Air Management in Reciprocating Internal Combustion Engines - the Challenges of CO2 reduction

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Contents

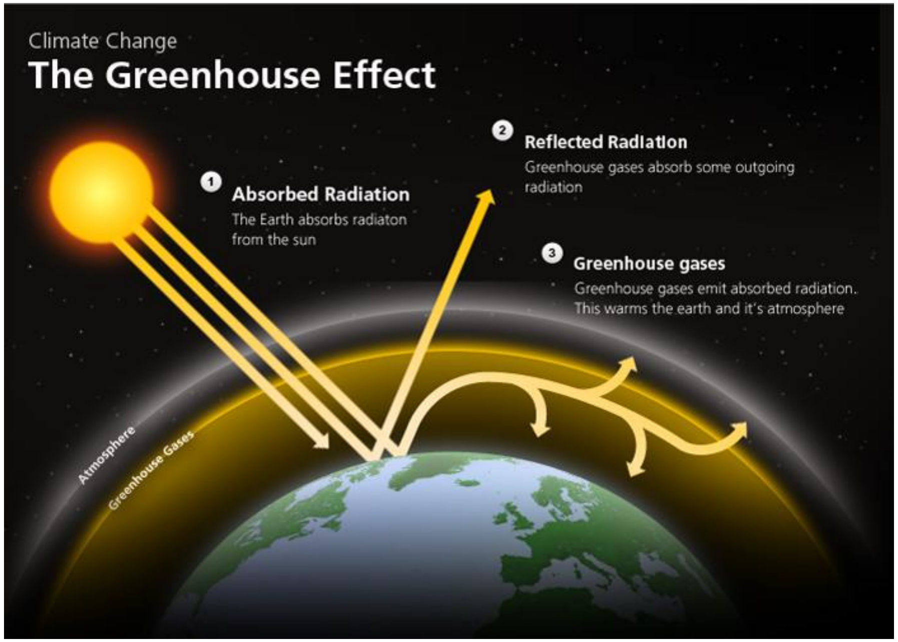
- Incentives
- Techniques
- Challenges
- Options

CO2 Greenhouse effect

- The climate is changing and the planet is getting warmer.
- CO_2 is a contributing factor.
- Significant amounts of CO_2 is produced by **internal combustion engines.**
- Cars, ships, trains and airplanes all contribute.

Regulations to contain the situation

- This has raised concern and as a consequence policy makers have enforced emission regulations and incentives.
- As part of the solution auto makers have been targeted as well.

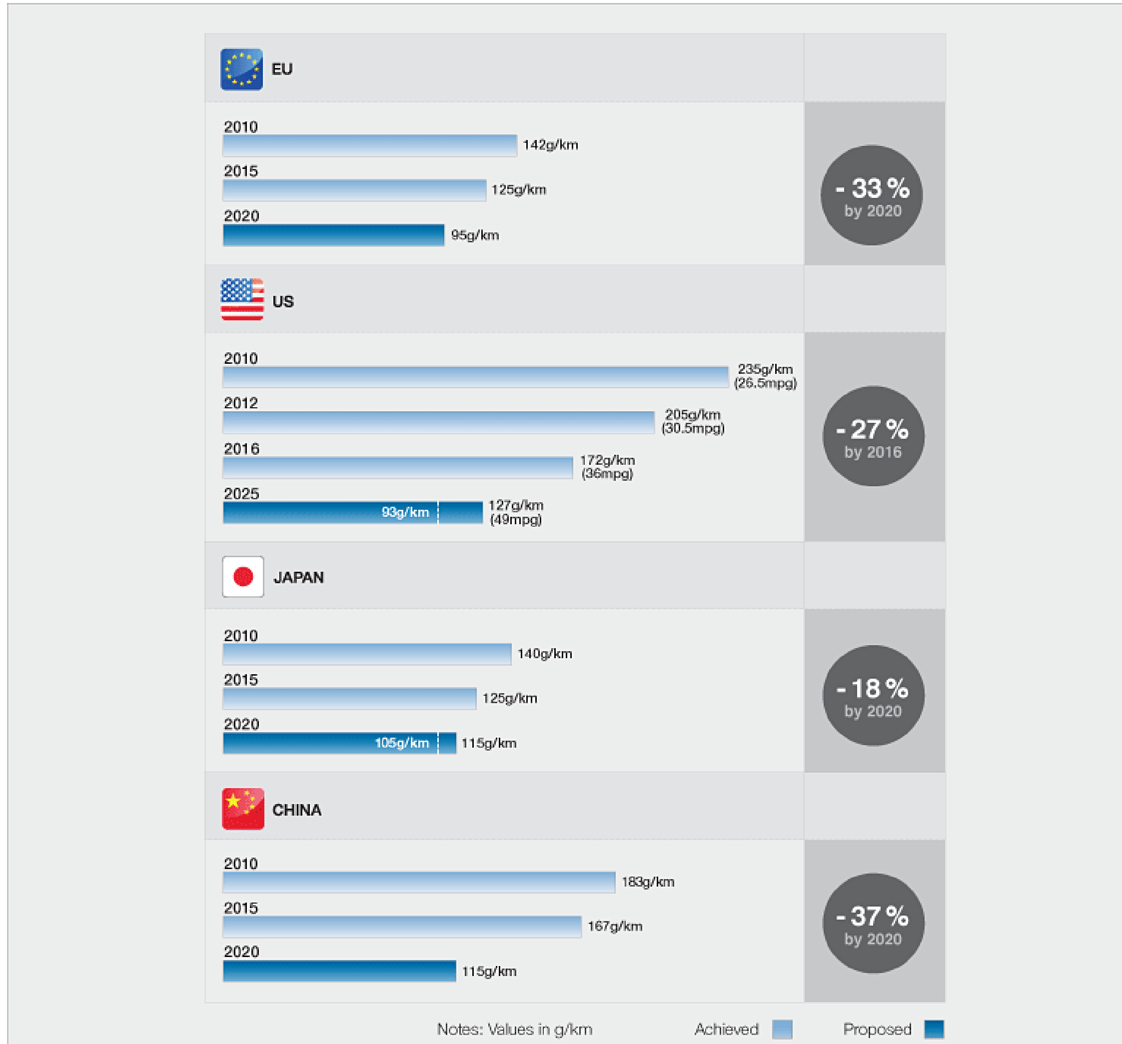


Emission Targets

- World wide CO2 emission limits for specified driving cycles.
- Violating the limits equals the increased cost of vehicle ownership and running cost (Road Tax).

CO_2 Emissions Regulations – Light Vehicles
(Source: ICCT)

Passenger cars



Tightening legislation in Europe, the US, Japan and China is driving demand for ultra fuel efficient engines and stimulating the move to engine downsizing.

Driving Cycles

White Paper

DEVELOPMENT OF TEST CYCLE CONVERSION FACTORS AMONG WORLDWIDE LIGHT-DUTY VEHICLE CO^2 EMISSION STANDARDS

BY JÖRG KÜHLWEIN, JOHN GERMAN, ANUP BANDIVADEKAR

Ideally Cars with No CO_2

- The way to reduce CO_2 emission in cars is either to **stop using fossil fuels** and look for an alternative source of energy **or** try to **use it more efficiently**.

Improvements can come from:

- **Lighter** Vehicles**.**
- Better **Tyres.**
- More efficient **gearbox** and **transmission system** with fewer losses as power is being transferred from the **engine to the Wheels**.
- More efficient **engines**.

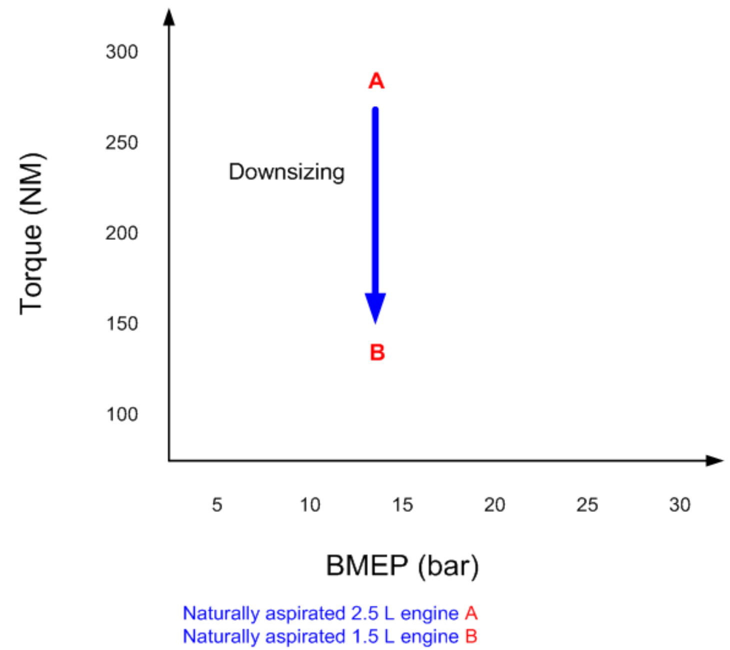
Efficiency in Engines

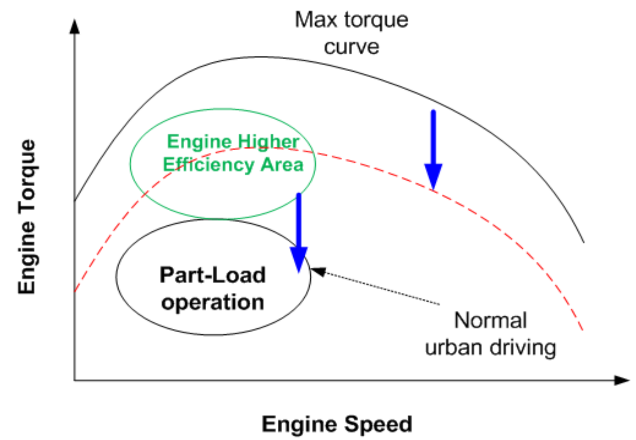
can be improved by:

- Optimal fuel injection and ignition
  - Injection timing; multiple injections (Temporal Distribution)
  - Fuel quantity and where in-chamber (Spatial Distribution)
  - Spark timing (in SI engines) and spark intensity
- VVT Variable Valve timing
  - Adjusting opening and closing of the cylinder valves for various engine speeds to optimise BMEP.
- Downsizing
  - Making engines smaller

Downsizing

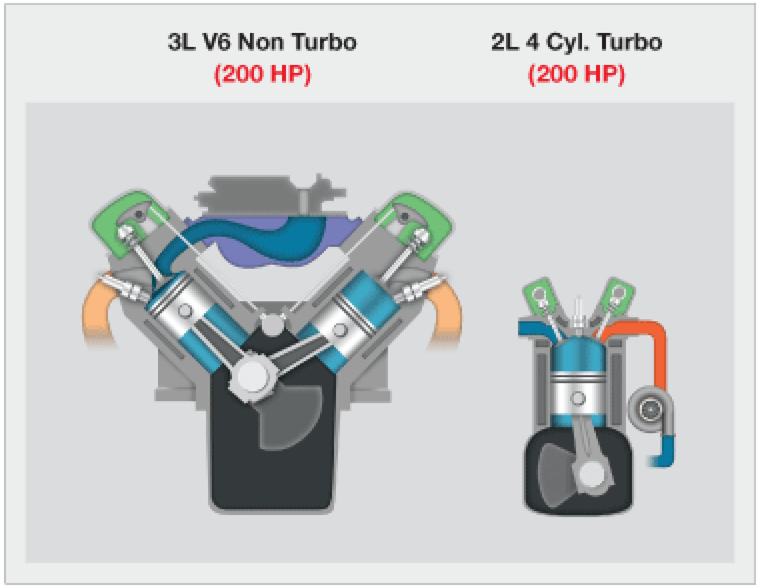
- Smaller engine means
- less weight
- less friction
- less volume of air to displace and so less pumping loss associated with that.
- But it also means less torque and power output
- P.V=T.θ





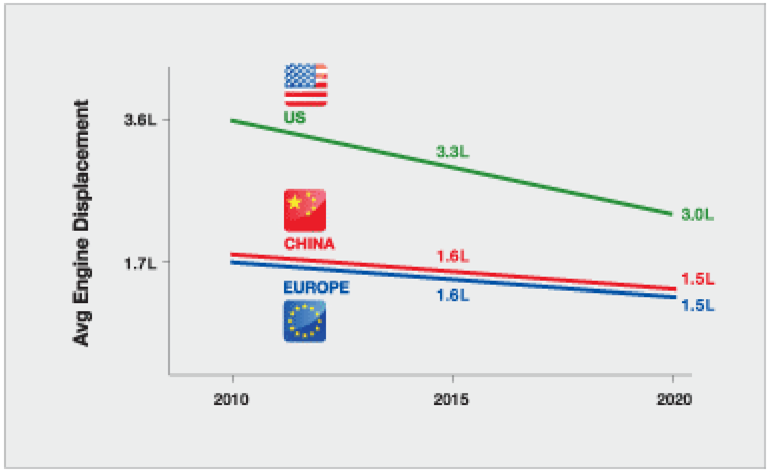
Downsizing Trend

Turbo + Small Engine = Fuel Economy



By harnessing the energy from exhaust gas otherwise wasted, turbocharger helps a smaller engine to perform like a bigger one with better fuel efficiency.

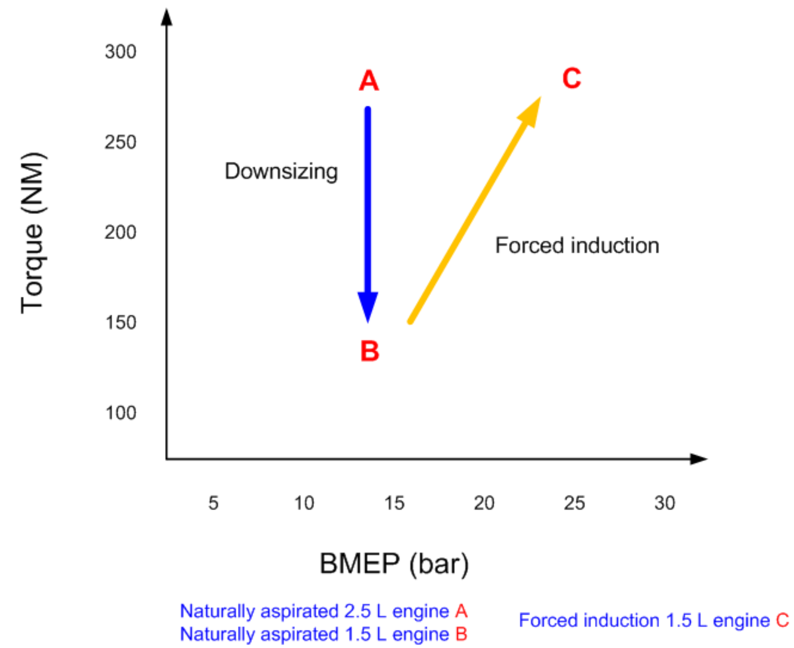
Engine Downsizing Trend
(Source: Global Insight & Honeywell)

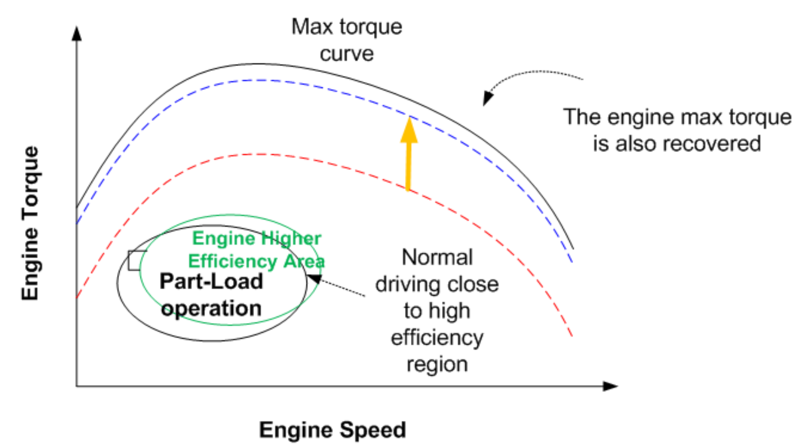


Turbo's ability to deliver big engine performance in smaller displacement power blocks will increasingly support an automotive industry downsizing agenda focused on meeting fuel efficiency targets while maintaining impressive driveability.

Forced Induction

- Downsizing can be realised by forced induction.
- Purpose: To increase the charge density using a compressor at intake.
- With compression comes rise in charged air temperature that reduces the density.
- Enabled using supercharging and/or turbocharging.





Combustion

Thermal energy contained within the system

Internal Energy

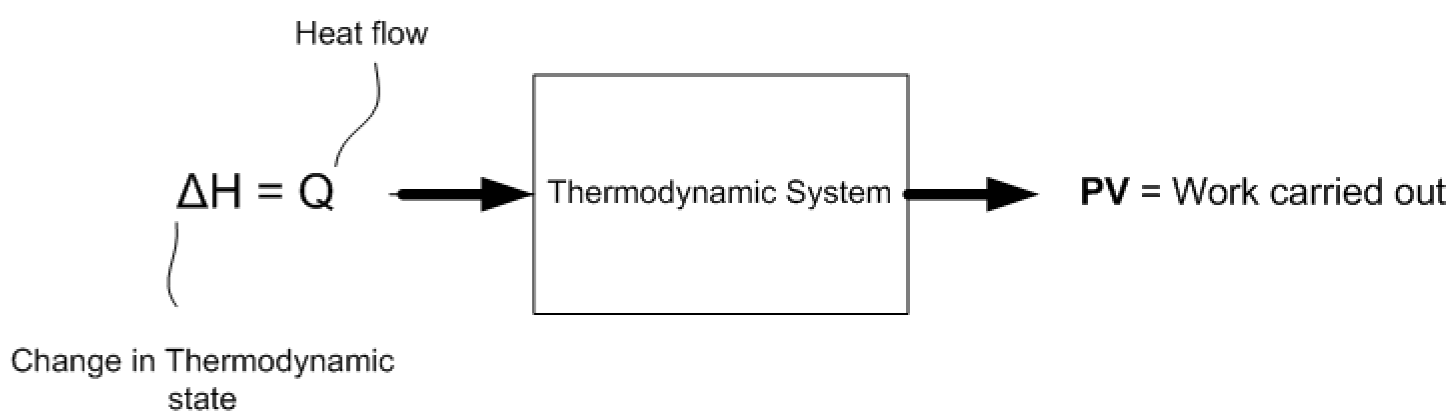
Enthalpy (Thermodynamic potential)

Work done on / by the system

Mechanical energy

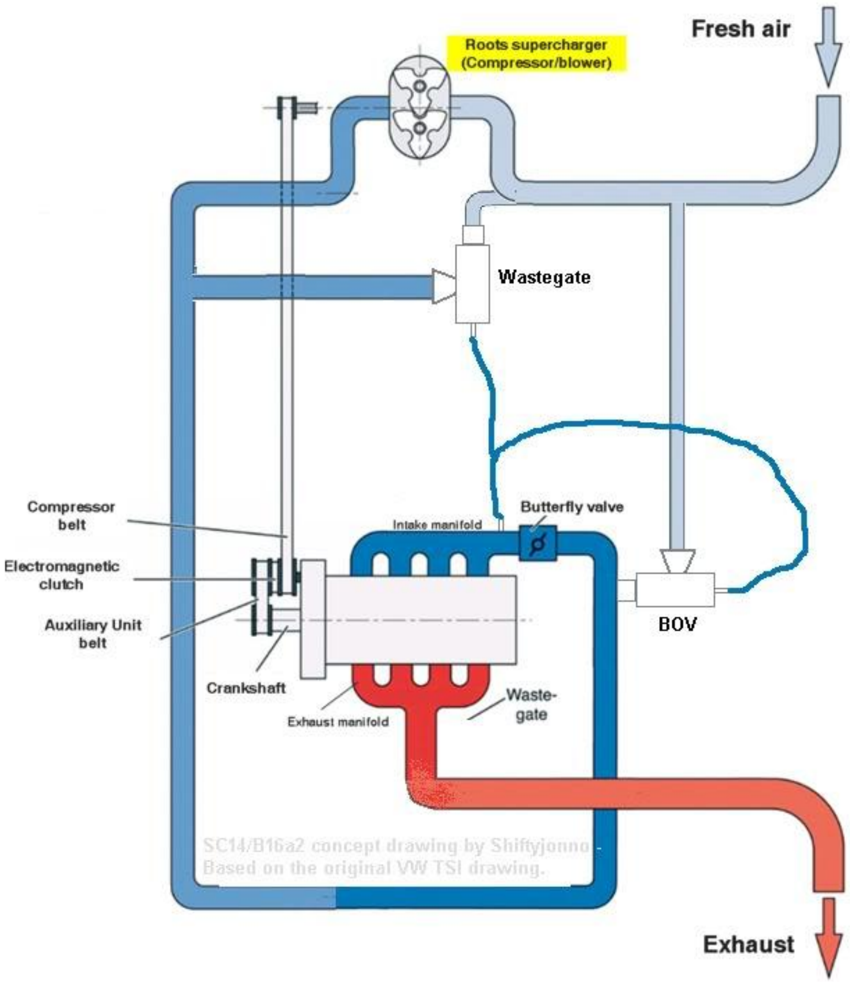
$$U = H - PV$$

Or if you prefer **H = U + PV**



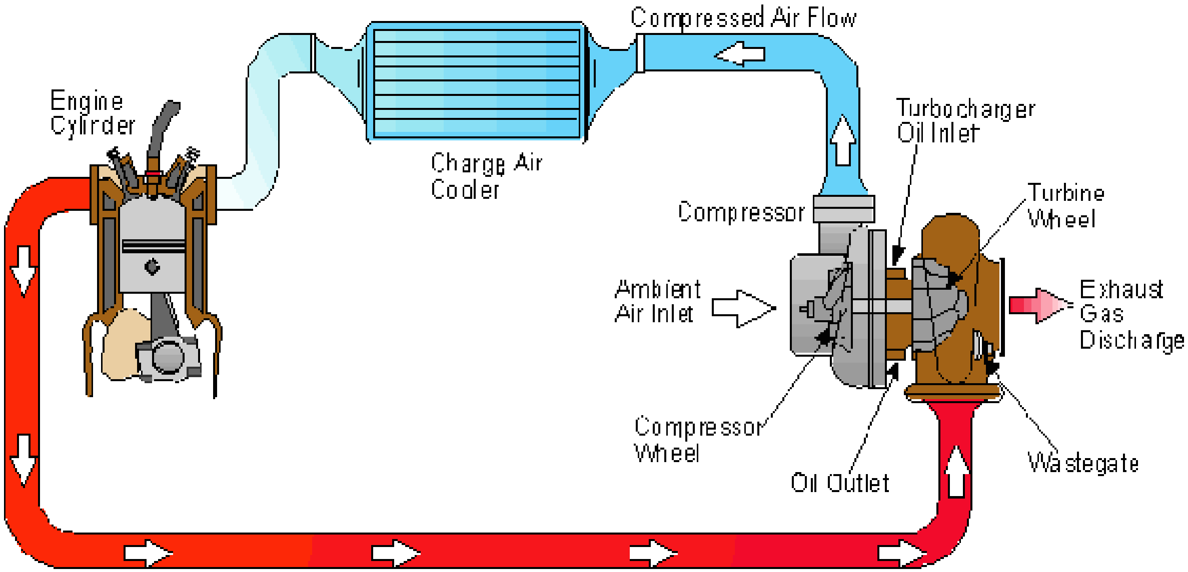
Supercharging

- Compressor powered by engine output.
- No throttle response delay (Boost-lag) as superchargers apply boost in direct proportion to the engine speed (RPM).
- Compressor high efficiency is limited to range of RPM.
- Use of variable speed drives can address this issue. By decoupling the compressor speed from engine speed.
- Supercharging can be realised mechanically or electrically.

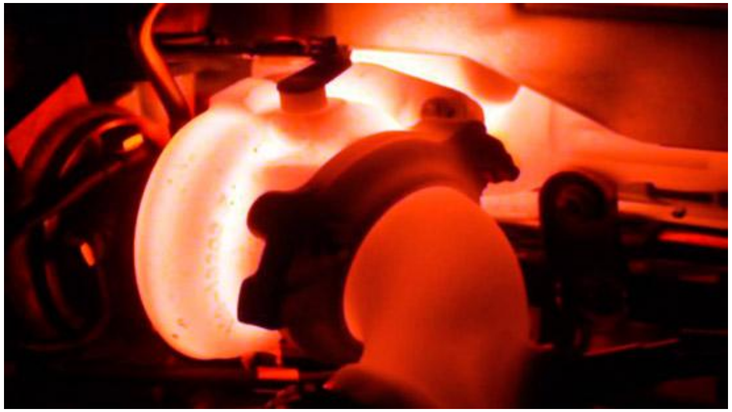


Turbocharging

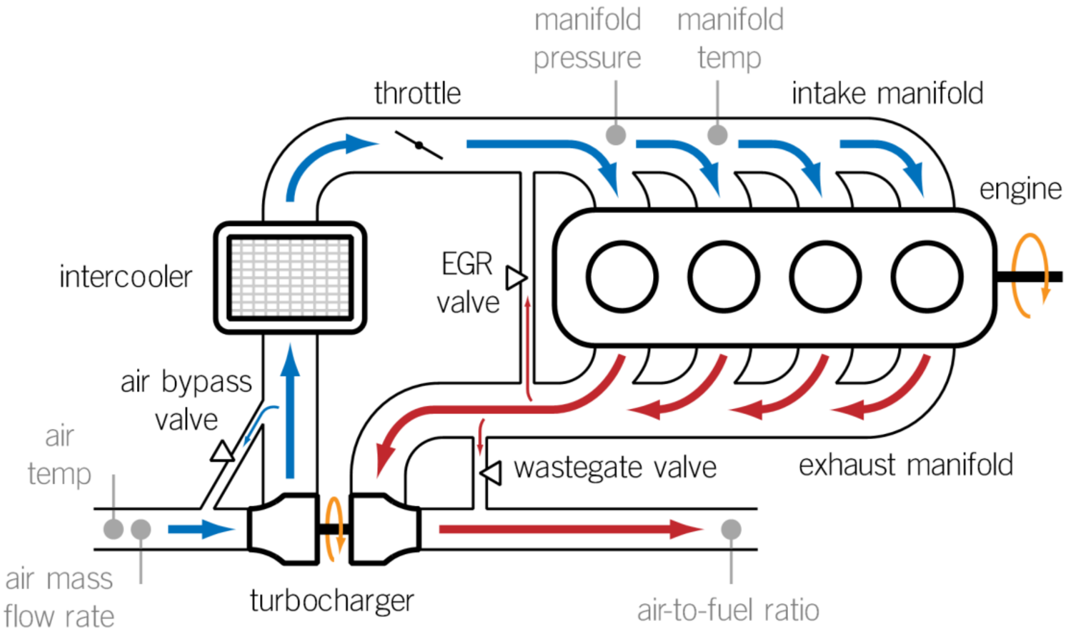
- Compressor powered by exhaust turbine
- Uses ‘wasted’ exhaust energy
- Affects exhaust treatment
- Boost-lag problem
- Limited high efficiency flow range.



Air-path

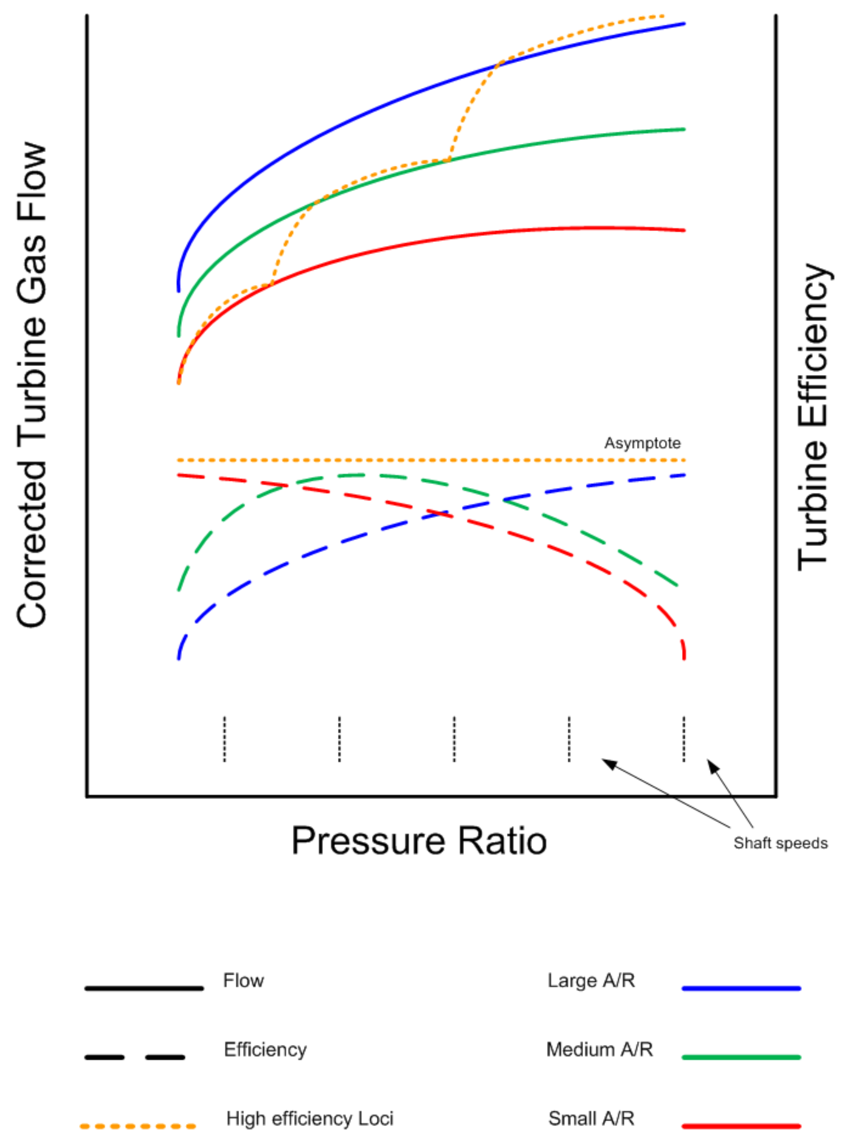


- Manifolds
- Exhaust gas circulation –EGR
- Waste-gate
- Air by-pass valve
- Throttle valve
- Intercooler
- EGR cooler



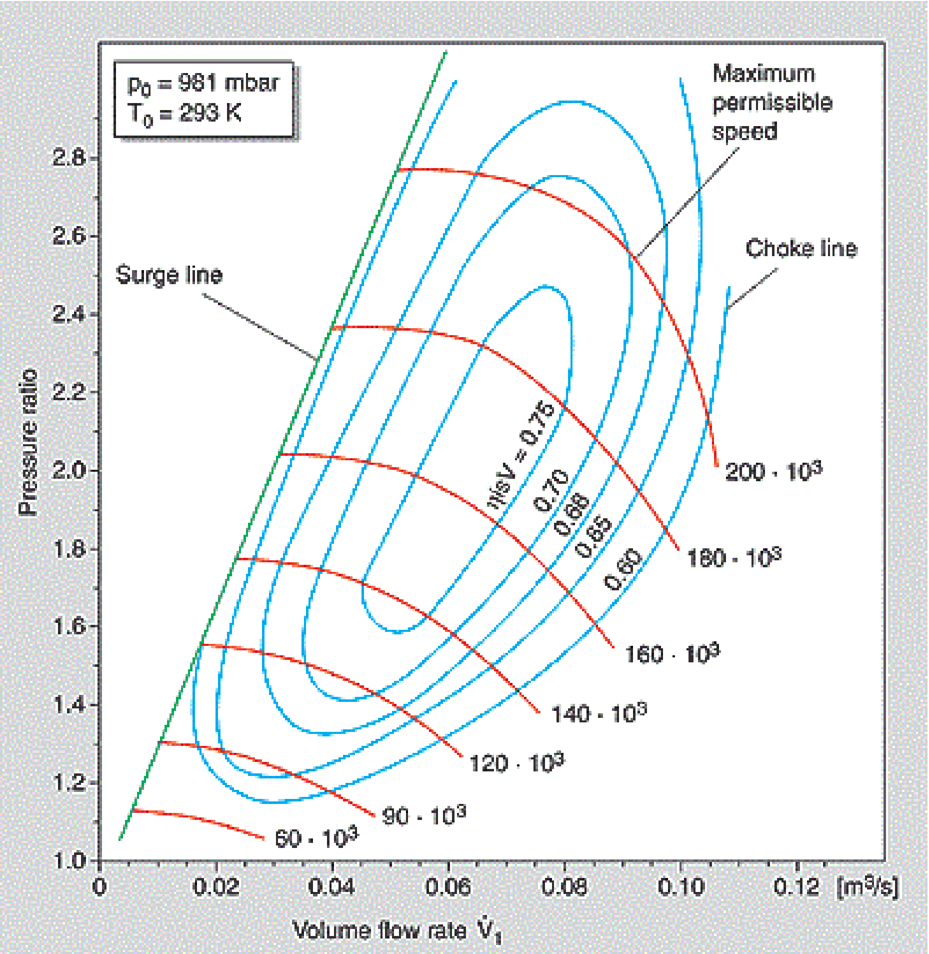
Radial inflow Turbine

- The goal is to reach higher shaft speeds at shortest time possible with available gas flow.
- $T = J \cdot d\omega / dt$
- Rotational inertia $J = mr^2$
- The mass m is the combined mass of the turbine wheel and compressor wheel and the shaft assembly.
- Aspect ratio A/R; a geometrical measure
- Choked flow
- Choked flow avoided by waste-gate valve
- Flow and Turbine efficiency adjusted by VGT



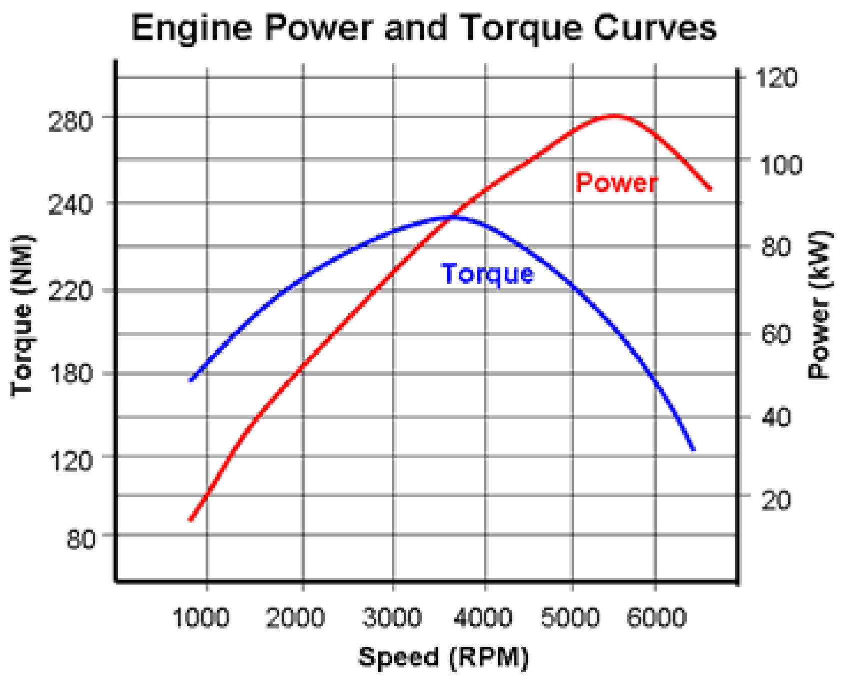
Compressor

- Compressor creates pressure (boost) and airflow based on the speed of rotation.
- Surge
- Blow off and by pass valves to prevent surge
- Choked flow



Engine and Turbocharger Matching

- Turbochargers are only very efficient for a narrow range of flow(speeds); often at higher operating speeds.
- while engines operate over a wide range of speeds.
- As part of the engine design strategy turbo's compressor high efficiency area is matched with the region where the engine is more likely to operate around.
- This compromises the out of range operations in terms of efficiency and performance.
- VGT can help to some extend with the turbine side of the efficiency.
- The issue of throttle response delay will remain.

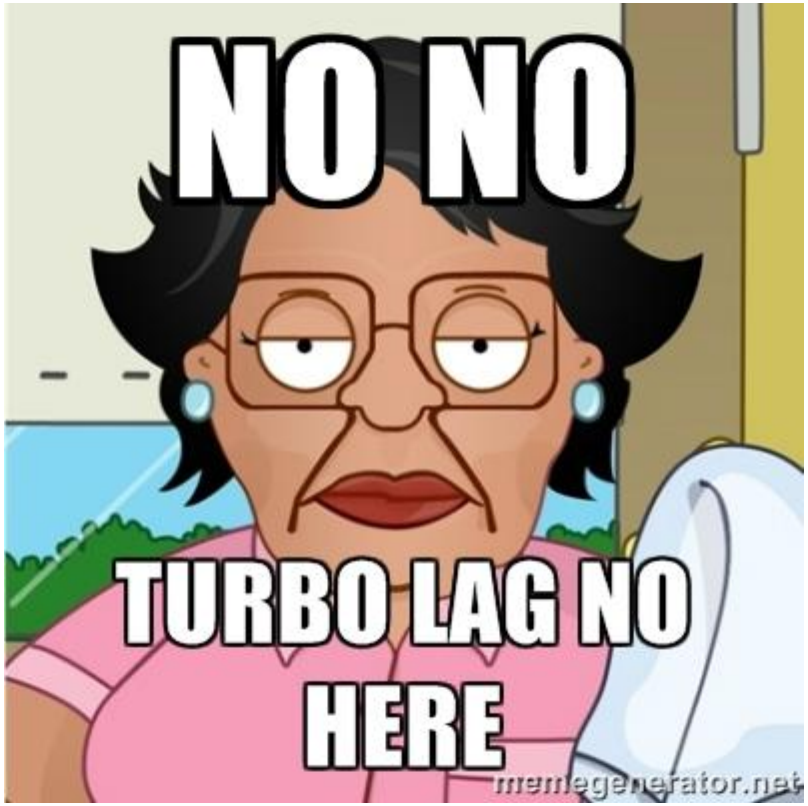


Turbo-Lag

- Rotational inertia
- $J = mr^2$
- $T = J \cdot d\omega/dt$
- Larger turbo is a less responsive turbo
- Smaller turbo more responsive but inefficient at higher gas-flow rates.

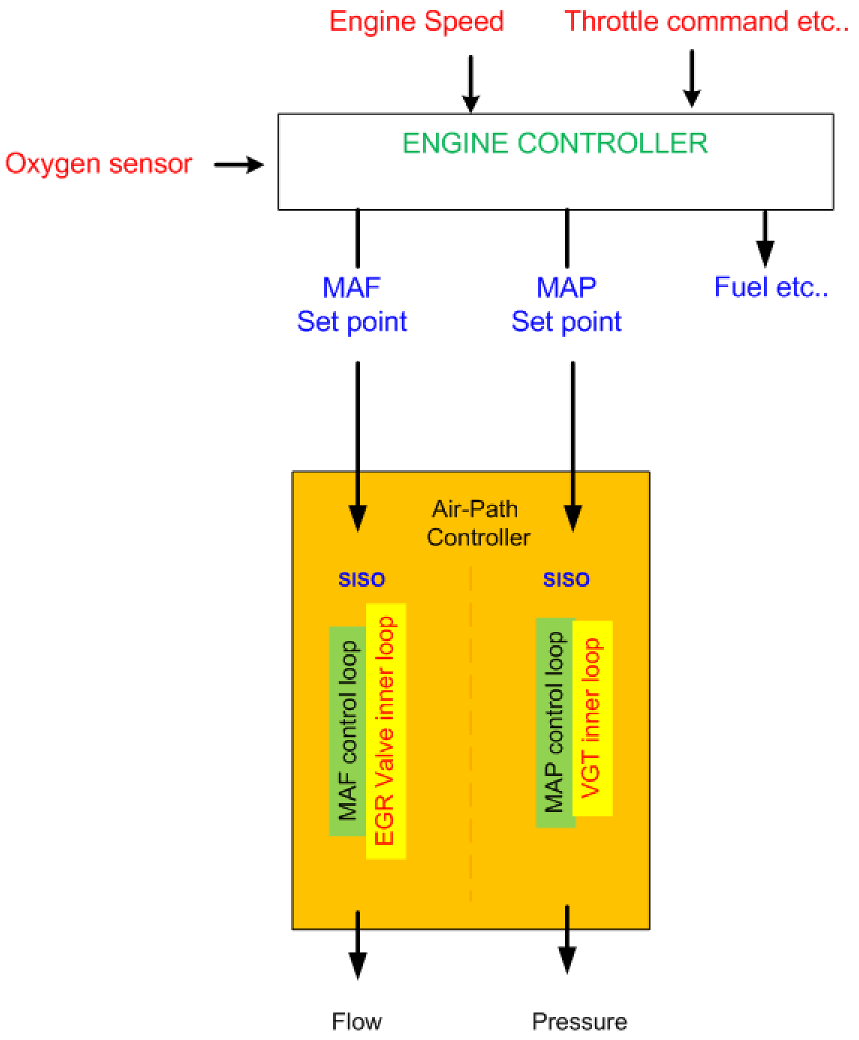
So what can be done?

- Combine supercharging with turbocharging.
- Switch to Super mode during transients and back to Turbo mode when engine is at steady state.
- Not an efficient approach during Urban driving cycle.
- More complex Turbo structures.
- Divide and match.



Conventional air-path control

- Distributed strategy.
- Two independent SISO channels.
- Control variables are coupled.
- Coupling effect is treated as uncertainty due to disturbance on each channel by the controller.
- This can work with 2 channels fine but prolongs the transient response of the system significantly if the number of channels increases.



Conclusion

- Given the nature of the challenges involved; In the light of more advance control, we may justify further investigations into incorporating more complex turbocharging structures into the air-path system to pave the way for more sever downsizing that can lead to more thermal efficiency and CO_2 reductions.