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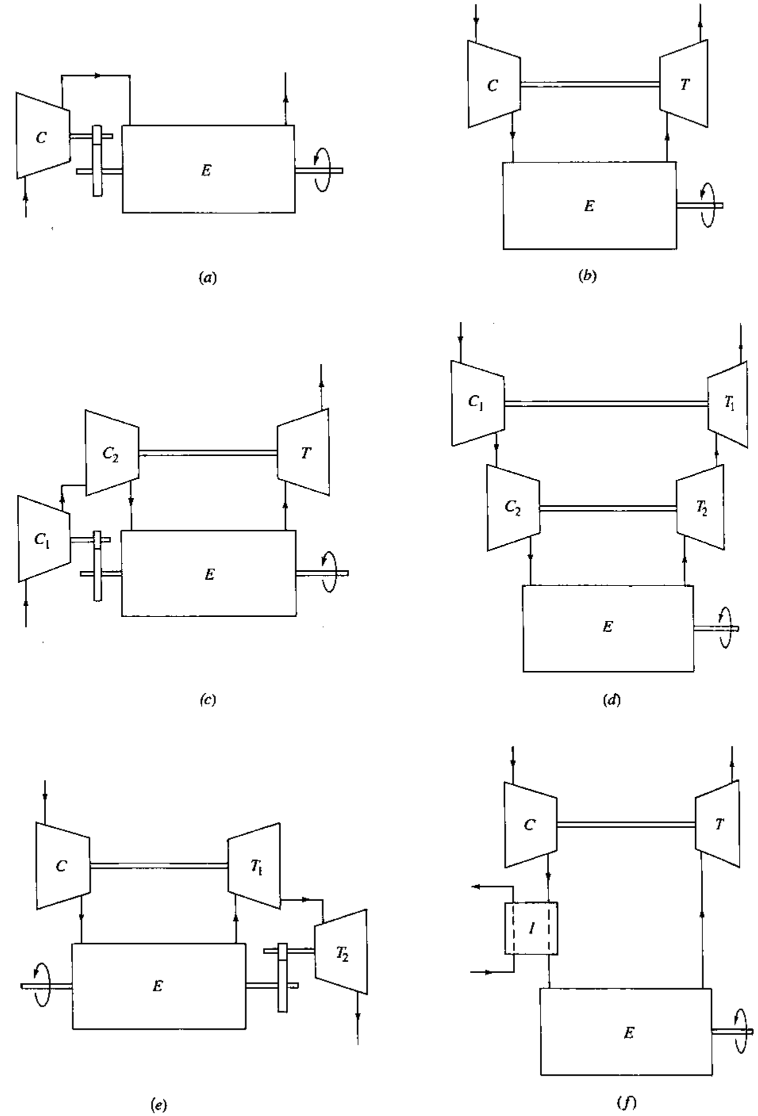
EEN-E2002, Internal Combustion Air Management 2, supercharging

Basshuysen Chapter 11 Supercharging of Internal Combustion Engines
Heywood Chapter 6 Gas exchange process

January 2019, Martti Larmi

The six basic ways of supercharging and turbocharging, Heywood Fig. 6-37

C Compressor
T Turbine
E Engine
I   Charge air cooler / Inter cooler



Adiabatic flow in during compression

$$h_0 = h + \frac{C^2}{2}$$

Subscript 0 refers to total conditions, i.e. dynamic effects included

$$T_0 = T + \frac{C^2}{2c_p}$$

$$p_0 = p\left(\frac{T_0}{T}\right)^{\gamma/(\gamma-1)}$$

$$-\dot{W} = \dot{m}(h_{0,out} - h_{0,in})$$

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Isentropic efficiency

Subscript 1refers to conditions before compressor and subscript 2 after the compressor, s refers to isentropic

C compressor

TT total to total
TS total to static

$$\eta_c = \frac{\text{reversible power requirement}}{\text{actual power requirement}}$$

$$\eta_{CTT} = \frac{(p_{02}/p_{01})^{(\gamma-1)/\gamma} - 1}{(T_{02}/T_{01}) - 1}$$

$$\eta_{CTS} = \frac{T_{2s} - T_{01}}{T_{02} - T_{01}} = \frac{(p_2/p_{01})^{(\gamma-1)/\gamma} - 1}{(T_{02}/T_{01}) - 1}$$

$$-\dot{W}_C = \dot{m}_i c_{p,i}(T_{02} - T_{01}) = \frac{\dot{m}_i c_{p,i} T_{01}}{\eta_{CTT}} \left[\left(\frac{p_{02}}{p_{01}} \right)^{(\gamma-1)/\gamma} - 1 \right]$$

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Isentropic and mechanical efficiency

Subscript 3refers to conditions before turbine and subscript 2 after the turbine

T turbine

TT total to total
TS total to static

$$\eta_t = \frac{\text{actual power output}}{\text{reversible power output}}$$

$$\eta_{TTT} = \frac{1-(T_{04}/T_{03})}{(p_{04}/p_{03})^{(\gamma-1)/\gamma} - 1}$$

$$\eta_{TTS} = \frac{T_{03}-T_{04}}{T_{03}-T_{04s}} = \frac{1-(T_{04}/T_{03})}{(p_4/p_{03})^{(\gamma-1)/\gamma} - 1}$$

$$-\dot{W}_T = \dot{m}_e c_{p,e}(T_{03}-T_{04}) = \eta_{TTT}\dot{m}_e c_{p,e} T_{03}\left[1-\left(\frac{p_{04}}{p_{03}}\right)^{(\gamma-1)/\gamma}\right]$$

$$-\dot{W}_C = \eta_m \dot{W}_T$$

Superchargers

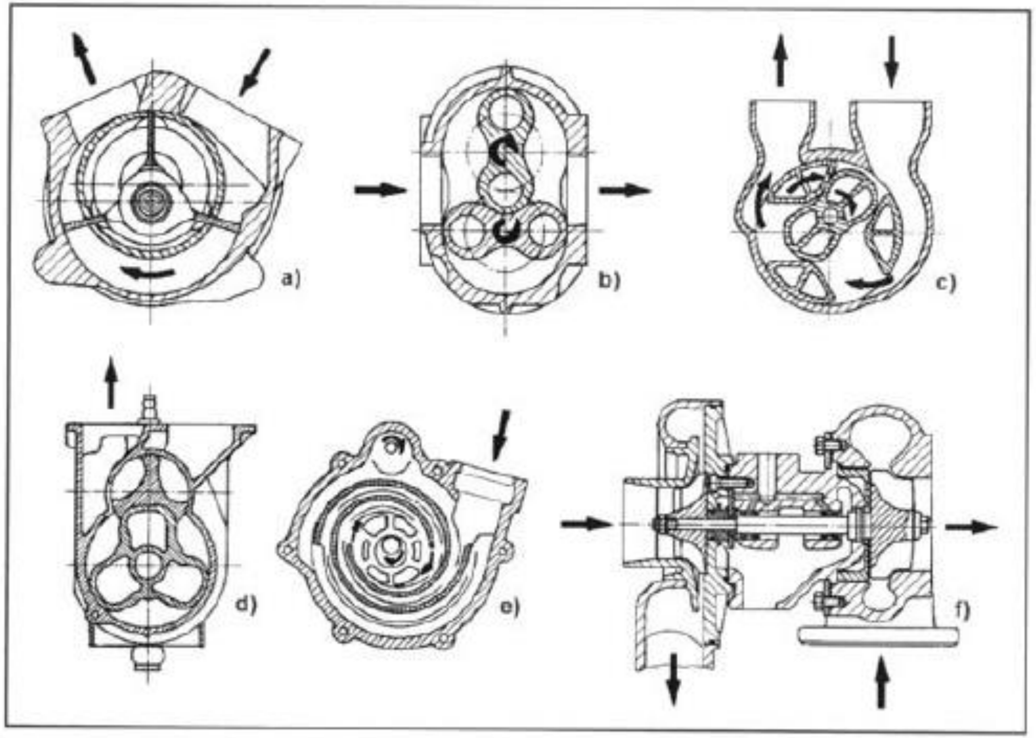
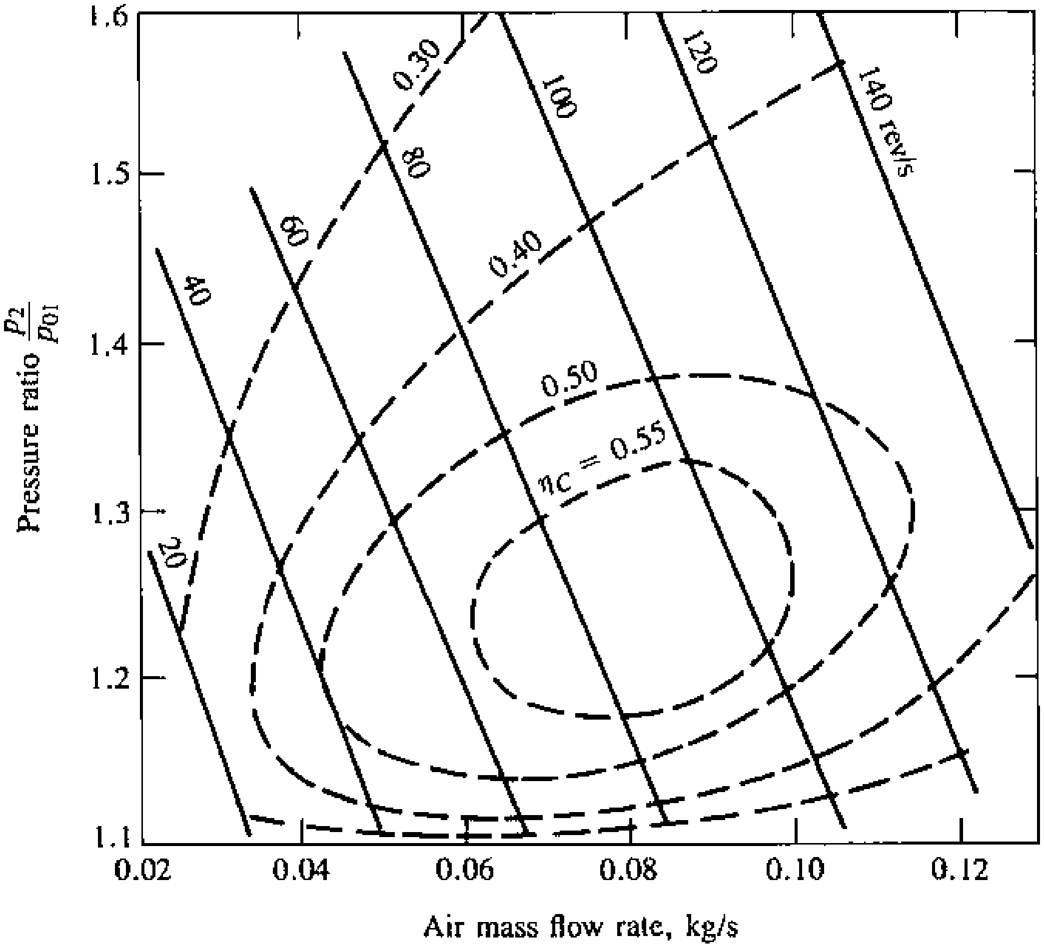
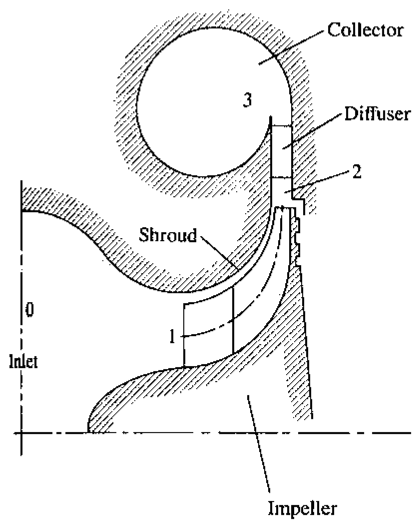


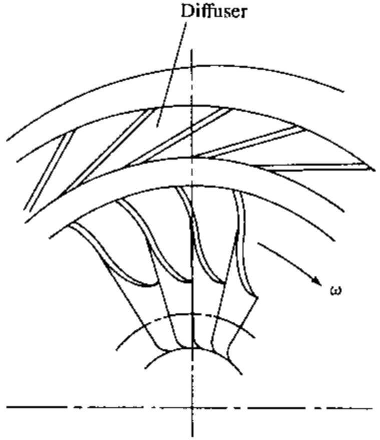
Fig. 10-60 Overview of the different designs of blowers and superchargers: (a) Vane-type superchargers, (b) Roots superchargers, (c) Rotary piston superchargers, (d) Screw compressors, (e) Spiral superchargers (G-superchargers), (f) Turbochargers.

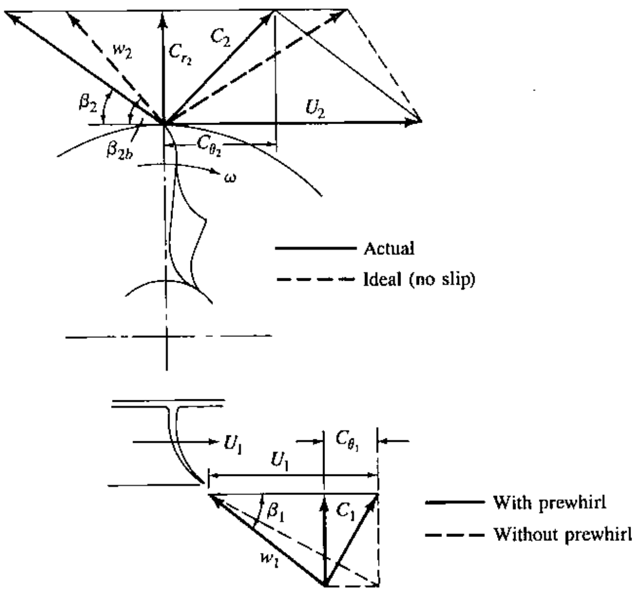
Mechanical compressor map



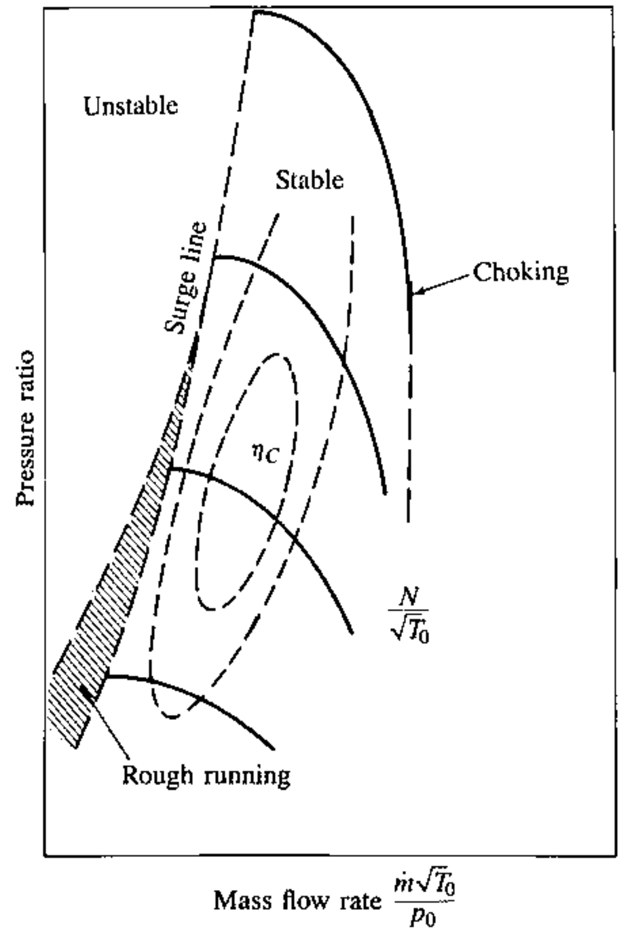
Turbocharger compressor







Turbocharger compressor map 1



Turbocharger compressor map 2

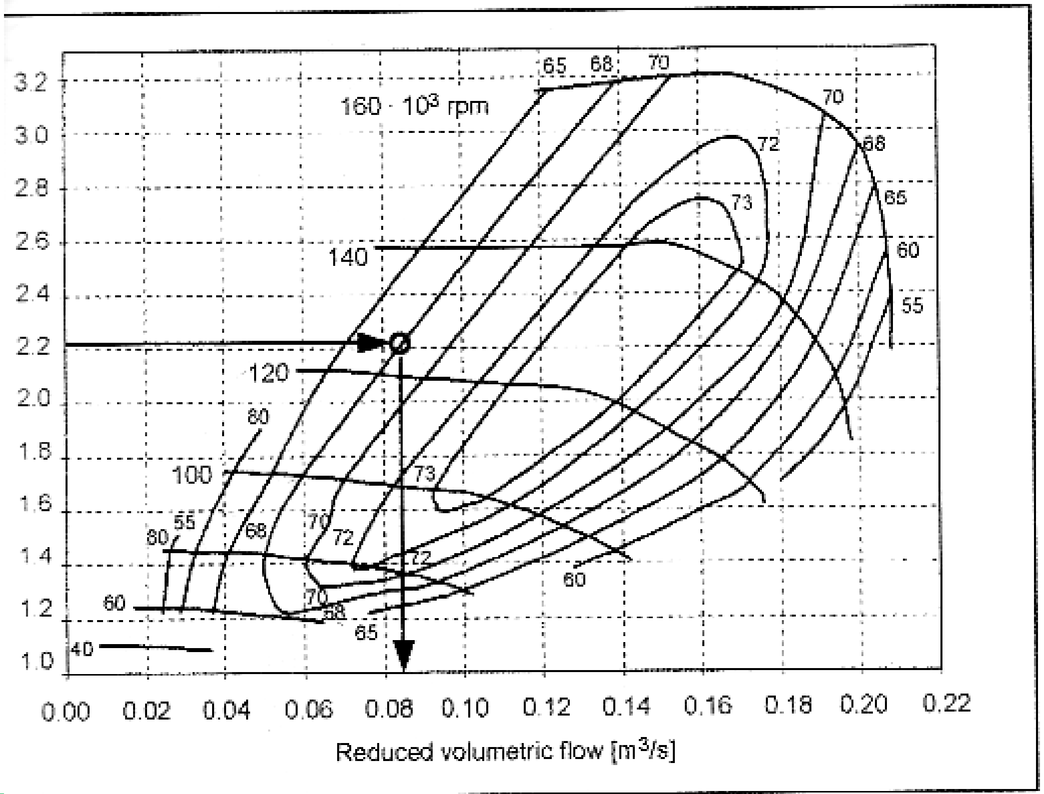
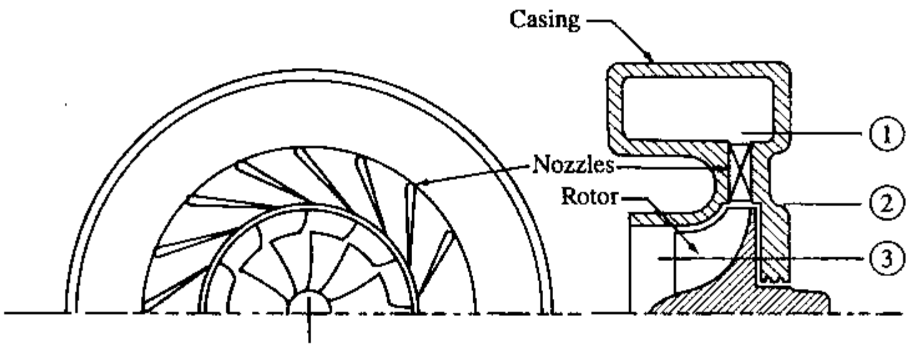
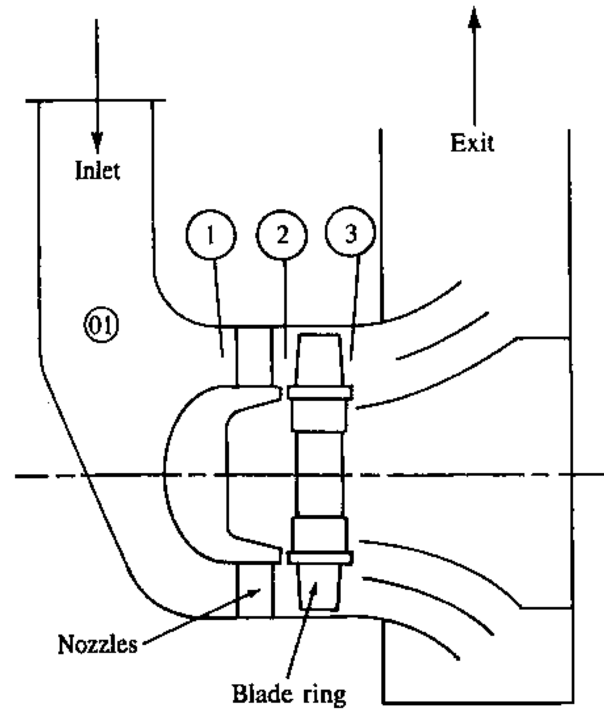


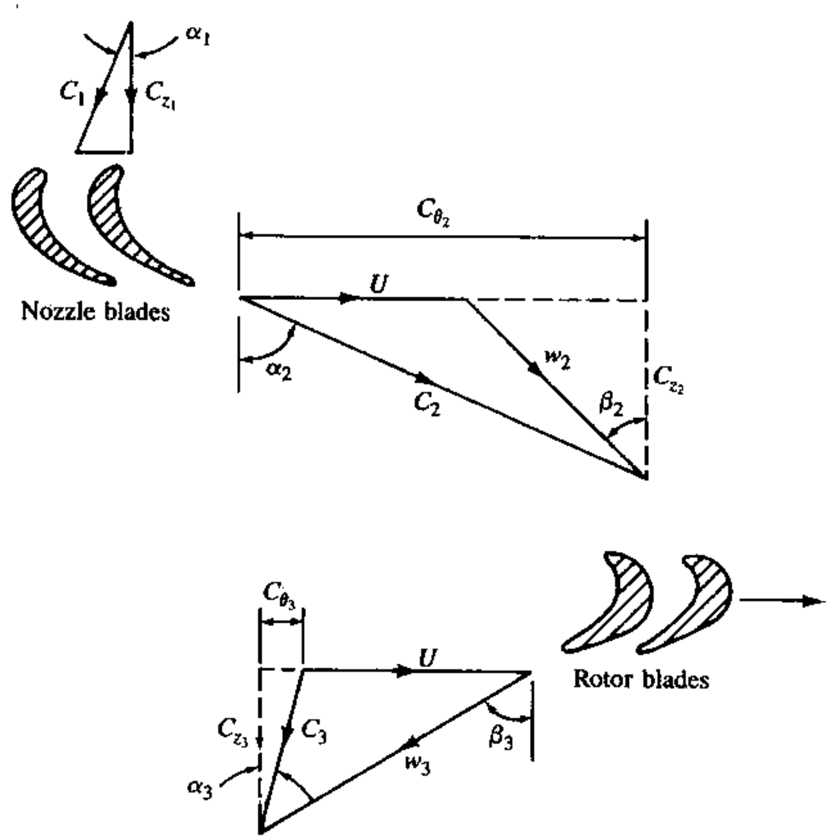
Fig. 11-9 Compressor map.

Turbocharger radial turbine and axial turbine





Velocity triangles of an axial turbine



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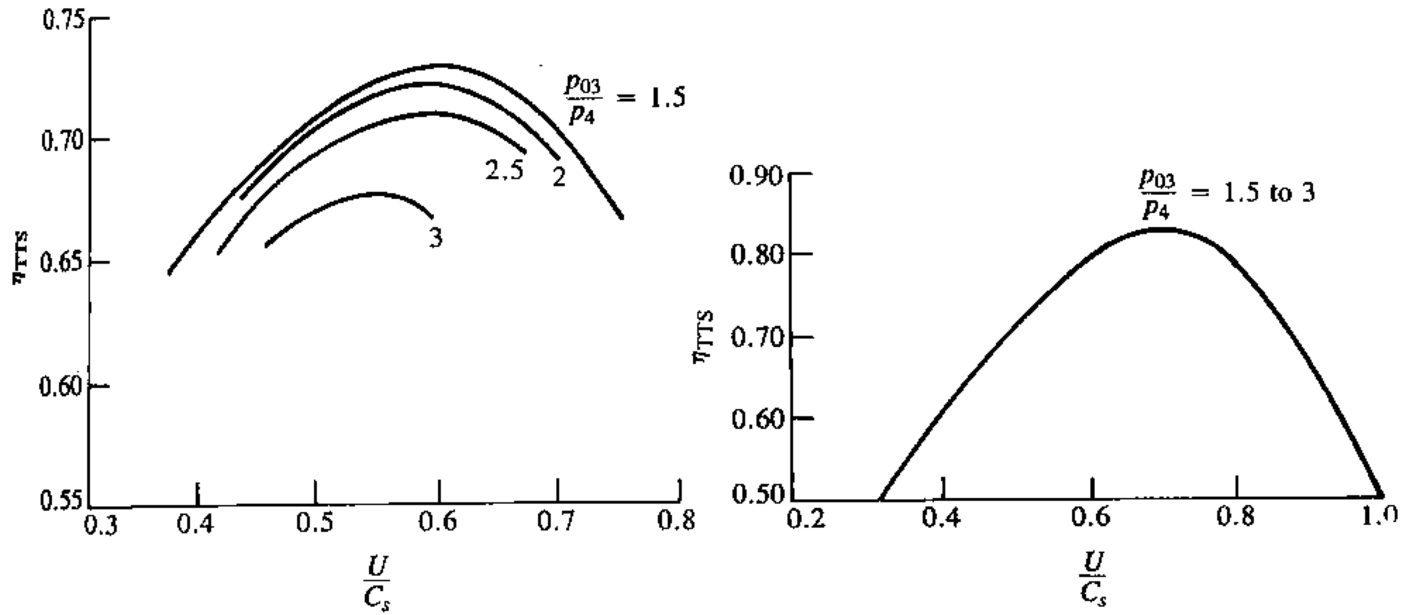
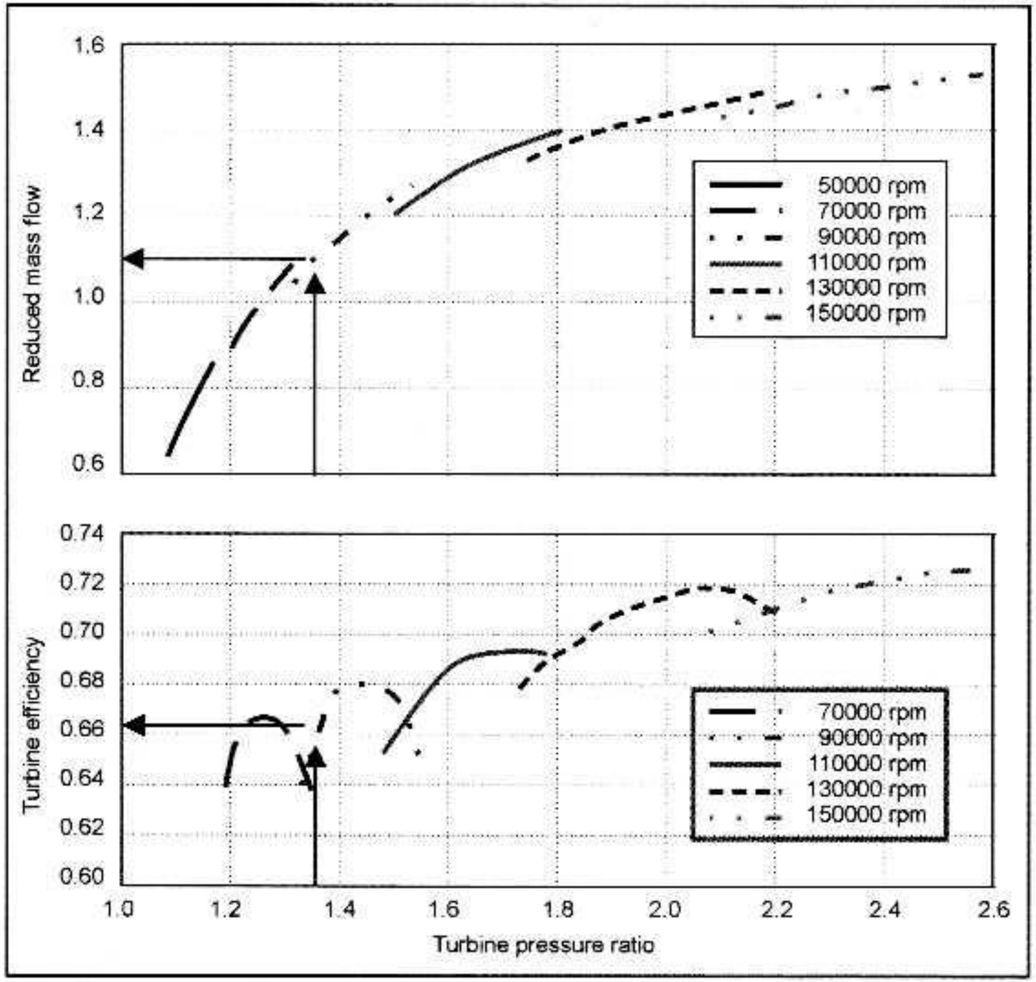
Turbine isentropic efficiency and blade speed ratio U/C$_s$



(a) Axial flow

(b) Radial flow

Turbine map



Reduced mass flow
1.6
1.4
1.2
1.0
0.8
0.6
50000 rpm
70000 rpm
90000 rpm
110000 rpm
130000 rpm
150000 rpm
Turbine efficiency
0.74
0.72
0.70
0.68
0.66
0.64
0.62
0.60
70000 rpm
90000 rpm
110000 rpm
130000 rpm
150000 rpm
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
Turbine pressure ratio

Gas exchange and turbine loading

Turbine loading:

a) Pulse turbocharging: narrow piping, unsteady flow, high pulses, fast reaction

b) Constant pressure turbocharging: large volume in exhaust system, steady flow in turbine, slow reactions, high turbine efficiency

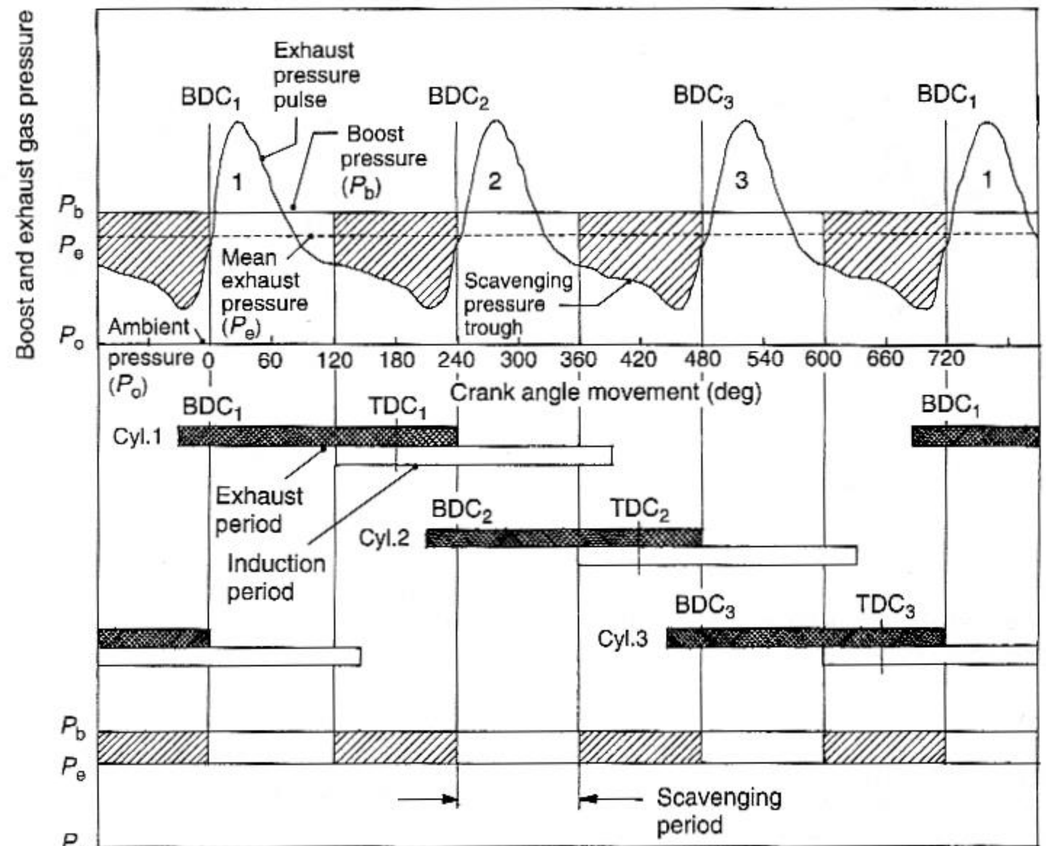
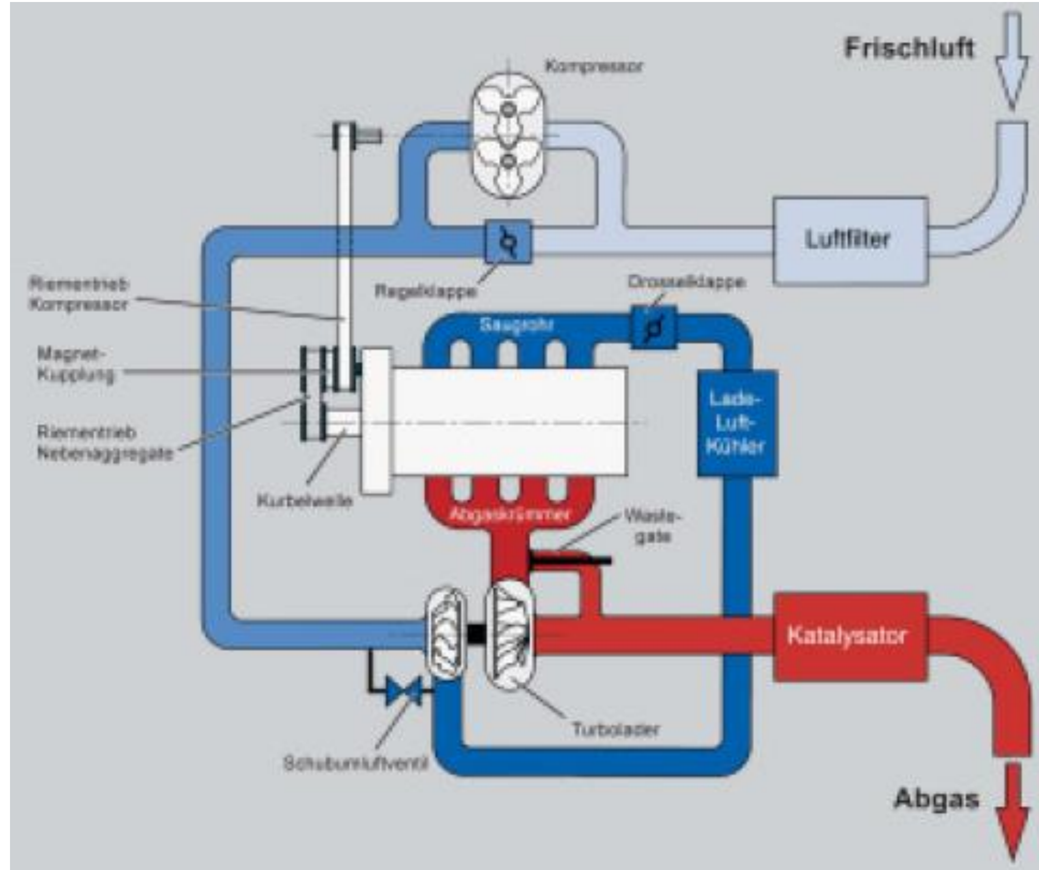


Fig. 6.47 Exhaust gas pressure variation in activated six-cylinder turbocharged engine manifold

VW TSI Charging system



Flow through the engine and flow through the compressor

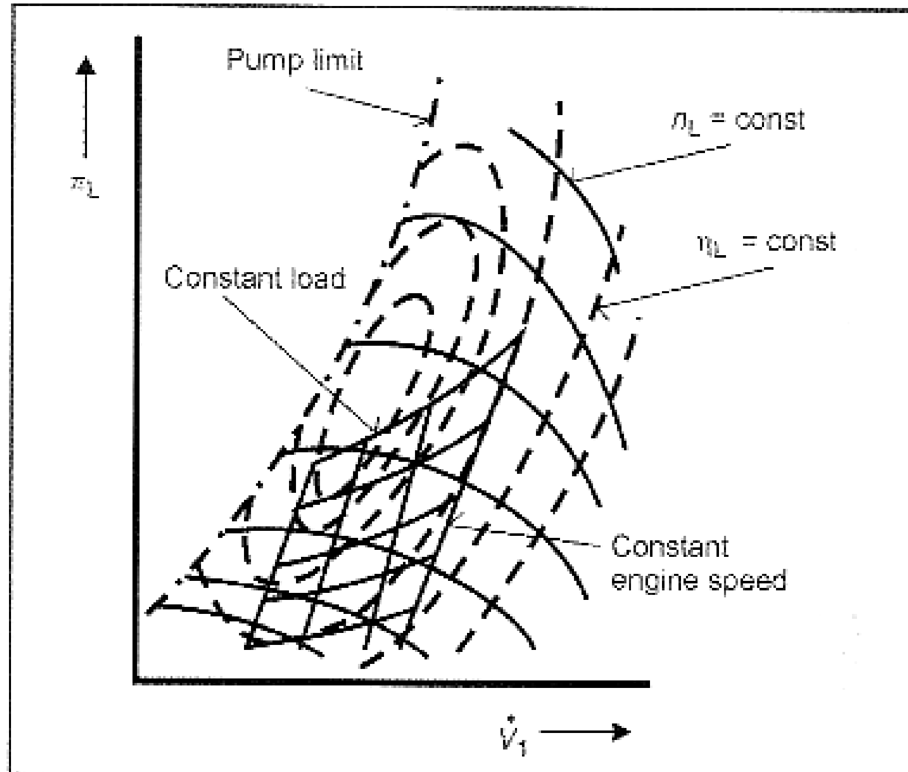


Fig. 11-26 Superimposition of maps.