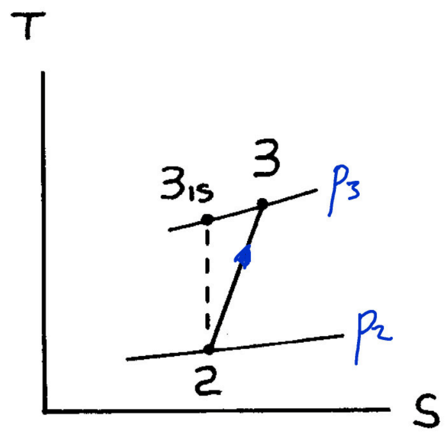
PERFECT GAS

Compressor isentropic efficiency (page 34):

The minimum work required for Δp.

$$\eta_{comp} = \frac{\text{Ideal work}}{\text{Actual work}} = \frac{T_{3is} - T_2}{T_3 - T_2}$$

$$\frac{T_{3is}}{T_2} = \left(\frac{p_3}{p_2}\right)^{\frac{\gamma-1}{\gamma}}$$



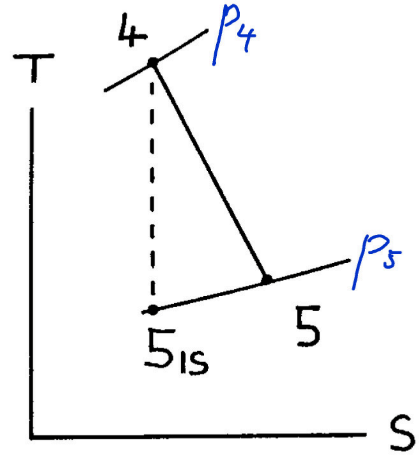
$$\dot{W}_c = \dot{m}_a C_p(T_3 - T_2) = \dot{m}_a C_p(T_{3is} - T_2)/\eta_{comp}$$

Turbine isentropic efficiency (page 34):

$$\eta_{turb} = \frac{\text{Actual work}}{\text{Ideal work}} = \frac{T_4 - T_5}{T_4 - T_{5is}}$$

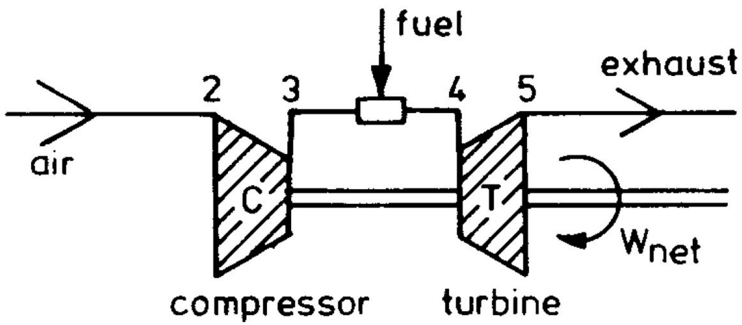
$$\frac{T_{5is}}{T_4} = \left(\frac{p_5}{p_4}\right)^{\frac{\gamma-1}{\gamma}}$$

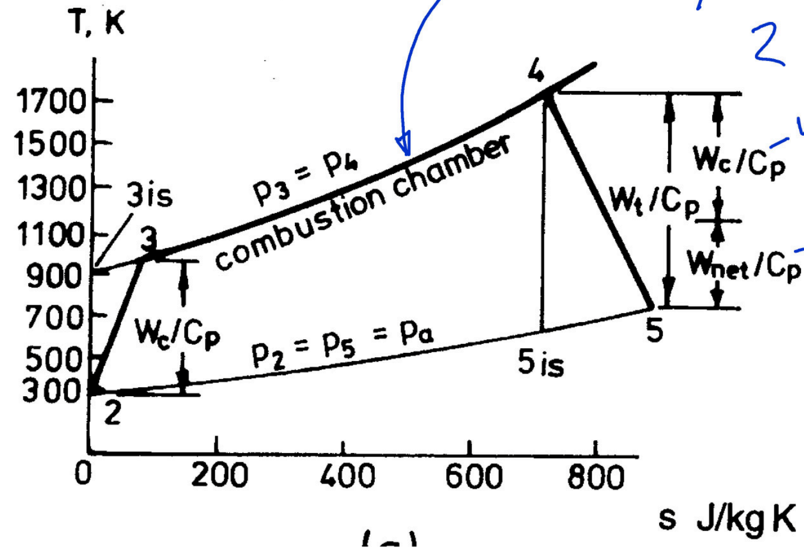
The maximum work possible from Δp



$$\dot{W}_t = \dot{m}_a C_p(T_4 - T_5) = \dot{m}_a C_p(T_4 - T_{5is}) \times \eta_{turb}$$

Simple gas turbine “cycle” (pages 31-32):





Heat input

2 parts:

– work to comp.

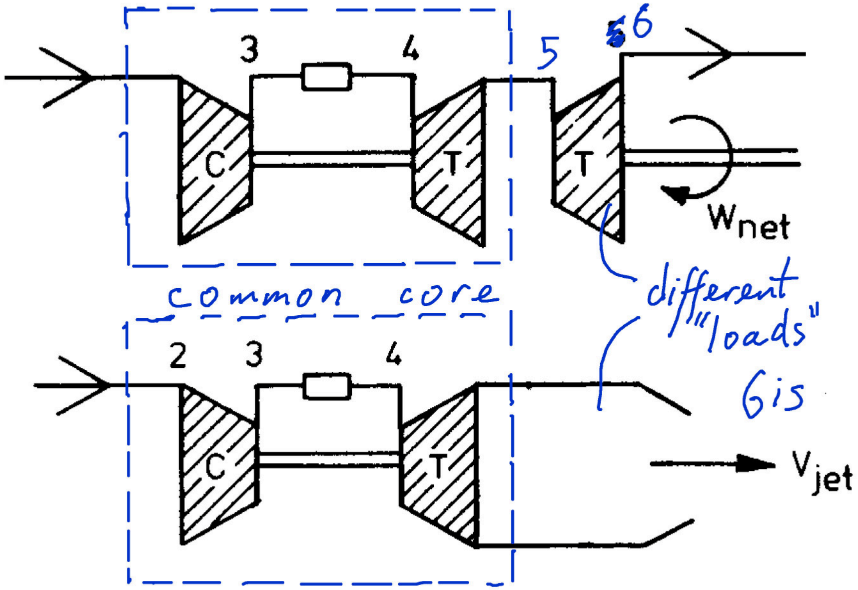
– net work left

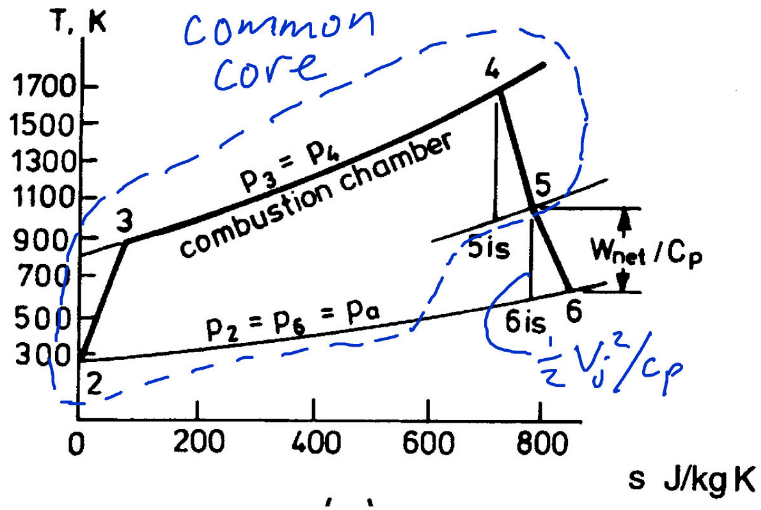
$\dot{W}_{net} = \dot{W}_t - \dot{W}_c$

Heat input $= \dot{m}_f LCV = \dot{m}_a C_p (T_4 - T_3)$

Turbine can be split into 2 parts.

Two different ways of applying a "load" to a gas turbine (pages 31-32):





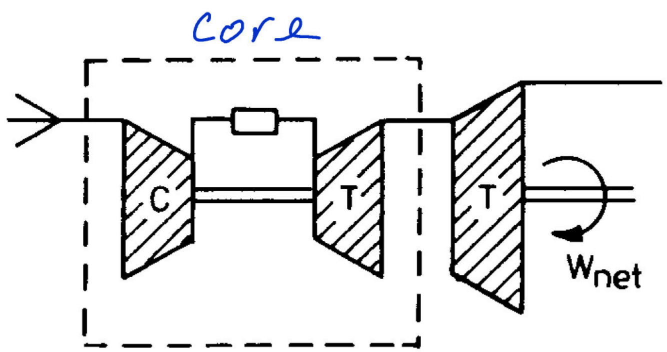
Note: $\frac{1}{2}\dot{m}_a V_j^2 \times \eta_{turb} = \dot{W}_{net}$

Producing purely shaft-power or purely a propelling jet represents the two extremes of how the basic gas turbine can "drive" a load.

The basic gas turbine "core" can drive various types of "load" (page 31):

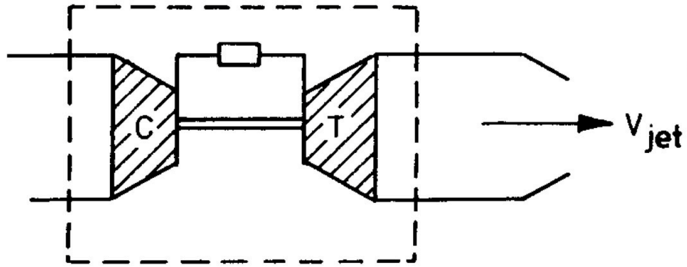
Two extremes

Core gas turbine "drives" a shaft.



All w_x

Core gas turbine "drives" a propelling jet.

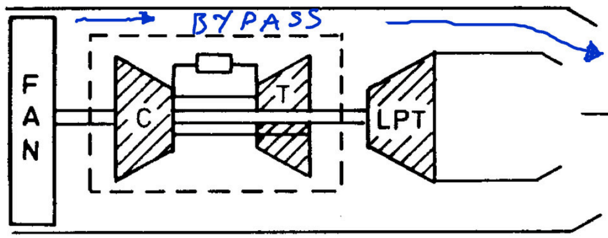


All $\frac{1}{2}V_j^2$

Core gas turbine "drives" both:

a shaft to drive the fan

and a propelling jet.



Bypass jet engine

Combination

$w_x \rightarrow$ bypass

remainder $\rightarrow \frac{1}{2}V_j^2$

$\dot{m}_a \uparrow \quad V_j \downarrow$

Can optimise core separately, then think about what is the best "load".

View the different arrangements (shaft-power, jet and bypass) as just a core gas turbine with an applied "load". Hence, investigate different designs for the core gas turbine in terms of work output ($\dot{W}_{net}$) and cycle efficiency (η_{cycle}).

Page 35.

Define the cycle pressure ratio: $r = p_3/p_{ambient} = p_4/p_{ambient}$ $p_{ambient} = p_2$

$$\dot{W}_{net} = \dot{m}_a C_p T_2 \left[\underbrace{\frac{T_4}{T_2}\left(1 - \frac{1}{r^{(\gamma-1)/\gamma}}\right)\times \eta_{turb}}_{w_{turb}} - \underbrace{\left(r^{(\gamma-1)/\gamma} - 1\right)/\eta_{comp}}_{w_{comp}} \right] \qquad \text{(eqn 4.8)}$$

$$\frac{\dot{W}_{net}}{\dot{m}_a c_p T_2} = fn\left(\frac{T_4}{T_2}, r, \eta\right)$$

$$\eta_{cycle} = \frac{\dot{W}_{net}}{\underbrace{\dot{m}_a C_p (T_4 - T_3)}_{\text{heat input}}} = \frac{\dot{W}_{net}}{\dot{m}_f \, LCV} \qquad \text{(eqn 4.8 \& 4.9)}$$

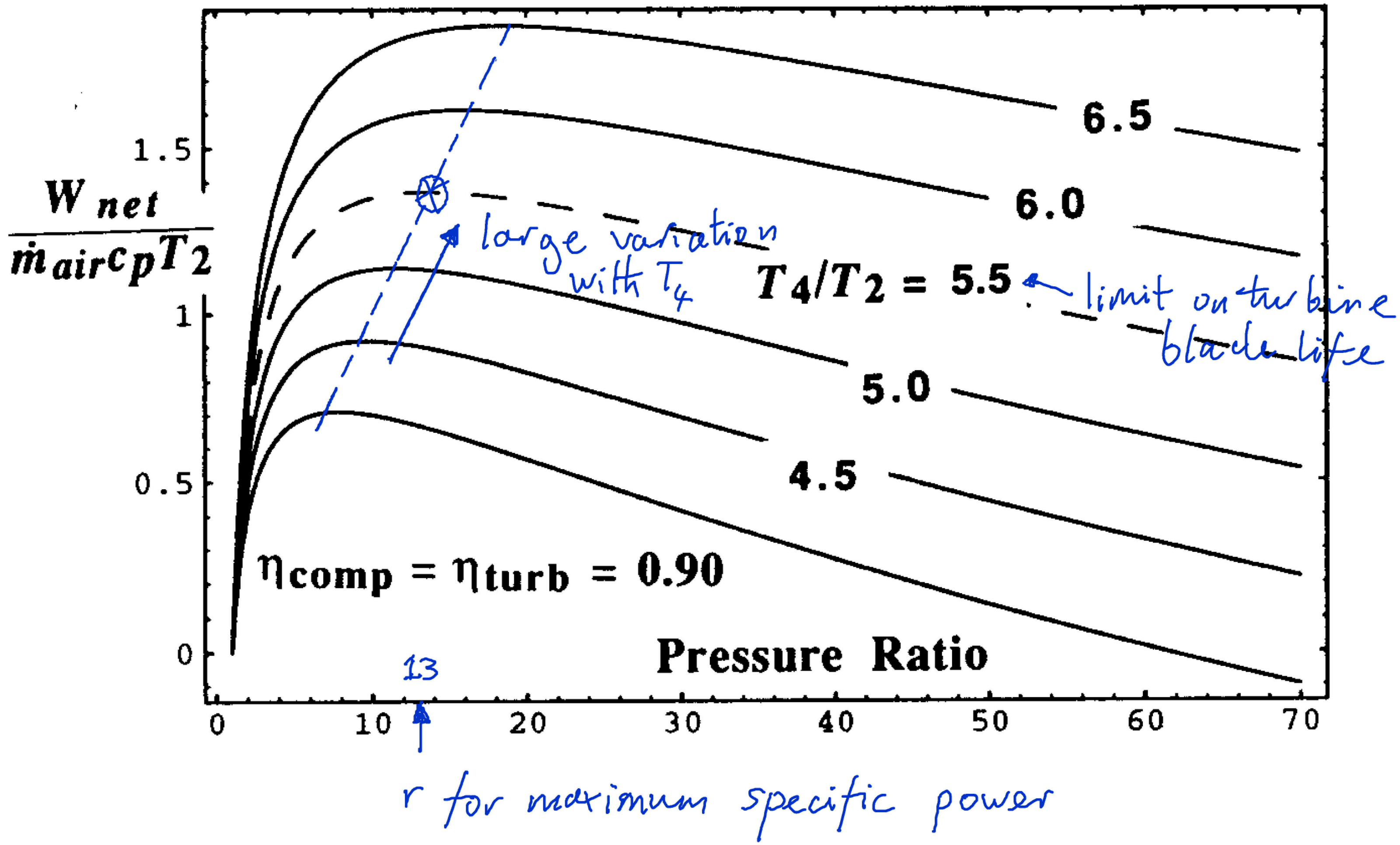
$\dot{W}_{net}$: $\frac{1}{2}\dot{m}_a V_j^2 \eta_{turb}$

From earlier:
$$\eta_{th} = \frac{\Delta KE}{\dot{m}_f \, LCV} = \frac{\frac{1}{2}\dot{m}_a (V_j^2 - V^2)}{\dot{m}_f \, LCV} \qquad \text{(eqn 3.7 \& 3.8)}$$

V^2: fixed

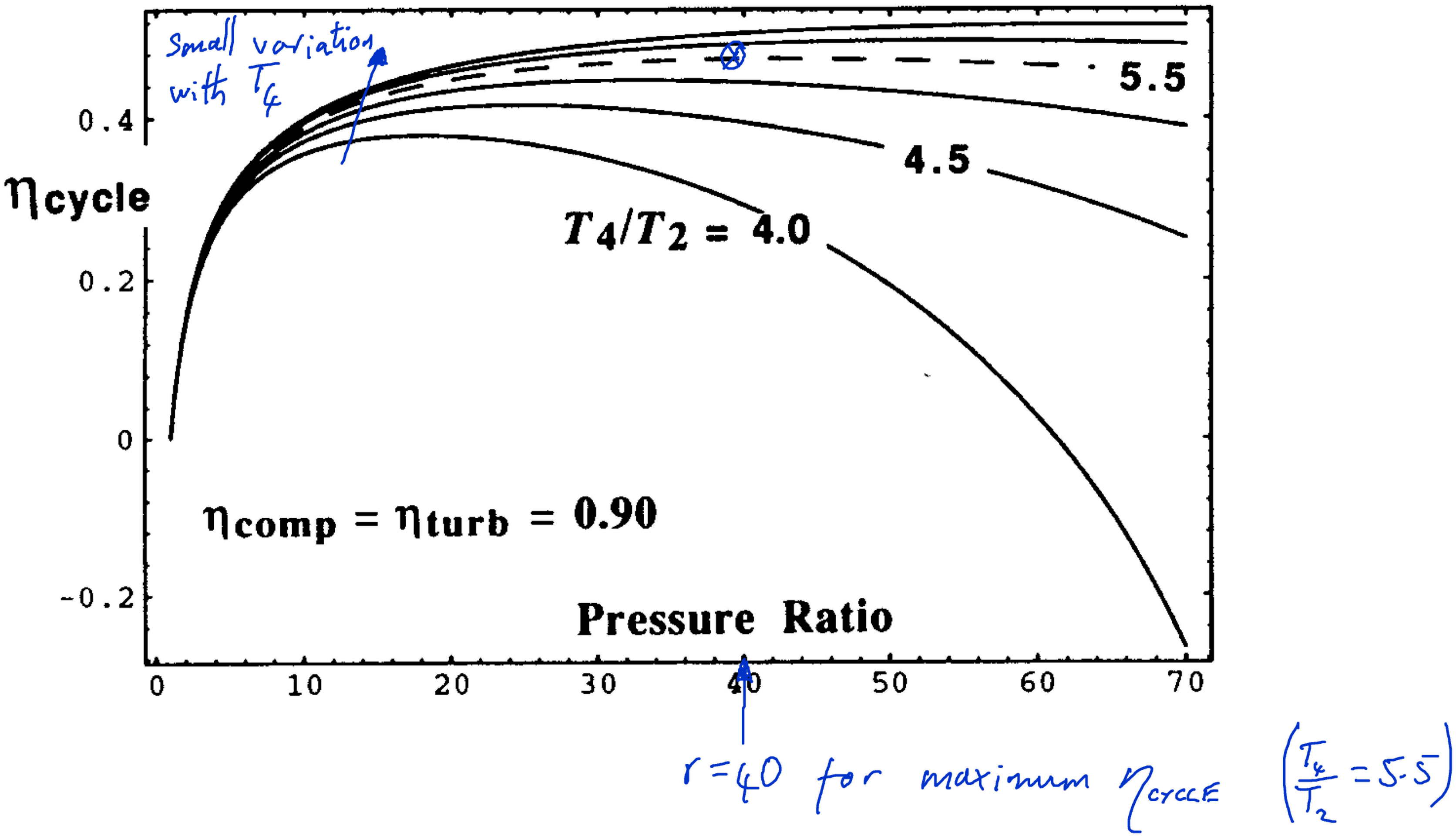
Hence η_{cycle} and η_{th} are <u>almost</u> equivalent. (vary in the same way)

Output power versus cycle pressure ratio given turbine entry temperature (page 36)



Maximum output power occurs at relatively low pressure ratio.

η_{cycle} versus cycle pressure ratio given turbine entry temperature (page 36)



Maximum η_{cycle} occurs at relatively high pressure ratio (and is relatively flat).

Summary of gas turbine cycle results:

1) Power output depends strongly on turbine entry temperature. $\frac{T_4}{T_2}$ (fuel flow)

2) Maximum power output occurs at low pressure ratio (≈ 12). MILITARY application

3) Maximum η_{cycle} occurs at high pressure ratio (≈ 30 - 50). CIVIL application

4) η_{cycle} is a strong function of compressor and turbine efficiency.

5) Trends are the same for both closed and open cycles. η_{th}, η_{CYCLE} are comparable

6) At a pressure ratio of about 40 and $T_4/T_2 = 5.5$, $\underbrace{\eta_{cycle} = 0.47}$ is reasonable.
basis for the NLA engine design. ⇒ a decent engine "core"

Demo using GASTURB: Variations in power output and η_{cycle} for a gas turbine.