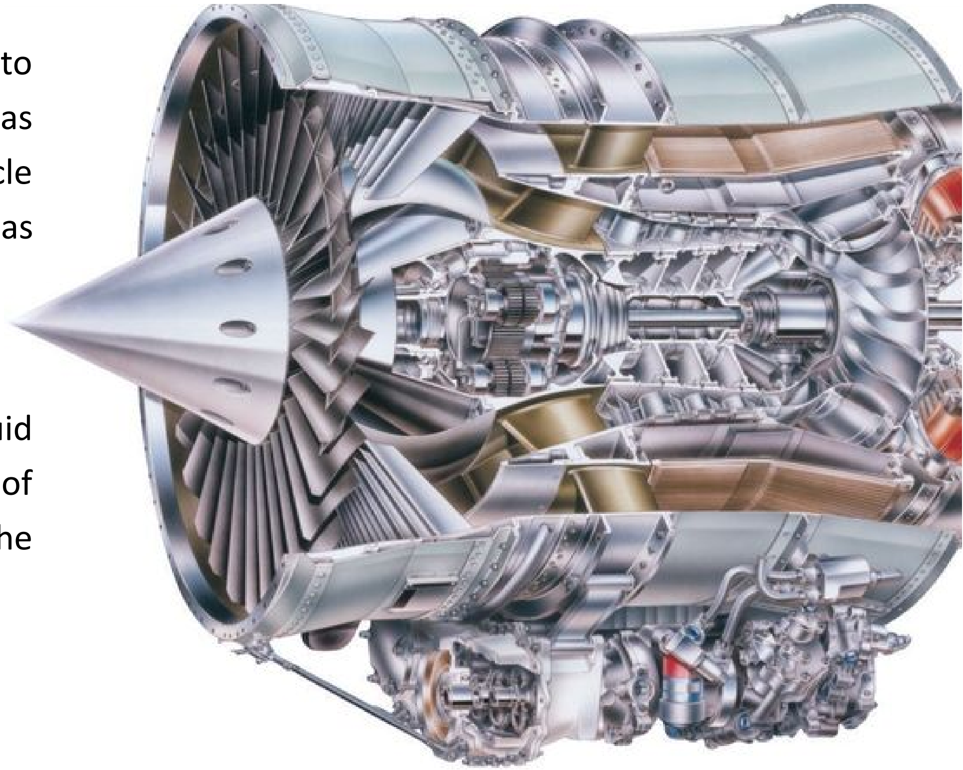
5. Engine Component Operation:
Compressor

Purpose

The purpose of a compressor is to increase the total pressure of the gas stream to that required by the cycle absorbing as minimum shaft power as possible.

Compression of the working fluid is necessary to ensure the possibility of conversion of heat supplied in the combustion chamber into work done.

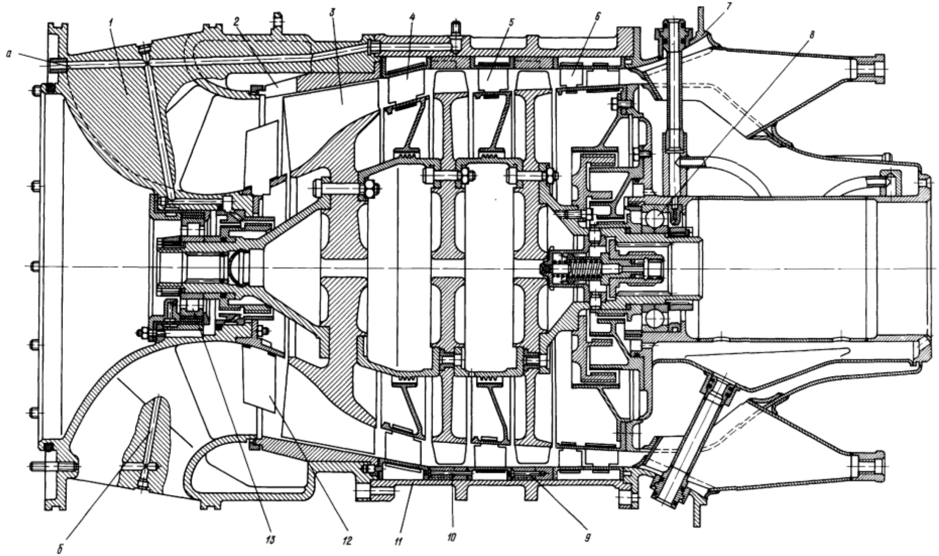


Classification

Compressors can be classified:

- by number of spools:
  - single-spool
  - multi-spool
- by number of stages
  - single-stage
  - multi-stage
- by the type of stage:
  - axial
  - centrifugal
  - diagonal
  - combined

  (axi-centrifugal, diagonal-axial, etc.)



Operational parameters

G_{2corr}, $\frac{\text{kg}}{\text{s}}$ - corrected mass flow rate at inlet of the compressor.

$$G_{2corr}=\frac{m\cdot 101\,325\cdot F_2\cdot q(\lambda_2)}{\sqrt{288.15}};$$

$$G_{2corr}\sim q(\lambda_2);$$

$$G_{2corr}=G_2\cdot\frac{101\,325}{p_2^*}\cdot\sqrt{\frac{T_2^*}{288.15}}.$$

$q(\lambda_2)$ - relative flux density at the inlet of the compressor.

$q(\lambda_3)$ - relative flux density at the outlet of the compressor.

$q(\lambda_3)$ defines the throughput capacity of a component system behind the compressor (a combustion chamber, a following spool of compressor).

π_c^* - compressor pressure ratio.

π_c^* is the ratio of total pressure values at exit and inlet of the compressor

$$\pi_c^* = \frac{p_3^*}{p_2^*}.$$

n, min^{-1} - rotational speed (speed of revolution).

$n_{corr.2}$, min^{-1} - corrected rotational speed.

$$n_{corr.2} = n\sqrt{\frac{288}{T_2^*}}.$$

Compressor efficiency

η_c^* - isentropic efficiency (adiabatic efficiency).

Isentropic efficiency is a ratio of ideal work of compression $L_{c\,s}$ and actual work of compression L_c which correspond to the same compressor pressure ratio π_c^*:

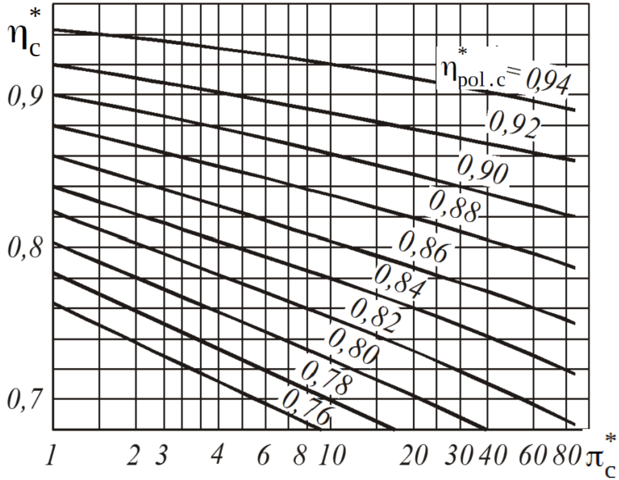
$$\eta_c^* = \frac{L_{c\,s}}{L_c}.$$

$\eta^*_{pol.c}$ - polytropic efficiency.

Equation accurately predicts the relationship between the isentropic efficiency of a compressor and the compressor pressure ratio for a given polytropic efficiency:

$$\eta^*_c = \frac{\left(\pi_c^{*\frac{k-1}{k}} - 1\right)}{\left(\pi_c^{*\frac{k-1}{k\cdot\eta^*_{pol.c}}} - 1\right)}.$$

Primarily a value of $\eta^*_{pol.c}$ depends on the type of a compressor stage.



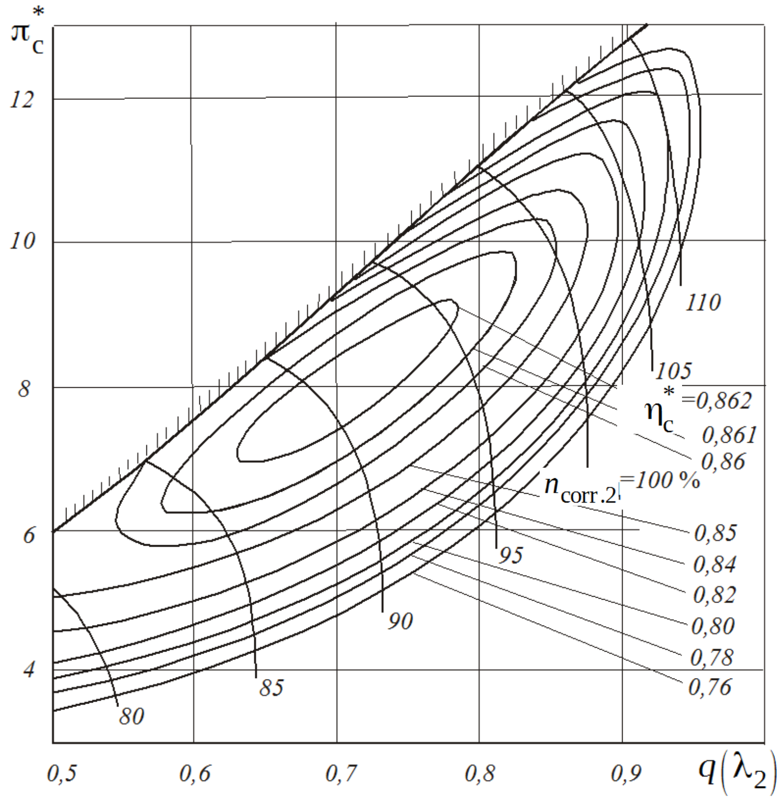
Stage type	$\eta^*_{pol.c}$	$\pi^*_{c.stage}$	$q(\lambda_2)$
Subsonic	0,88...0,92	1,15...1,35	0,70 ... 0,80
Transonic	0,87...0,90	1,40...1,75	0,75 ... 0,90
Supersonic	0,83...0,86	>1,75	0,80 ... 0,92
Centrifugal	0,76...0,80	2,5 ... 8,0	0,70 ... 0,85

Subsonic compressor stages provide the highest efficiency. They are commonly used in compressors of engines designed for passenger, cargo and other aircraft for which the primary feature is high fuel efficiency.

Transonic and especially supersonic stages can obtain a higher pressure ratio but lower efficiency. They are used as the first stages of high-load compressors, such as the fan of the turbofan engine, which reduces their size and weight.

Small-scale compressors ($G_2 < 5...10 \frac{\mathrm{kg}}{\mathrm{s}}$) have reduced efficiency ($\Delta \eta^*_{\mathrm{pol.c}} = -(1...5)\%$).

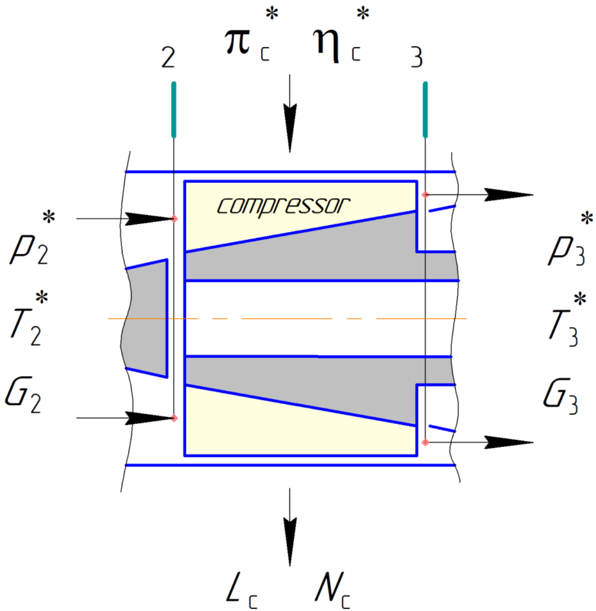
Compressor Map is a chart that shows the performance of a compressor in terms of compressor pressure ratio π_c^*, corrected rotational speed $n_{\text{corr}.2}$, corrected flow rate G_{2corr} (or relative flux density $q(\lambda_2)$), and isentropic efficiency η_c^*.



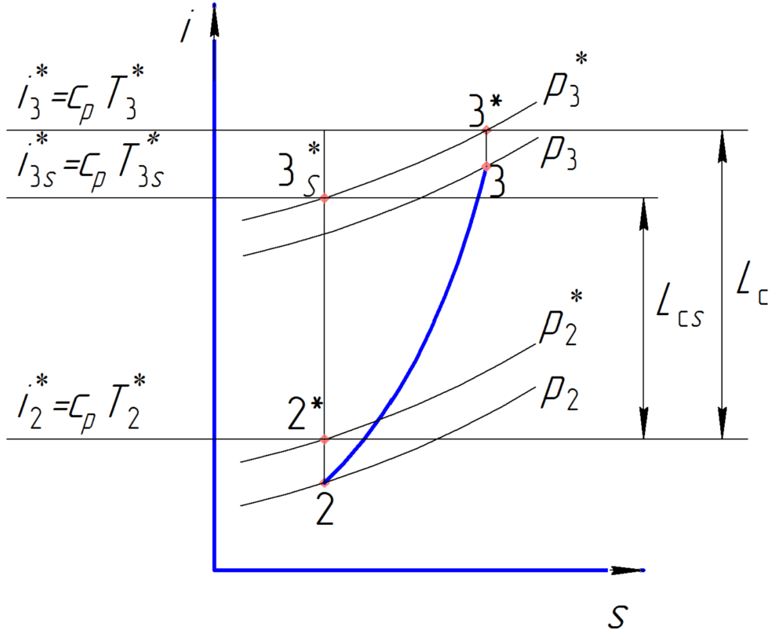
Complete maps are based on compressor rig test results or can be predicted by a CFD software. The map of a similar compressor can be suitably scaled.

Compressor operating

Calculation Scheme



i-s diagram



Ideal compression process:

$$\Delta i^*_{\mathrm{c}\,s} = L_{\mathrm{c}\,s} = i^*_{3\,s} - i^*_2 = c_p \left(T^*_{3\,s} - T^*_2 \right);$$

$$L_{\mathrm{c}\,s} = c_p \cdot T^*_2 \left(\frac{T^*_{3\,s}}{T^*_2} - 1 \right) = c_p \cdot T^*_2 \left(\left(\frac{p^*_3}{p^*_2} \right)^{\frac{k-1}{k}} - 1 \right);$$

$$L_{\mathrm{c}\,s} = c_p \cdot T^*_2 \left(\pi_{\mathrm{c}}^{*\frac{k-1}{k}} - 1 \right).$$

Actual compression process:

$$\Delta i^*_{\mathrm{c}} = L_{\mathrm{c}} = i^*_3 - i^*_2 = c_p \left(T^*_3 - T^*_2 \right);$$

$$L_{\mathrm{c}} = \frac{L_{\mathrm{c}\,s}}{\eta^*_{\mathrm{c}}}.$$

Compressor Performance Calculation

Compressor work:

$$L_{c}=c_{p}\cdot T_{2}^{*}\left(\pi_{c}^{*\frac{k-1}{k}}-1\right)\frac{1}{\eta_{c}^{*}},\ \frac{\text{кJ}}{\text{kg}}.$$

Total temperature at the exit of the compressor:

$$T_{3}^{*}=T_{2}^{*}+\frac{L_{c}}{c_{p}},\ \text{K}.$$

Total pressure at the exit of the compressor:

$$p_{3}^{*}=p_{2}^{*}\cdot\pi_{c}^{*},\ \text{kPa}.$$

Mass flow rate at the exit of the compressor:

$$G_{3}=G_{2},\ \frac{\text{kg}}{\text{s}}.$$

Compressor power:

$$N_{c}=G_{2}\cdot L_{c},\ \text{kW}.$$

Fan Performance Calculation

Fan performance calculation includes calculation of two compressors:

- **lpc** – a part of the fan that compresses the air passed through the engine core including booster stages;
- **fII** — a part of the fan that compresses the air passed through the bypass.

Each of compressors is characterized by the corresponding pressure ratio and efficiency, which in general case can be differ.

The ratio of mass flow rates through secondary and primary flowpaths is specified by the bypass ratio:

$$m = G_{12} / G_{21} \ .$$

The total power consumed by the fan is equal to the sum of lpc and fII power values:

$$N_{\mathrm{f}} = N_{\mathrm{lpc}} + N_{\mathrm{fII}} \ .$$