UNIVERSITA' degli STUDI di ROMA
TOR VERGATA

Effect of turbo-compounding technology on the performance of internal combustion engines

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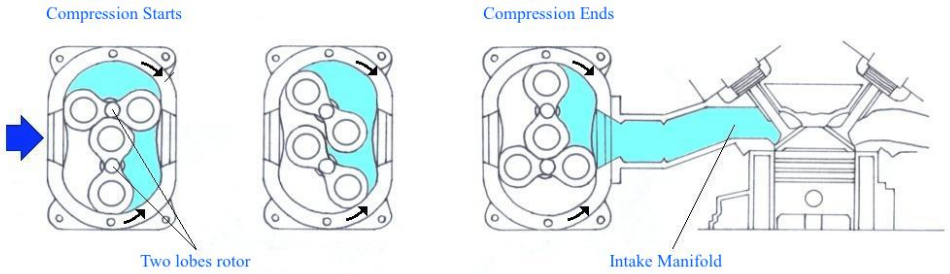
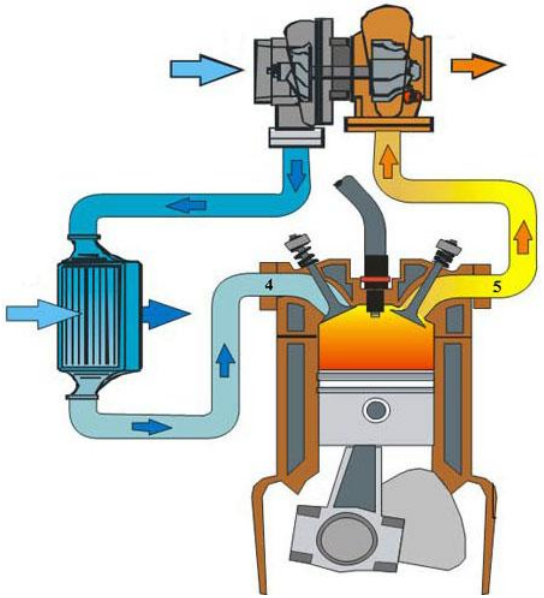
Context

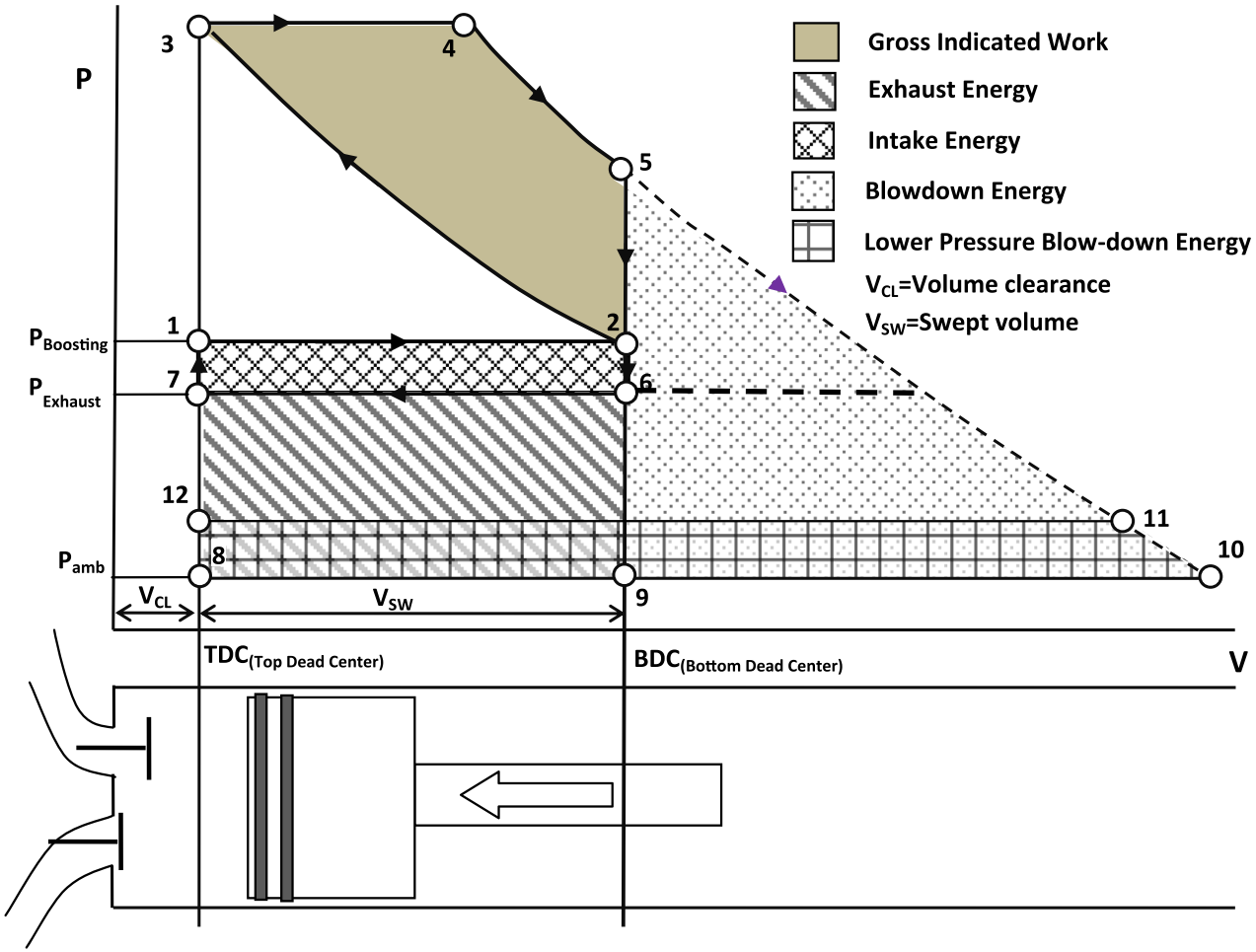
Forced Induction : is the process of delivering compressed air to the intake of an IC engine





- **Supercharging** : mechanically driven compressor
- **Turbocharging** : compressor is coupled to an exhaust gases driven turbine

Exhaust Gases Energy



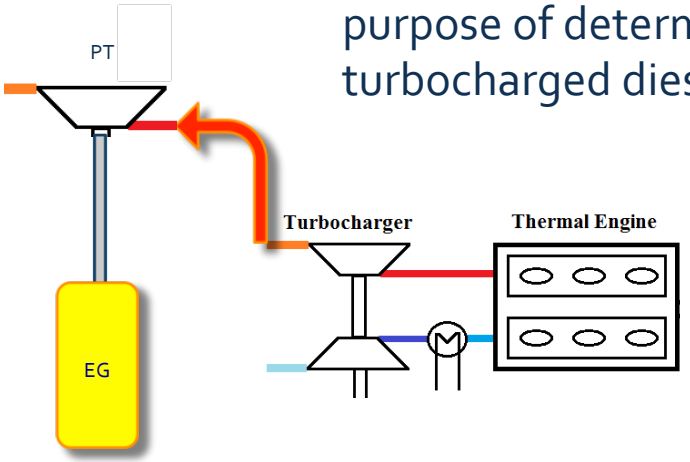
Electric Turbo-Compounding System

Issue : Unexploited waste heat up to 30 – 40 % only partially recovered by the turbocharger group in the standard engine configuration

Application : Installation of a Power Turbine coupled to an electric generator

- Utilization of exhaust energy for additional power generation
- Conversion to mechanical or electrical energy
- Useful energy is stored in battery packs

Analysis : Conducted by assuming as varying parameter the rotational speed of power turbine shaft ranging from 60 krpm to 110 krpm, with the purpose of determining the interaction between the PT and a turbocharged diesel engine at different loads for fixed engine speed.



= Standard engine + turbo-compounding

Reference engine specifications

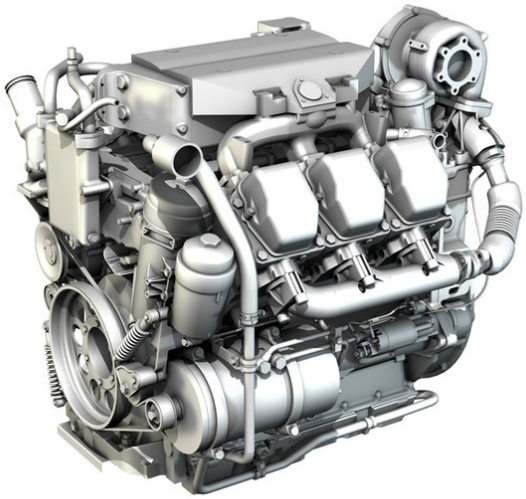
The diesel engine considered is a six-cylinders turbocharged truck engine with the following operating data

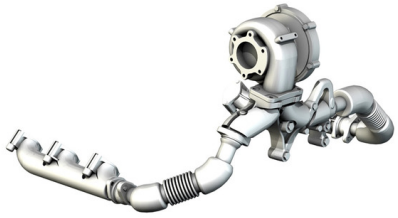
Operating data for the standard engine without turbocompounding.

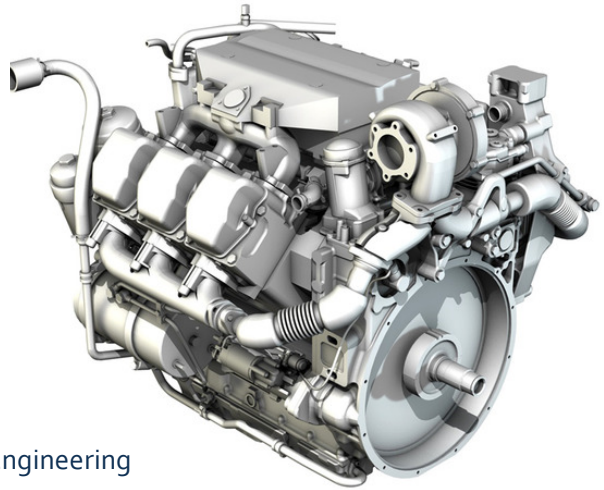
Load (%)	$\dot{m}_{fuel}$ (kg/h)	Injection advance (deg ATDC)	p_{boost} (bara)	AF (−)	p_{exh} (bar)	T_{exh} (°C)	Power (kW)
100	28.03	−8	3.08	24.41	2.66	585.40	334.13
75	20.88	−8	2.65	28.65	2.41	501.95	248.86
50	13.92	−7	2.23	35.11	2.24	420.20	165.91

Operating data for the standard turbocharger.

Load (%)	Eff_{compr} (%)	Eff_{turb} (%)	N_{TC} (krpm)
100	72.0	72.0	98.84
75	73.5	73.5	89.301
50	73.0	73.0	79.191







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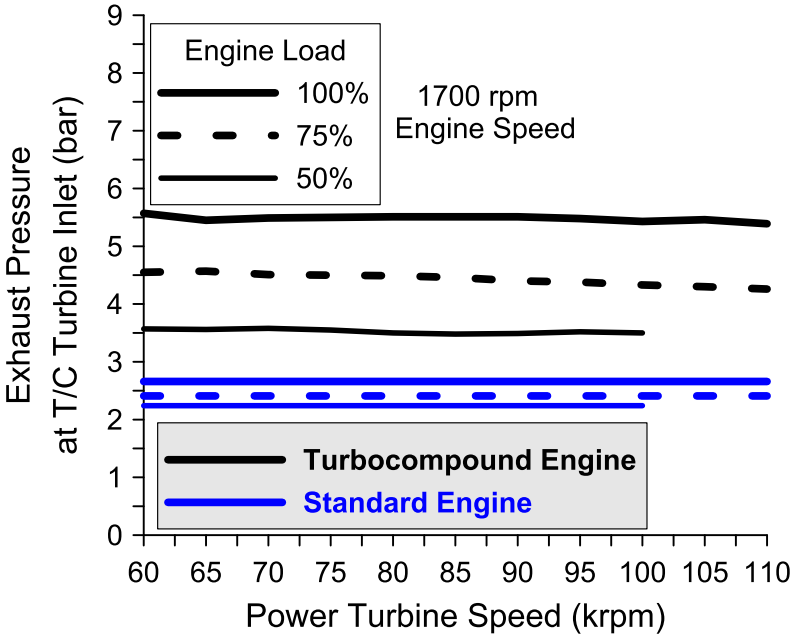
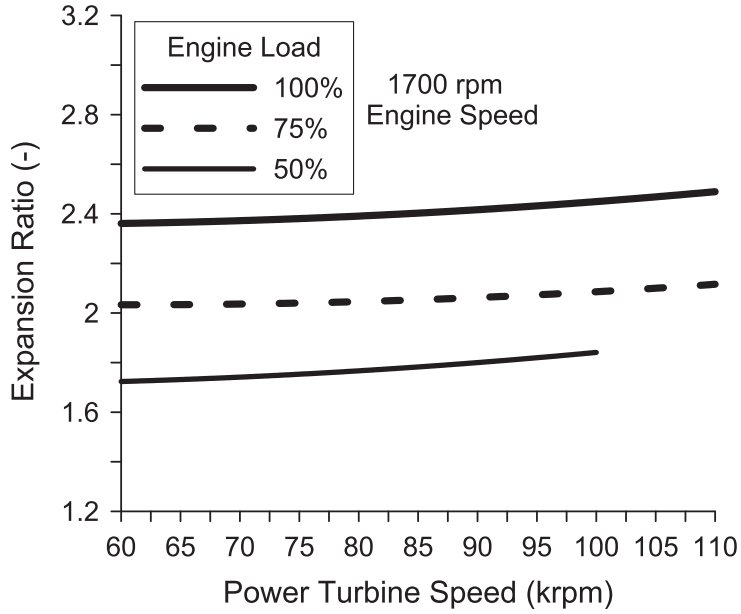
Effect on exhaust pressure at T/C turbine inlet and on power turbine expansion ratio





The operation of the rotational PT opposes the free flow of exhaust gases to the ambient :

- Significant increase of backpressure at the exhaust manifold connecting the engine with the T/C turbine

$$\Delta P_{50\%} = 1.26 bar$$
$$\Delta P_{75\%} = 2.09 bar$$
$$\Delta P_{100\%} = 2.84 bar$$

- T/C turbine expansion ratio decreases $\beta = P_{ex} / P_{pt}$

Effect on T/C components efficiency

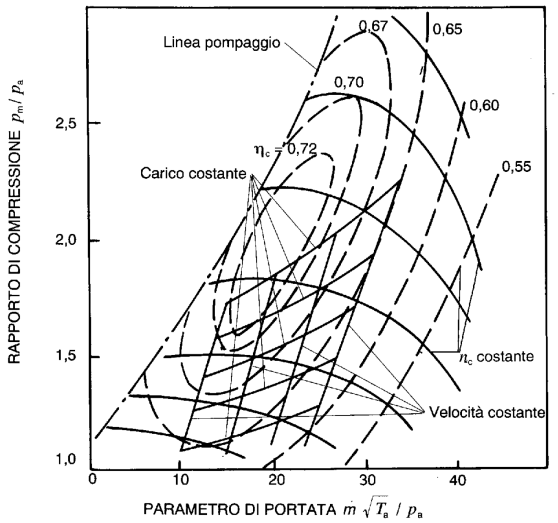
Starting from a fixed optimized value for the Efficiency :

➡ **Turbine :** efficiency decreases because of the expansion ratio reduction

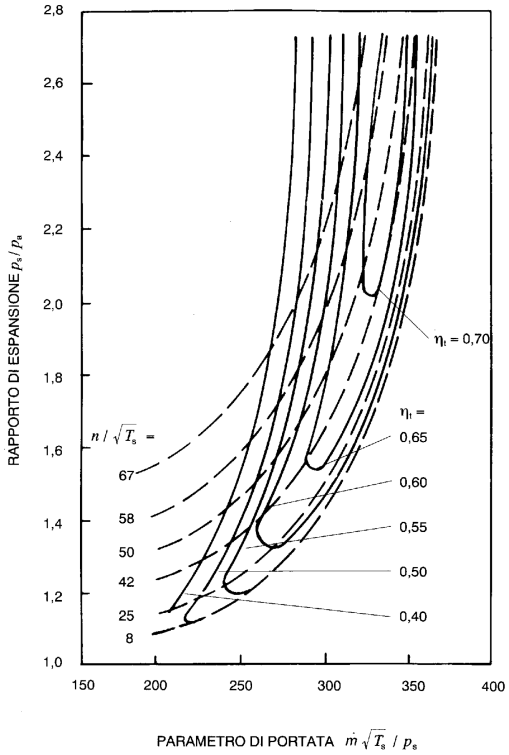
→ Reduction of turbine generated torque

→ Reduction of T/C shaft rotational speed

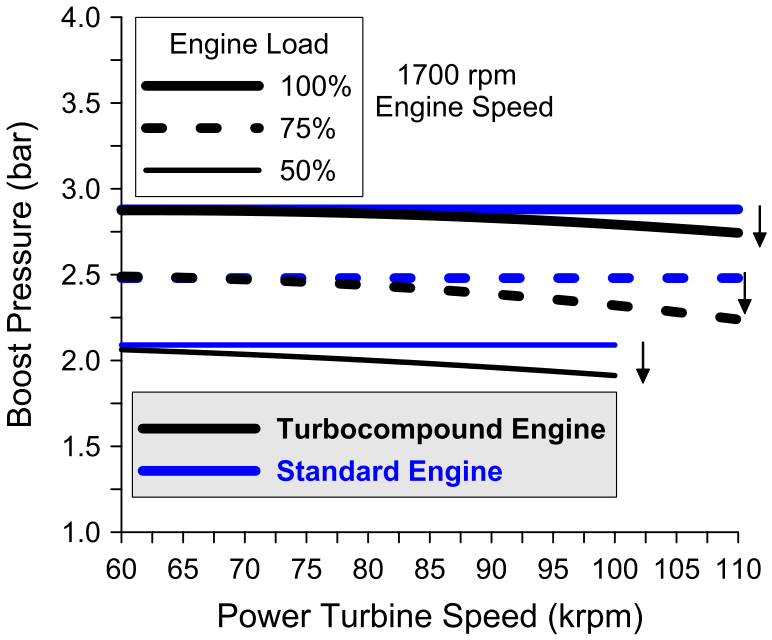
➡ **Compressor :** efficiency decreases due to shaft rotational speed reduction which changes the value of the boost pressure

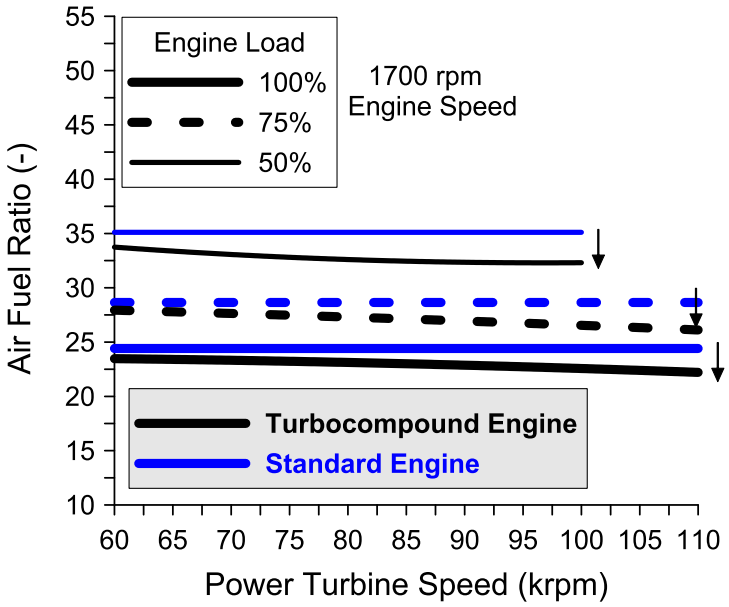


Efficiencies reduction are due to the fact that the turbocharger is not working at its designed operating point which is assumed for the standard engine configuration



Effect on boost pressure and on air fuel ratio





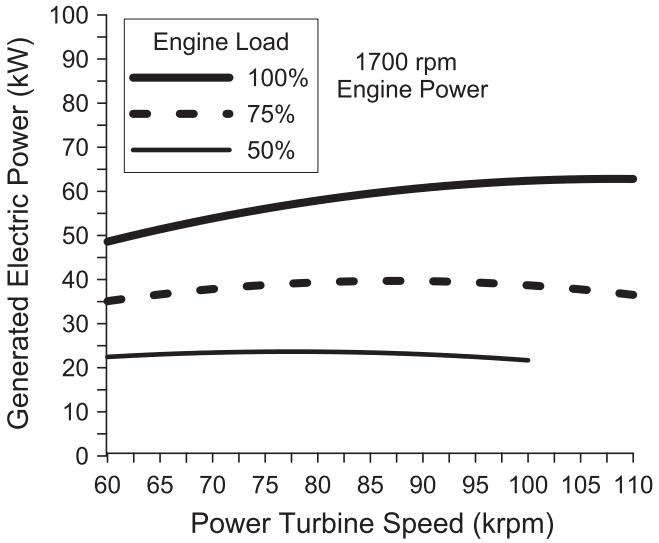
Limited reduction of boost pressure attributed to the aforementioned T/C shaft rotational speed decrease

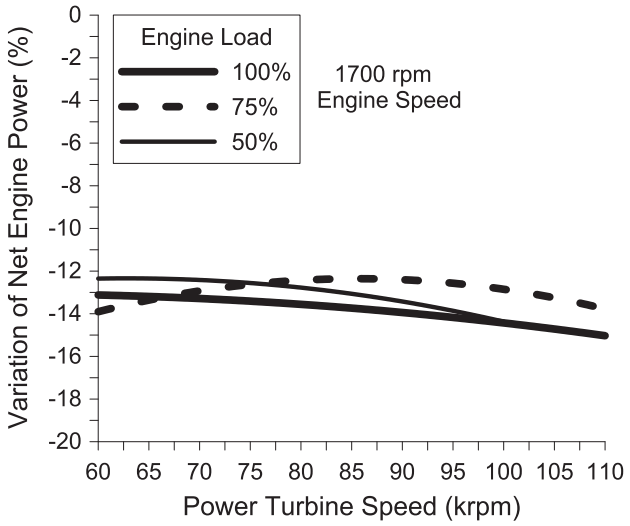
Rather limited especially for low PT speeds

For fixed mass of fuel injected the mass of air drawn is reduced due to the effect on boost pressure resulting into a α curtailment

$$\alpha = m_a / m_f$$

Electric power generation and net engine power



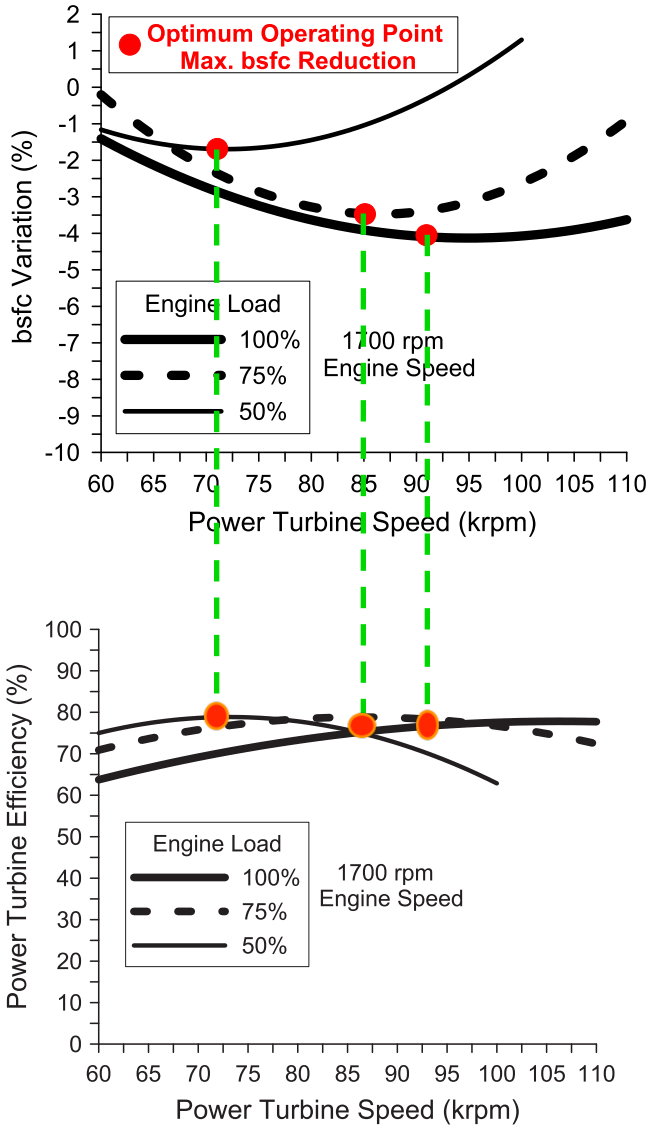


Gains are enhanced with increasing engine load due to the higher thermal energy associated with the exhaust gases expanding in the power turbine showing different behaviors for each engine load

- Maximum achieved values
  - 62 kW at 100%
  - 39 kW at 75%
  - 23 kW at 50%
- Significant decrease of engine power up to 15% due to the air fuel ratio reduction

$$P_{tot} = P_{engine} + P_{electric}$$

Effect of power turbine speed on sfc

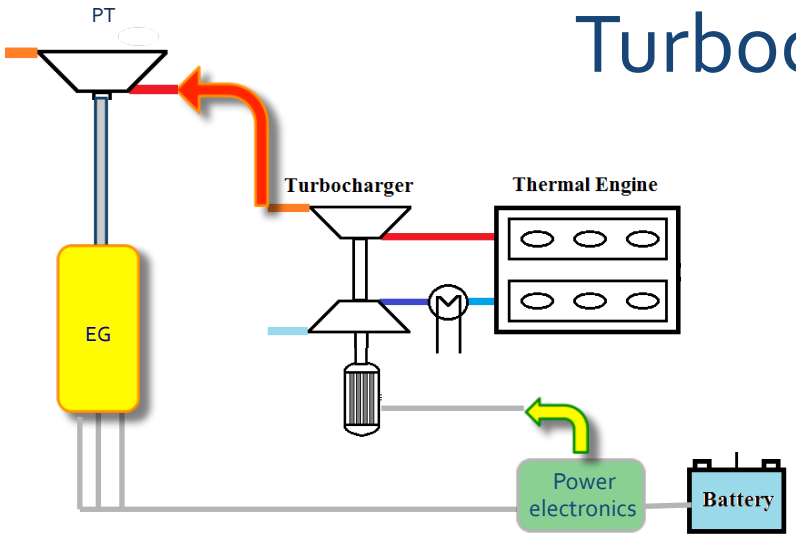


At all loads the positive effect of the applied turbo compounding technology on sfc is enhanced with increasing power turbine speed up to a certain point which is defined as the operating point of the turbo-compounding engine

Engine load	sfc variation	PT speed
50%	2.1%	70 krpm
75%	3.6%	85 krpm
100%	4.5%	90 krpm

$$sfc = \frac{m_{fuel}}{P_{engine} + P_{electric}} \longrightarrow sf(\%) = \frac{sfc_{tc} - sfc_{st}}{sfc_{tc}} \times 100\%$$

Turbocharger Dynamic Behavior



Compressor : $P_C = \dot{m}_a / \eta_c \, c_{p\_a} T_a (\beta_c^{\lambda a} - 1)$

Turbine : $P_{T=} (\dot{m}_a + \dot{m}_f) \eta_T c_{p\_e} T_e (1 - \beta_T^{\lambda})$

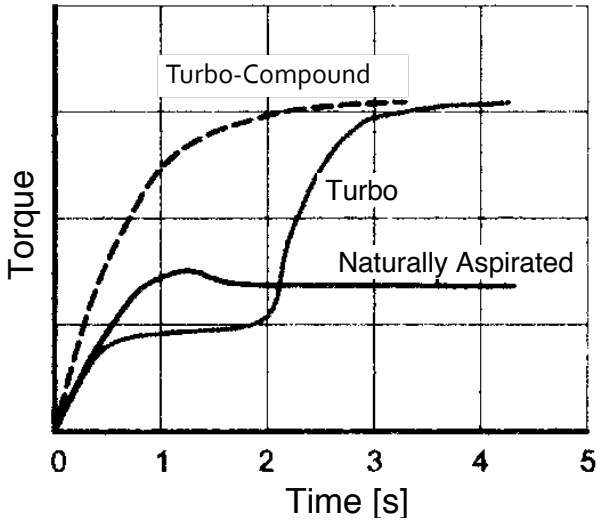
$$P_T - P_C + P_{el} = J\omega(d\omega/dt) \quad \Leftrightarrow \quad M_T - M_C = J(d\omega/dt) - M_{el}$$

At steady state :

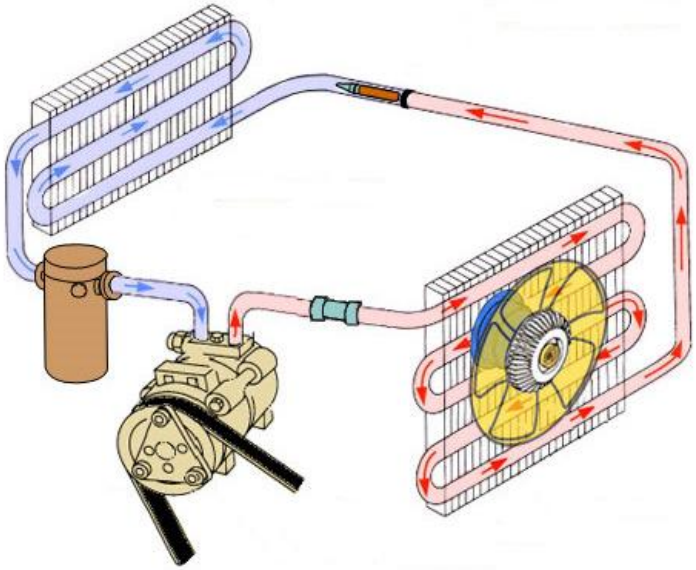
- $d\omega/dt = 0$
- $P_{el} = 0$

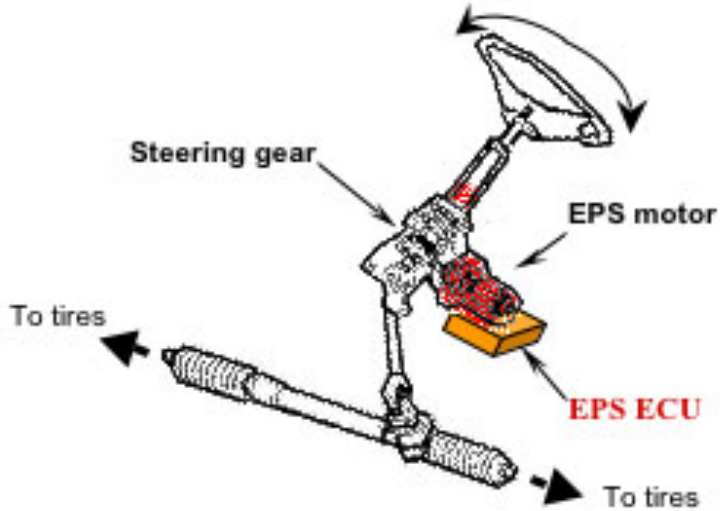
$\Rightarrow \quad P_T = P_C$

$$\frac{M_T - M_C + M_{el}}{J_{TC} + J_{el}} > \frac{M_T - M_C}{J_{TC}}$$



Electric motor mounted on the turbocharger shaft improve the turbo-charger's dynamics only if the angular acceleration of the electrically assisted turbocharger exceeds that of the baseline turbocharger.





Other possible energy uses

Thank you

for your attention