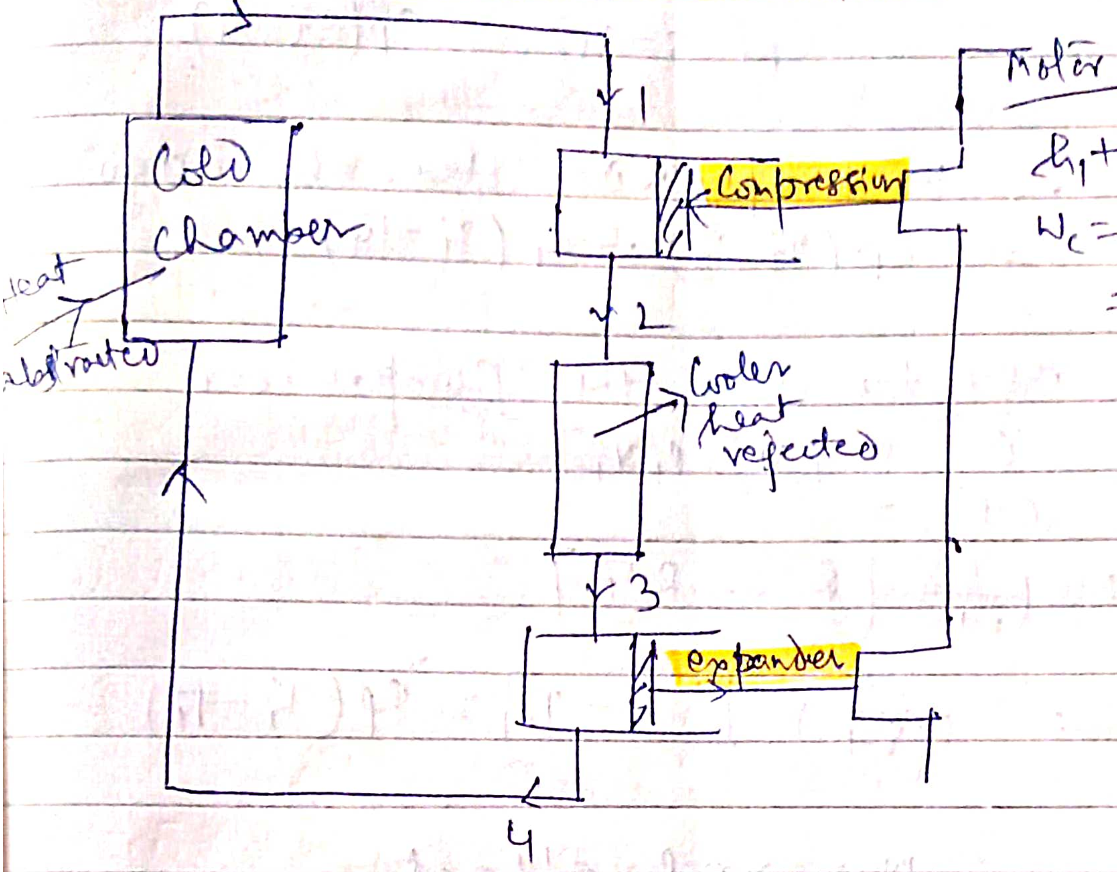
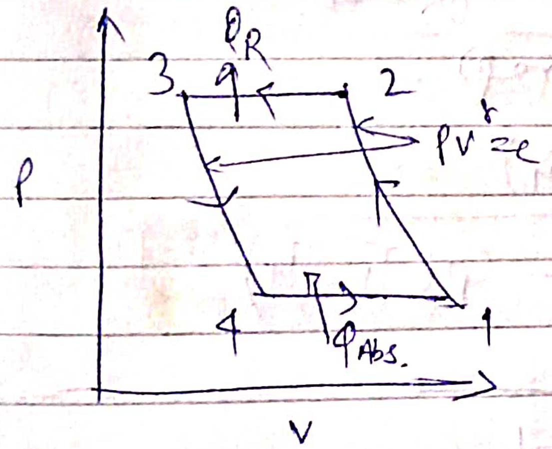
Bell Coleman Cycle

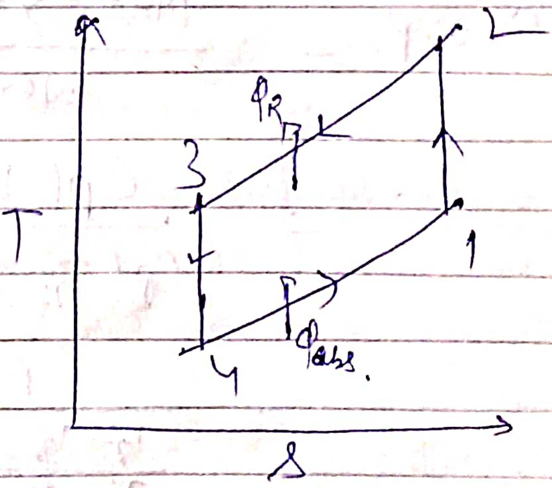


$h_1 + W_c = h_2$

$W_c = h_2 - h_1$

$= C_p(T_2 - T_1)$





Process 1-2: Isentropic Compression. No heat transfer

Process 2-3: Constant pressure heat rejected

$= C_p(T_2 - T_3)$

Process 3-4: Isentropic expansion. No heat transfer.

Process 4-1: Constant pressure heat abstraction

$= C_p(T_1 - T_4) =$ Net refrigerating effect

Work required = Compressor work − expander work

$= C_p(T_2 - T_1) - C_p(T_3 - T_4)$

or → Heat rejected − Heat abstracted

$= C_p(T_2 - T_3) - C_p(T_1 - T_4)$

[Work reqd. to run the compressor

$= \frac{\gamma}{(\gamma-1)}[P_2V_2 - P_1V_1]$

$= \frac{\gamma}{(\gamma-1)}[RT_2 - RT_1]$

$= \frac{\gamma R}{(\gamma-1)}[T_2 - T_1] = C_p(T_2 - T_1)$

$$C.O.P = \frac{\text{Net. ref. effect}}{\text{Work reqd.}}$$

$$= \frac{C_p(T_1 - T_4)}{C_p(T_2 - T_3) - C_p(T_1 - T_4)}$$

$$= \frac{1}{\frac{T_2 - T_3}{T_1 - T_4} - 1}$$

1−2: $\frac{T_1}{P_1^{\frac{\gamma-1}{\gamma}}} = \frac{T_2}{P_2^{\frac{\gamma-1}{\gamma}}}$ or $\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} = r_p^{\frac{\gamma-1}{\gamma}}$

3−4: $\frac{T_3}{T_4} = \left(\frac{P_3}{P_4}\right)^{\frac{\gamma-1}{\gamma}} = r_p^{\frac{\gamma-1}{\gamma}}$

$$\therefore \frac{T_2}{T_1} = \frac{T_3}{T_4} = \frac{T_2 - T_3}{T_1 - T_4} = r_p^{\frac{\gamma-1}{\gamma}}$$

$$\therefore \boxed{C.O.P = \frac{1}{r_p^{\left(\frac{\gamma-1}{\gamma}\right)} - 1}}$$

Bell coleman cycle

* Difference b/w Joule cycle & Brayton cycle

Reciprocating Compressor & Reciprocating expander } ⇒ Joule Cycle.

Centrifugal Compressors & Gas turbines } ⇒ Brayton Cycle.

Similarly, * Difference b/w Bell Coleman & Reversed Brayton cycle :

Reciprocating Compressor & Reciprocating expander } ⇒ Bell Coleman cycle

Centrifugal Compressor & Gas turbine } ⇒ Reversed Brayton cycle

$$w_c - w_t - q_R + q_A = 0$$

$$w_t - w_c = q_A - q_R$$

$$w_c - w_t = q_R - q_A$$

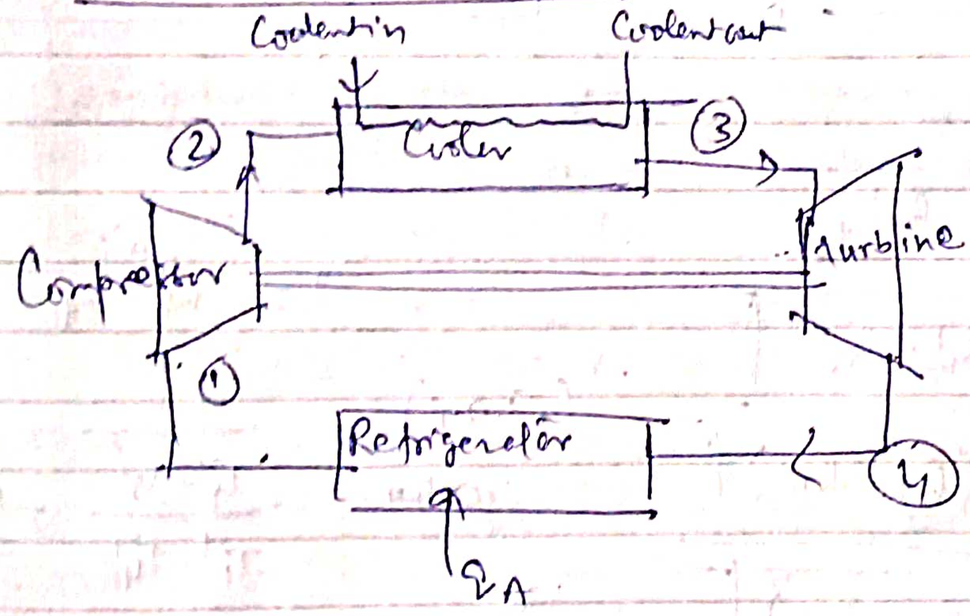
Gas Cycle Refrigeration

Difference b/w Bell-Coleman cycle and reversed Brayton cycle:

The Bell Coleman cycle refers to a closed cycle with expansion and compression taking place in reciprocating expander and compressor respectively and heat transfer absorption taking place in condenser and evaporator respectively.

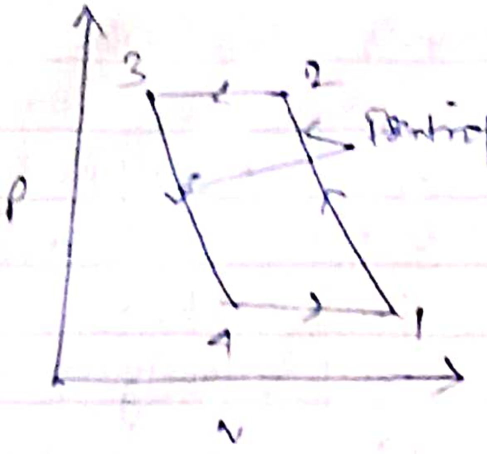
But with the advent of efficient centrifugal compressors and gas turbines, the process of compression and expansion can be carried out in centrifugal compressors and gas turbines respectively and very large flow rates of gases are possible.

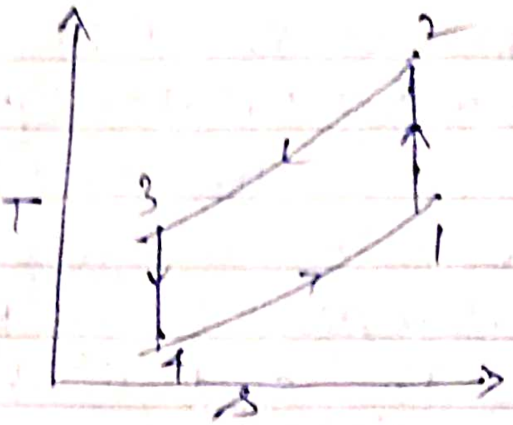
Reversed Brayton cycle:



$$(C.O.P)_{rev.\,Brayton} = \frac{Ref.\ effect}{Net\ W.D} = \frac{Q_A}{W_t - W_c} = \frac{1}{r_p^{\left(\frac{\gamma-1}{\gamma}\right)} - 1}$$

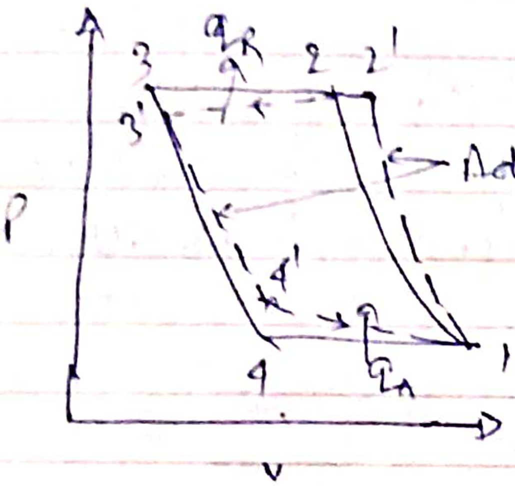
r_p - pr. ratio

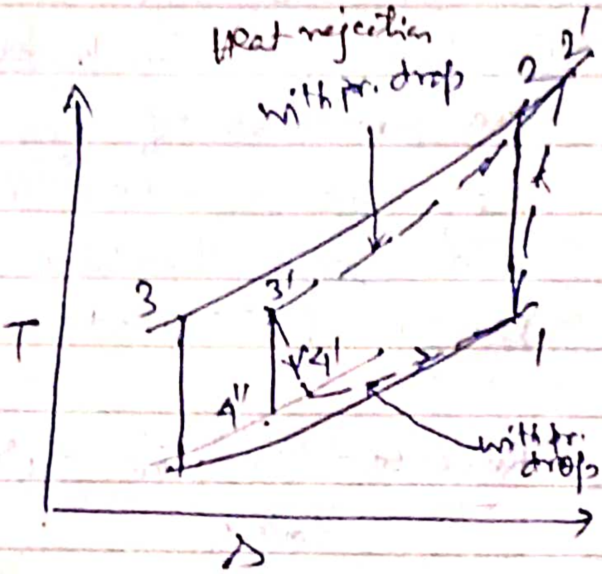




Actual diagram

⇓





$$\boxed{W_c = (h_2' - h_1)}$$

$$\boxed{q_R = (h_2' - h_3')}$$

$$\boxed{W_t = (h_3 - h_4')}$$

$$\boxed{q_A = (h_1 - h_4')}$$

$$\eta = \frac{q_A}{W_c - W_t}$$

$$(C.O.P)_{actual} = \frac{1}{\frac{T_2' - T_3'}{T_1' - T_4'} - 1}$$

The refrigeration cycle with air as the working substance became obsolete for the following main disadvantages:

(i) The apparatus grew bulky because of very large reciprocating compressor and expander piston displacement per ton of refrigeration.

(ii) Range of the temp in the cycle was very large resulting in very low co-efficient of performance and consequent large power requirements per ton of refrigeration. [If $(T_H - T_L)$ is larger then C.O.P is less]

With the art of building efficient centrifugal compressors and turbines which could handle very large flow rates with less bulk, the first disadvantage was overcome. Some of the modern air refrigeration systems have weight as low as 2 kg per ton refrigeration.

Specially, for aircraft application, the weight of the plant is a major consideration. And air is not to be stored in the aircraft as any other refrigerant would have to be. Thus despite low co-efficient of performance, air refrigeration system is preferred in air craft.

Gas turbine ~~pl~~ unit is used in Aircraft. Aircrafts moves with velocity of sound at high altitude. At high altitude, pressure is low and corresponding temp^r is low (near about −25°). At the same time, velocity of air is same as aircraft but at the point of contact (i.e. at aircraft surface), velocity of air is zero i.e. its (of air) total kinetic energy is converted to heat energy and it goes to air craft.

Hence body temp^r of air craft is very high. Whatever amount of air come in contact with air craft, the same amount of air pass out. i.e, mass of air is constant.

Hence the temp^r rise may be computed from the steady flow energy equation.

<u>SFEE</u>:

$$\delta q - \delta w_s = dh + d(KE) + d(PE)$$

Assuming entire process is adiabatic therefore $\delta q = 0$ & there is no shaft work $\delta w_s = 0$

& no change in elevation $d(PE) = 0$

$$\therefore \; dh + d(KE) = 0$$

$$h + \frac{V^2}{2} = \text{Const.}$$

$$h_1 + \frac{V_1^2}{2} = h_2 + \frac{V_2^2}{2}$$

The air flow decelerated in an adiabatic manner such that velocity is reduced to zero i.e. $V_1 = 0$

At zero velocity, all the condition is called stagnation condition and designated by symbol zero (0)

e.g., P_0, h_0, ρ_0, T_0

Therefore the above equation becomes

$$h_1 + \frac{V_1^2}{2} = h_0$$

Now, the general eqn is

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

$$\Rightarrow C_p T + \frac{V^2}{2} = C_p T_0$$

$$\Rightarrow T + \frac{V^2}{2 C_p} = T_0$$

$$\Rightarrow 1 + \frac{V^2}{2 \cdot \frac{\gamma R}{\gamma - 1} \cdot T} = \frac{T_0}{T}$$

$$\Rightarrow \frac{T_0}{T} = 1 + \frac{V^2 (\gamma - 1)}{2 c^2}$$

$$\Rightarrow \boxed{\frac{T_0}{T} = 1 + \left(\frac{\gamma - 1}{2}\right) M^2}$$

$C_p / C_v = \gamma$

$C_p - C_v = R$

$C_p = \frac{\gamma R}{\gamma - 1}$

$C_v = \frac{R}{\gamma - 1}$

$M = V/c = \frac{\text{Inertia vel.}}{\text{Sonic vel.}}$

$c = \sqrt{\gamma R T}$

Now, if $M = 1$, $\gamma = 1.4$

$$\frac{T_0}{T} = 1 + \left(\frac{0.4}{2}\right)(1)^2 = 1.2$$

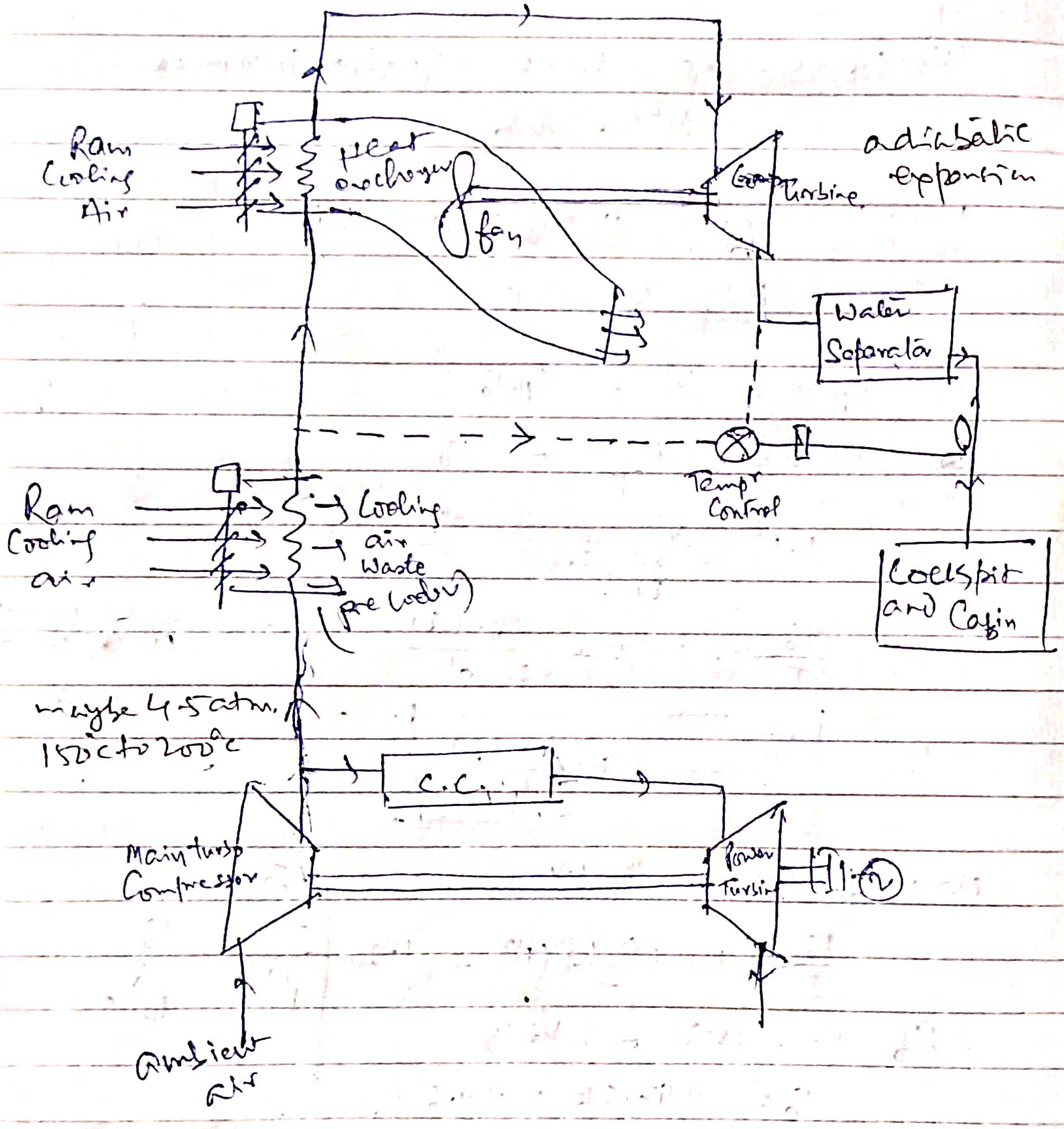
If $T = -25^\circ C = 248\ K$

$$T_0 = 297.6\ K = 24.6^\circ C.$$

Again,

$$\frac{T}{P^{\frac{\gamma - 1}{\gamma}}} = \frac{T_0}{P_0^{\frac{\gamma - 1}{\gamma}}}$$

Fig. illustrate the layout of an air cycle refrigeration system as employed for air conditioning the cockpit and cabin space of an air plane.



Some air can be bled from the main power plant compressor for refrigeration purposes. The compressed air may be at a pressure of 4-5 atm. and at a temp of about 150°c to 200°c. Therefore, it is essential to cool the compressed air. This is done in a pre cooler and heat exchanger where ram air from the atmosphere is passed.

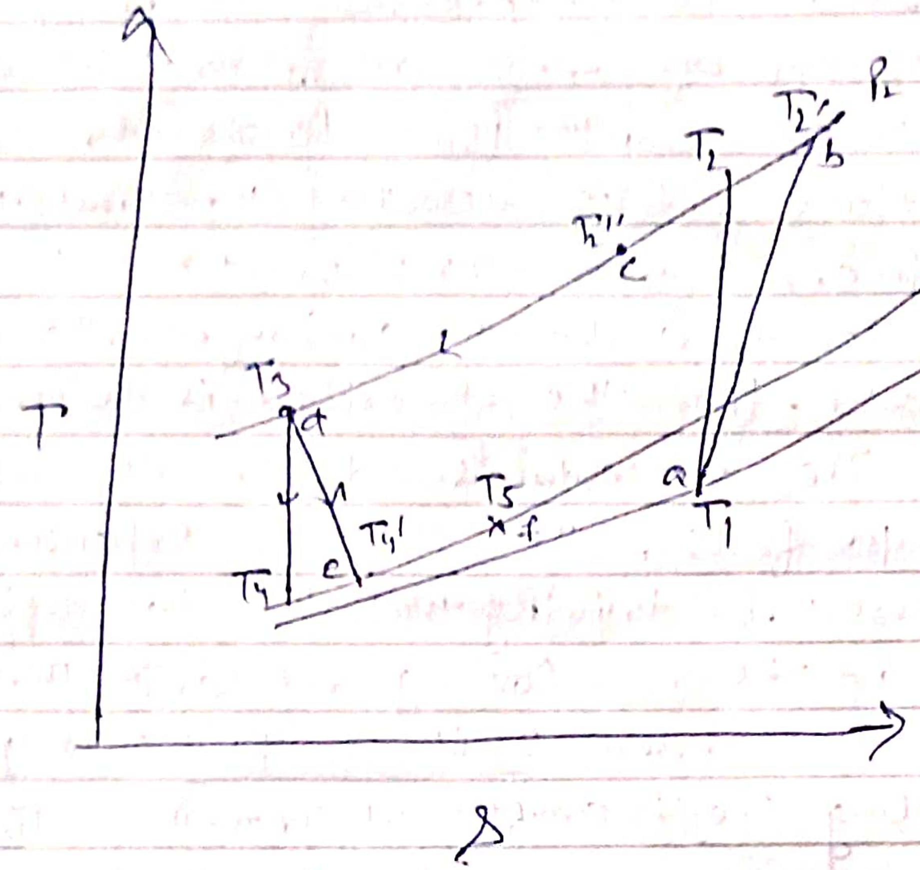
The air expands adiabatically and thus its temp falls. The work of expansion is harnessed for driving the fan to help draw in the ram cooling air and throw out to waste. This is particularly important for cooling the aircraft at ground. Turbine work is not available for the compressor.

The other important functional components of the system are the following:

(i) Water separator: The cooling of air beyond dew point results in condensation of moisture present in air.

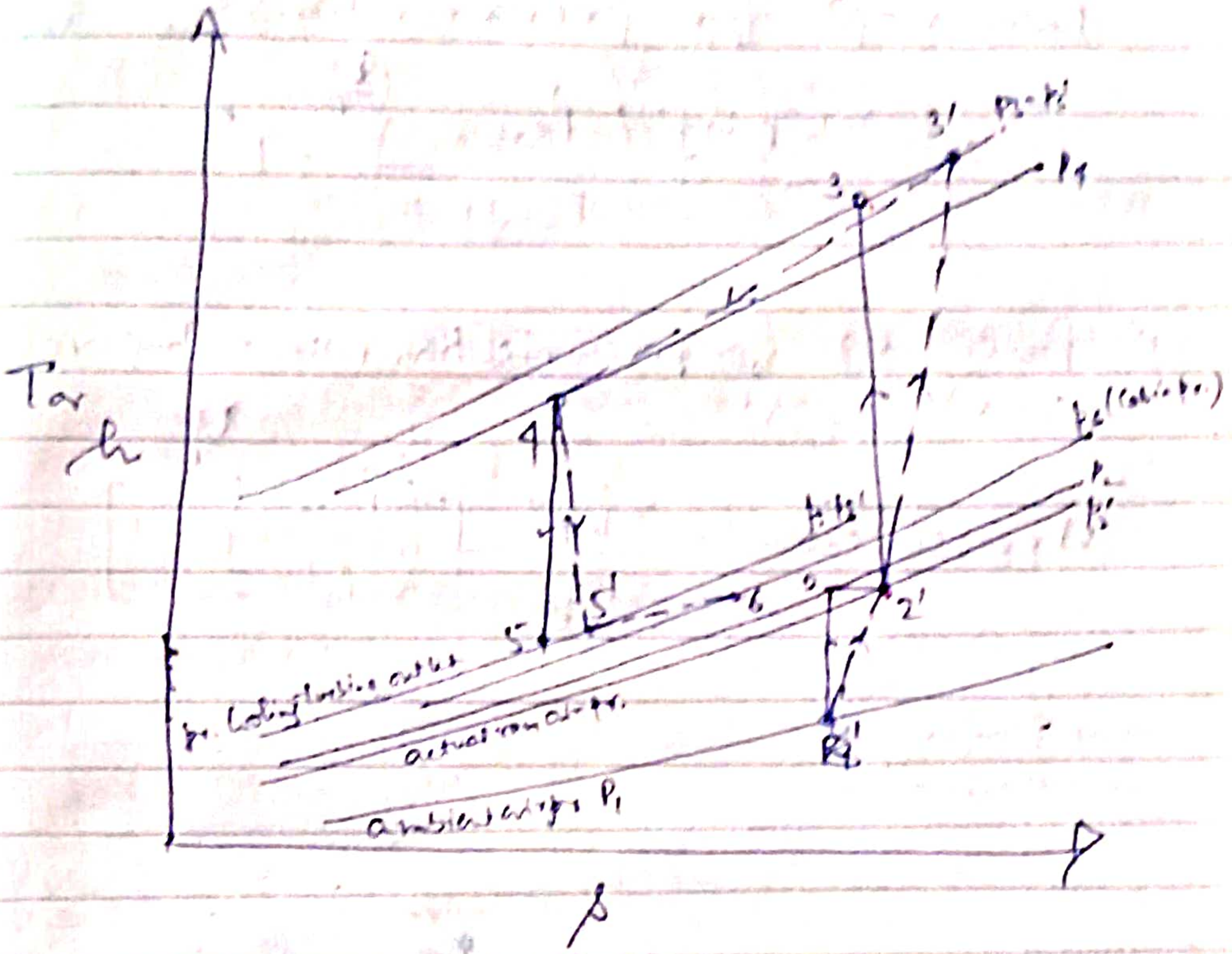
(ii) Arrangement for mixing the warm air after pre cooler with exit air from expander turbine to ensure desired temp of air supply to the cabin. The warm air by pass valve serves this purpose. It also serves the purpose of ensuring desired pressurised air to the cabin.

(iii) Arrangement for auxiliary ground air supply which can be mixed with the air supply bled from the main turbo compressor.



$w_c = C_p(T_2' - T_1) \times m_b$ ⟶ quantity of air bled for refrigeration purposes.

Air refrigeration cycle for Air craft with Ram Compression :



Ideal Ramming process 1-2

Actual Ramming process 1-2'

$$\eta_{Ram} = \frac{P_2' - P_1}{P_2 - P_1}$$

$$C.O.P = \frac{m_b C_p (T_6 - T_5')}{m_b C_p (T_3' - T_2')}$$ neglecting ram work and cooling turbine work.

$$COP = \frac{(T_6 - T_5')}{(T_3' - T_2') + (T_2' - T_1) - (T_4 - T_5')}$$ Considering ram work and turbine work

* Power reqd. for pressurisation (Including ram work)

$$= \frac{\dot{m}_b C_p T_1}{\eta_c}\left[\left(\frac{P_{cabin}}{P_{ambient}}\right)^{\left(\frac{\gamma-1}{\gamma}\right)} - 1\right]$$

* Power reqd. for pressurisation (excluding ram work)

$$W_{pressurisation} = \frac{\dot{m}_b C_p T_2'}{\eta_c}\left[\left(\frac{P_{cabin}}{P_2'}\right)^{\frac{\gamma-1}{\gamma}} - 1\right]$$