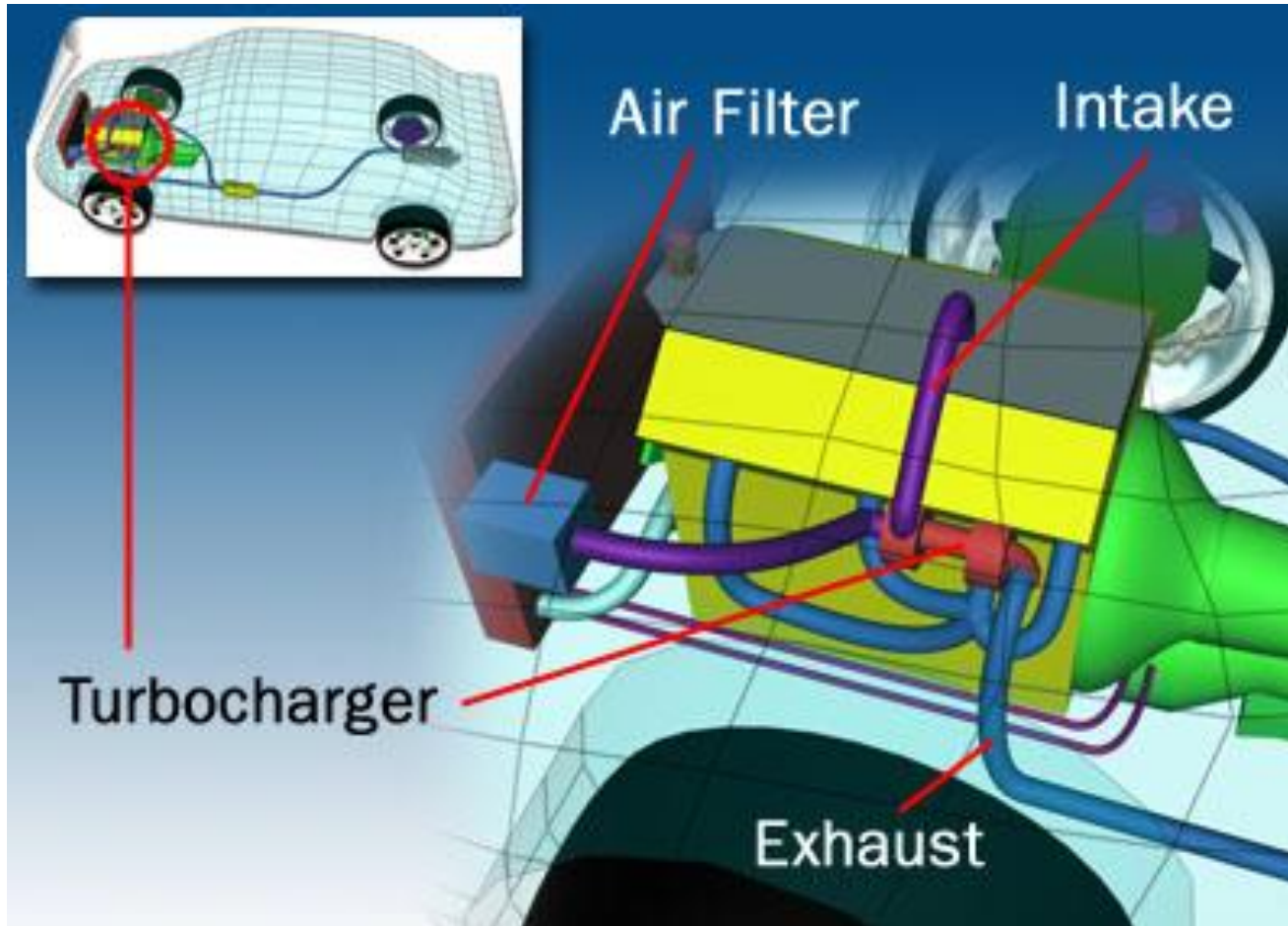
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Turbo System



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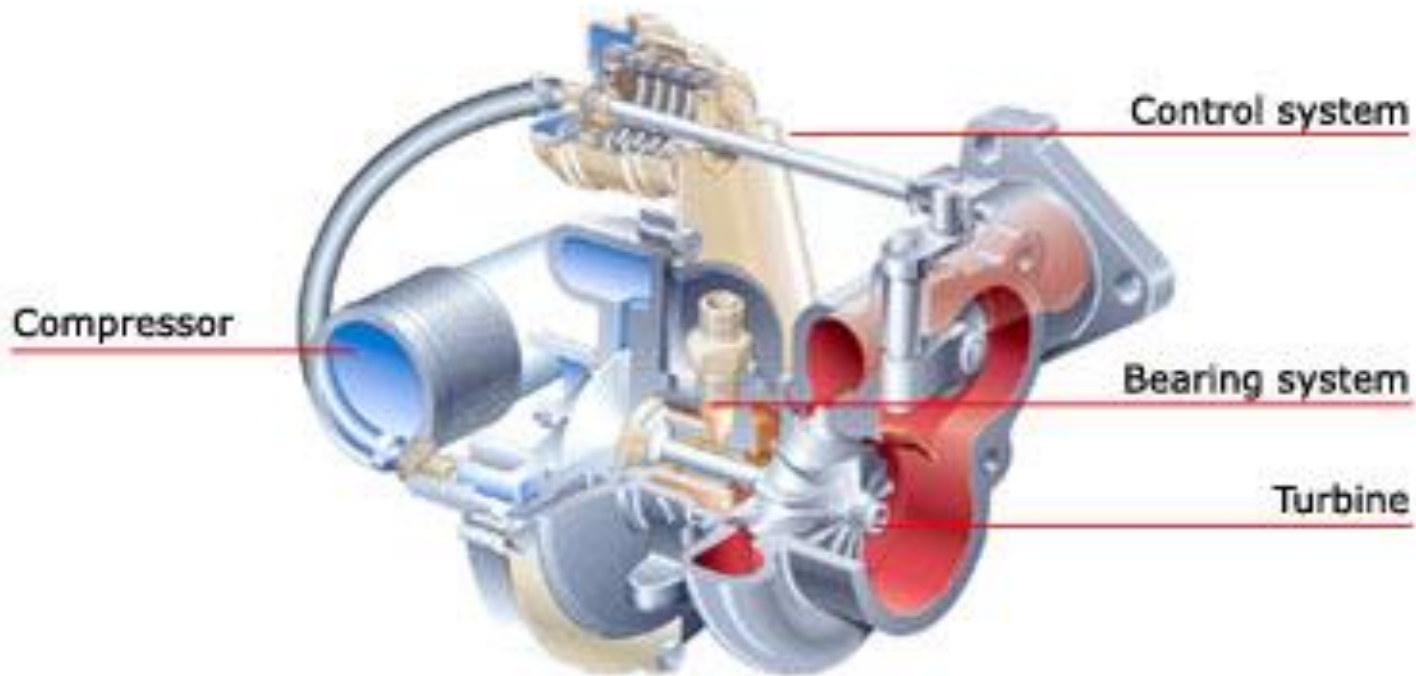
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Anatomy of a turbo



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Anatomy of a turbo



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COMPRESSOR SECTION

COMPRESSOR HOUSING

COMPRESSOR AMBIENT AIR INLET

TURBINE HOUSING

TURBINE EXHAUST GAS OUTLET

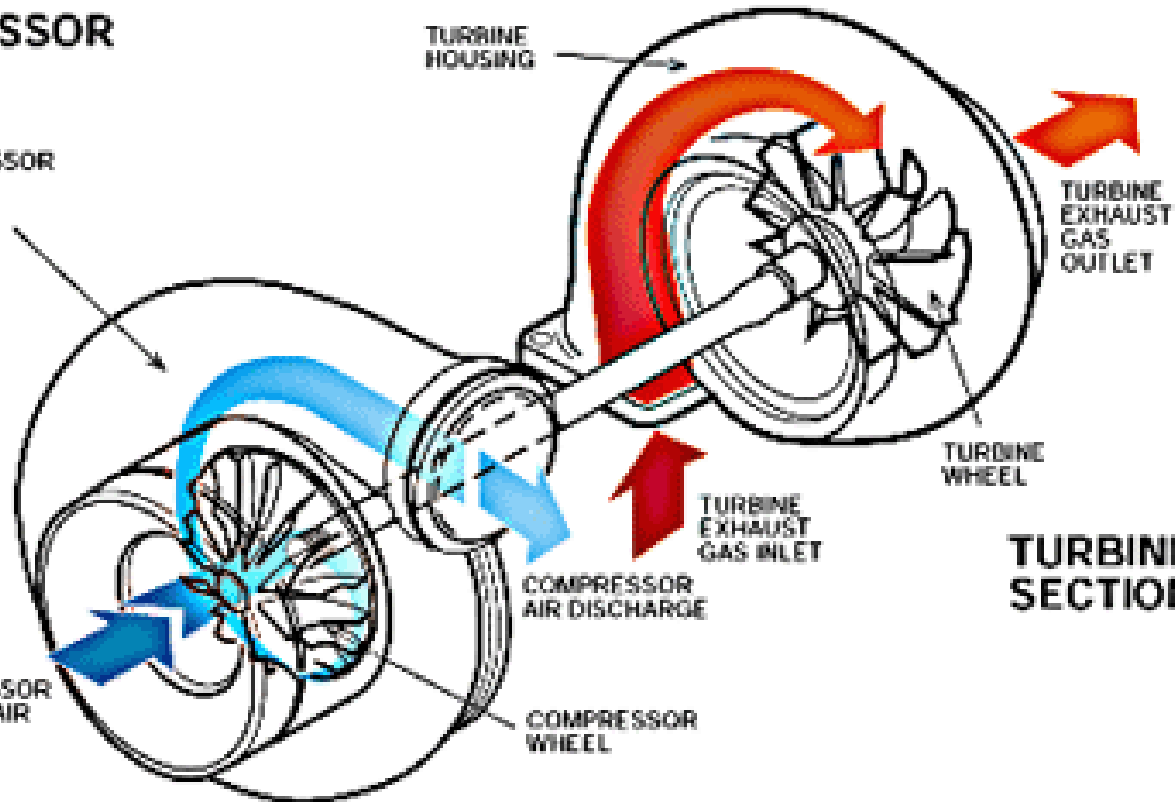
TURBINE WHEEL

TURBINE SECTION

TURBINE EXHAUST GAS INLET

COMPRESSOR AIR DISCHARGE

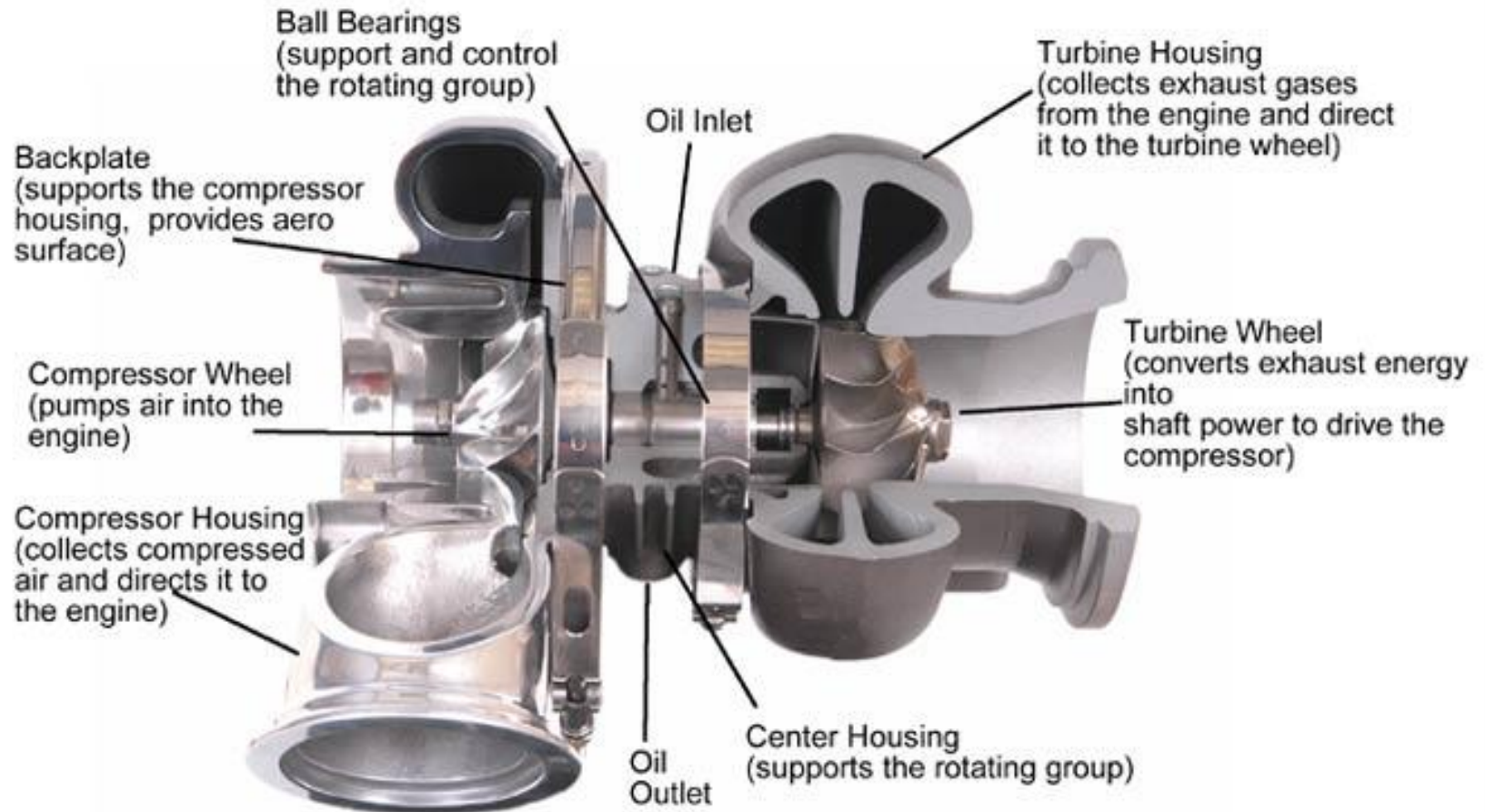
COMPRESSOR WHEEL



Anatomy of a turbo



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Anatomy of a turbo



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- **Turbine**

- Creates a pressure and temperature drop across the exhaust gases
- This pressure drop equates to the energy extracted by the turbine and converted to mechanical energy to drive the compressor
- Two main types – **axial** or **radial** flow
 - Axial type – flow through the wheel is only in the axial direction
 - Radial type – gas flows radially in from the outside of the wheel
 - Radial types predominate in Automotive applications
- Turbine performance is governed by the flow cross section
- Variable geometry turbines can be used to change the turbine performance at different engine speeds

Anatomy of a turbo



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- **Compressor**

- Consists of three main parts – compressor wheel, diffuser and housing
- Air is drawn in axially by the rotational speed of the wheel
- It is accelerated to a high velocity by the wheel and expelled in a radial direction
- Diffuser slows down the air (largely without losses) so that pressure and temperature rise
- The diffuser is formed by the compressor backplate and a part of the volute housing
- The volute housing further slows and collects the air, for delivery to the engine

Anatomy of a turbo



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- **Bearing System**

- Supports the common shaft on which the turbine and compressor are mounted
- Has to cope with rotational speeds of 150,000 rpm +
- Oil-fed hydrodynamic sleeve bearings used to support shaft
- Oil-fed thrust bearings



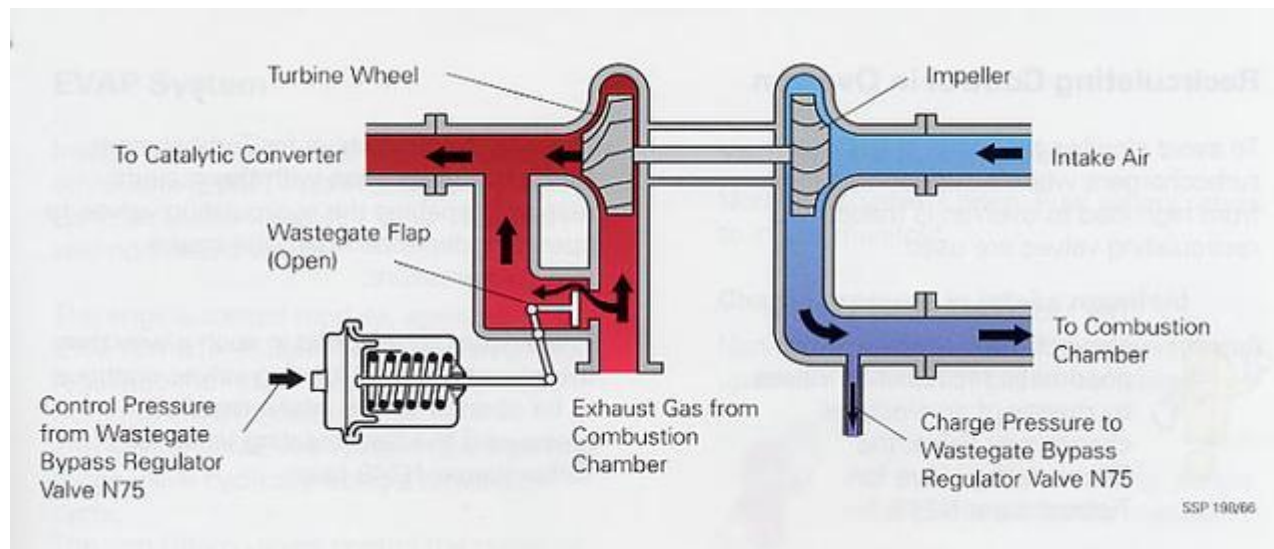
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- **Control System**

- Waste-gate valve allows exhaust gases to bypass turbine
- Controlled by boost pressure
- If this is too high, waste-gate opens to prevent turbine spinning too quickly at high engine speeds and to limit boost pressure



Anatomy of a turbo



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- **Turbocharger sizing**

- Turbo “lag”
- It takes a finite period of time for the turbocharger to spool up to speed as the accelerator pedal is pressed
- Reducing the inertia of the turbine (or fitting a smaller turbine) will allow the turbine to spool up more quickly
- A small turbo provides boost quickly and at low speeds
- A larger turbo provides more boost at higher engine speeds but will be subject to more noticeable lag
- Twin turbo’s etc can alleviate these issues