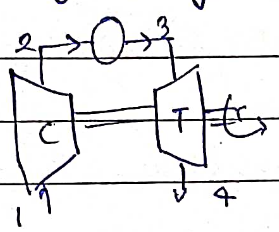
Applied Thermo - 22/03/22

Simple Gas Turbine Cycle.

Brayton Cycle. (Joule's cycle)

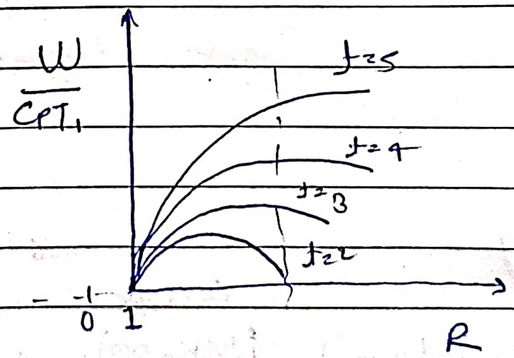


$$R = \frac{P_2}{P_1}, \quad t = \frac{T_3}{T_1} = \frac{T_{max}}{T_{min}}.$$

$$\eta = 1 - \left(\frac{1}{R^{\frac{\gamma-1}{\gamma}}}\right)$$

Non dimensional specific work.

$$\left(\frac{W}{C_p T_1}\right) = t\left(1 - \frac{1}{R^{\frac{\gamma-1}{\gamma}}}\right) - \left(R^{\frac{\gamma-1}{\gamma}} - 1\right)$$



when, $R = 1$, $R = t^{\frac{\gamma}{\gamma-1}}$ $\Rightarrow \frac{W}{C_p T_1} \to 0$

$$\frac{d\left(\frac{W}{C_p T_1}\right)}{d\left(R^{\frac{\gamma-1}{\gamma}}\right)} = 0$$

$\Rightarrow R = R_{optimum}$.

$$\Rightarrow \boxed{\left(R_{opt}\right)^{\frac{\gamma-1}{\gamma}} = \sqrt{t}}$$

$$\left(\frac{W}{C_p T_1}\right)_{max} = t\left(1-\frac{1}{\sqrt{t}}\right)-\left(\sqrt{t}-1\right)$$

Corresponding efficiency $= \eta_{max} = 1-\frac{1}{\sqrt{t}}$

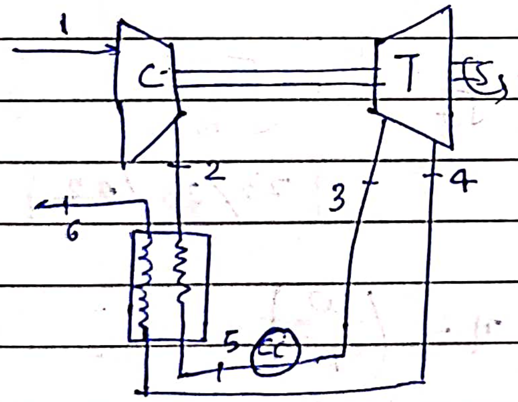
Inferences,

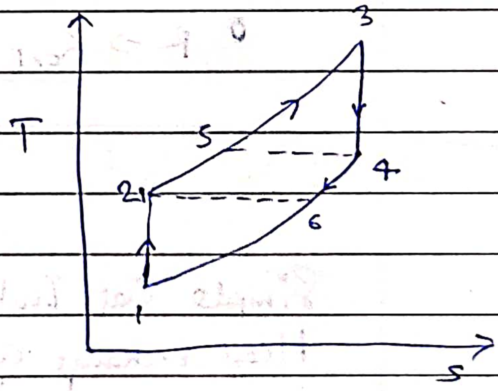
\# $T_4 > T_2$

\# $T_4 < T_2$ {not possible}.

\# All pressure ratios should fall between (1 and R_{opt})

Heat Exchange cycle :-





\# $W_{net} = C_p(T_3 - T_4) - C_p(T_2 - T_1)$

\# $Q_{in} = C_p(T_3 - T_5)$

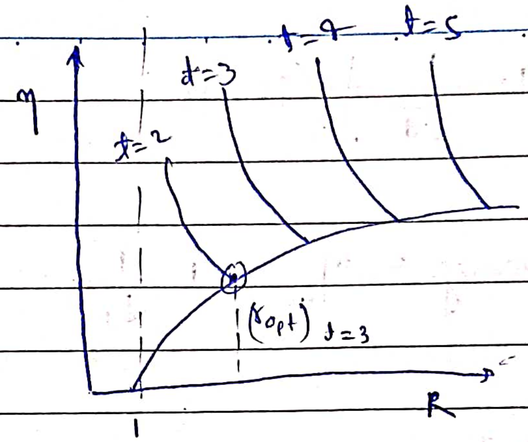
$$\eta = \frac{C_p(T_3-T_4) - C_p(T_2-T_1)}{C_p(T_3-T_5)}$$

{when $T_4 = T_5$}.

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

$$\boxed{\eta = 1 - \left[\frac{\left(\frac{T_2}{T_1}\right)-1}{\frac{T_3}{T_1} - \frac{T_4}{T_3}\frac{T_3}{T_1}}\right] = 1 - \frac{R^{\frac{\gamma-1}{\gamma}}}{t}}$$ for Heat exchange cycle.

$\left(\eta = 1 - \frac{1}{R^{\frac{\gamma-1}{\gamma}}}\right)$ for simple.



the 't' curves starts at $r=1$

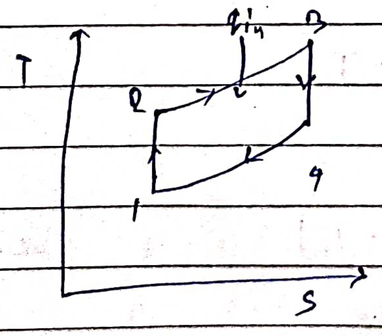
$$r=1 \Rightarrow \eta = 1-\frac{1}{t} = 1-\frac{T_1}{T_3}$$

⇒ for a given 't' there is r_{opt}.

$$R \to R_{opt} ; \ \eta = 1-\frac{1}{\sqrt{t}} = 1-\sqrt{\frac{T_1}{T_3}}$$

$\boxed{23/03/22}$

Simple Gas Turbine cycle
Heat Exchange Cycle } $\eta = \left(\frac{w}{C_pT_1}\right)$



$$\eta = 1-\frac{1}{R^{\frac{\gamma-1}{\gamma}}}$$

$$\left(\frac{w}{C_pT_1}\right) = \left(\frac{T_3}{T_1} - \frac{T_3}{T_1}\frac{T_4}{T_1}\right) - \left(\frac{T_2}{T_1}-1\right)$$

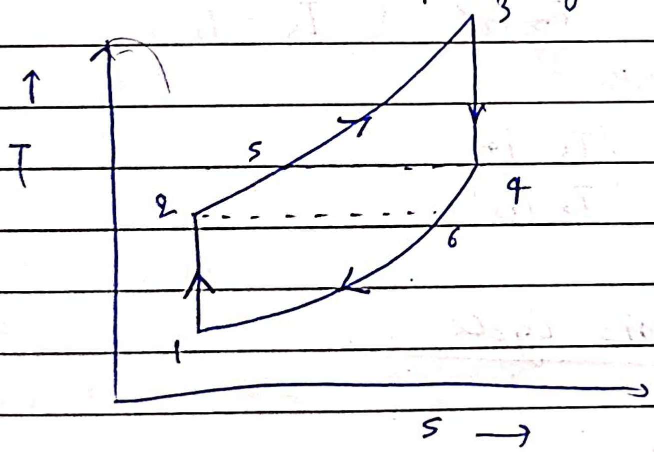
$$= t\left(1-\frac{1}{R^{\frac{\gamma-1}{\gamma}}}\right) - \left(R^{\frac{\gamma-1}{\gamma}}-1\right)$$

$$\frac{d\left(\frac{w}{C_pT_1}\right)}{d\left(R^{\frac{\gamma-1}{\gamma}}\right)} = 0 \Rightarrow R_{opt} = t^{\frac{\gamma}{2(\gamma-1)}}$$

$$\left(\frac{w}{C_pT_1}\right) \to 0 \quad \left\{ \begin{array}{l} R = 1 \\ R = t^{\frac{\gamma}{\gamma-1}} \end{array} \right\}, \quad \eta = 0$$

$$\left(\frac{w}{C_pT_1}\right) \to max \quad \left\{ R = R_{opt} = t^{\frac{\gamma}{2(\gamma-1)}} \right\},$$

For Heat Exchanger cycle

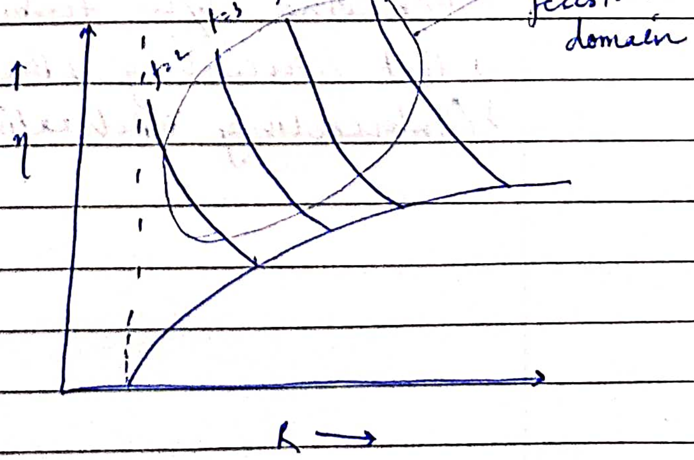


$q_{in} = C_p(T_3 - T_5)$

For ideal heat exchanger

$$\boxed{\eta = 1 - \frac{R^{\frac{\gamma-1}{\gamma}}}{t}} \qquad t = \frac{T_{max}}{T_{min}} = \frac{T_3}{T_1} \text{ - temp. Ratio.}$$

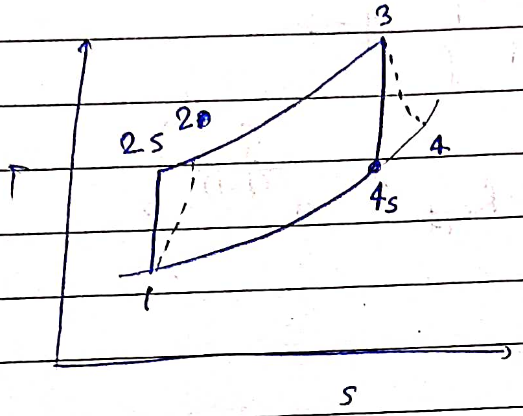
η v/s R



Practical Gas Turbine Cycle :-

Isentropic efficiency $\rightarrow \eta_c$

Component's efficiency $\rightarrow \eta_t$



$$\eta_c = \frac{C_p(T_{2s} - T_1)}{C_p(T_{2a} - T_1)} = \cancel{\frac{T_{2a} - T_1}{T_{2s} - T_1}} \quad \left(\frac{T_{2s} - T_1}{T_s - T_1}\right)$$

$$\eta_T = \frac{C_p(T_3 - T_4)}{C_p(T_3 - T_{4s})} = \left(\frac{T_3 - T_4}{T_3 - T_{4s}}\right)$$

Modifications to Basic Cycle :-

→ Improve work Ratio

$$WR = \frac{W_{net}}{W_{gross}} = \frac{W_T - W_c}{W_T} \quad \left\{ W_{gross} = \text{Turbine work} \right\}$$

→ Intercooling b/w compression stages.

→ Reheating b/w turbine stages.

→ ~~Int~~ Intercooling & Reheating ?

→ (Intercooling & Reheating) with heat exchanger

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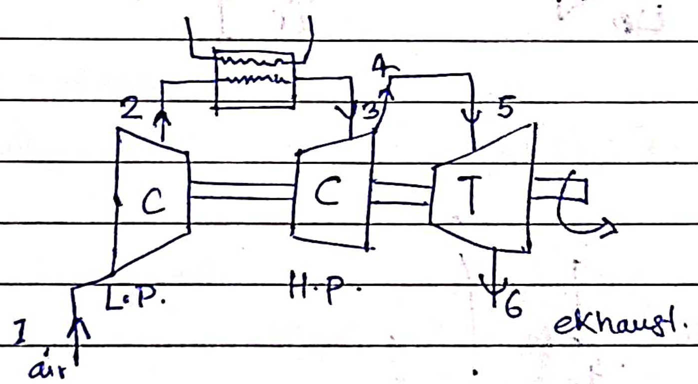
Modifications to Gas Turbine cycle:

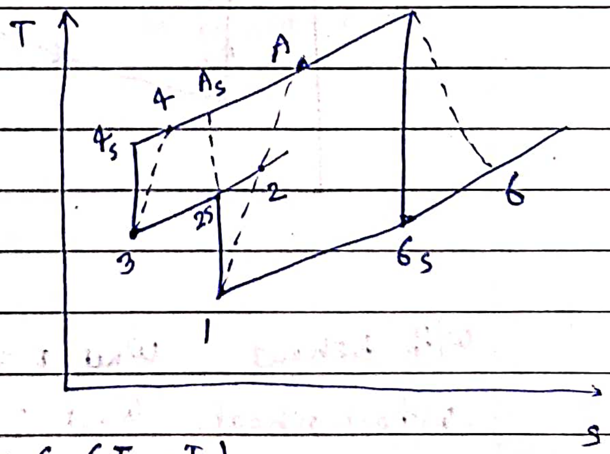
- ⇒ Intercooling cycle
- ⇒ Reheat cycle

] WR ↑, η ↓

- ⇒ Intercooling + Reheat] WR↑, η↓.

Intercooling cycle :-





With Intercooling:

$w_{in,i} = w_{12} + w_{34}$

$\Rightarrow w_{in,i} = C_p(T_2 - T_1) + C_p(T_4 - T_3)$

$q_{in,i} = C_p(T_5 - T_4)$

without Intercooling:

$w_{in} = C_p(T_A - T_1) = C_p(T_2 - T_1) + C_p(T_A - T_2)$

A = No Intercooling

A_s = No intercooling, isentropic.

$C_p(T_4 - T_3) < C_p(T_A - T_2)$

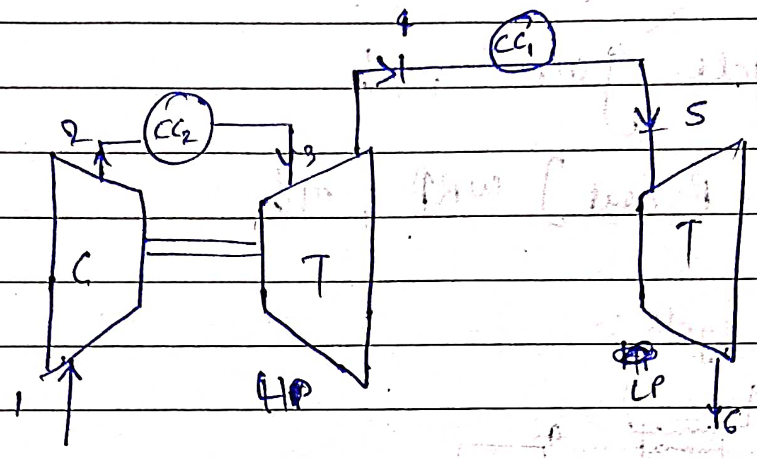
$\Rightarrow w_{in,i} < w_{in}$

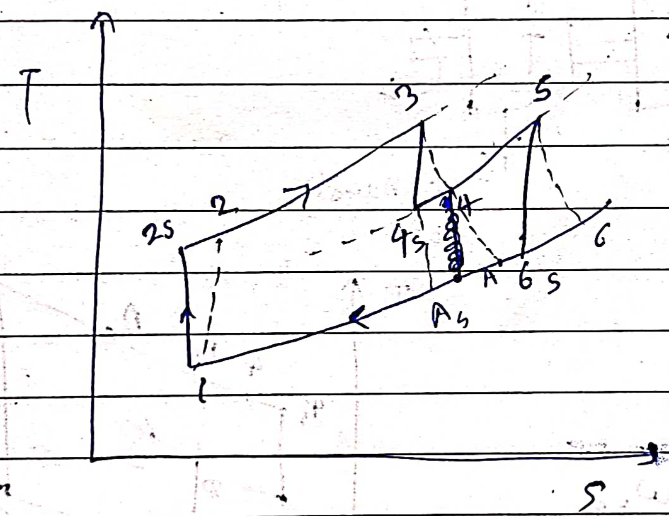
$\Rightarrow$ WR ↑

$q_{in} = C_p(T_5 - T_A)$

$\Rightarrow q_{in,i} > q_{in} \Rightarrow \eta \downarrow$

Reheat cycle:-





W/th Reheat, $w_{net,r} = C_{pg}(T_5 - T_6)$] LP Turbine.

without reheat, $w_{net} = C_{pg}(T_3 - T_A)$

∴ $w_{net,r} > w_{net}$

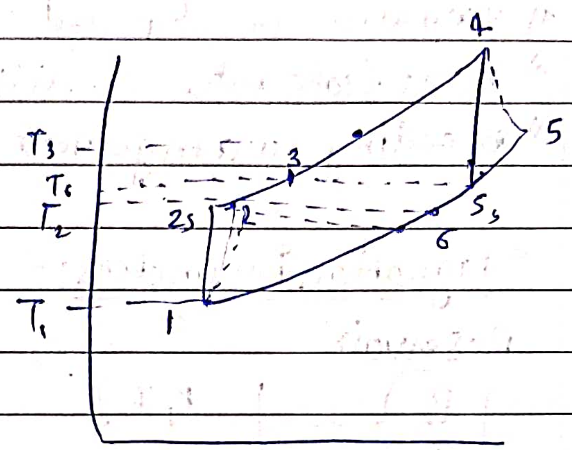
HP, Turbine ∴ $w_t = C_{pa}(T_2 - T_1) = w_c$

$q_{in,r} = C_{pa}(T_3 - T_2) + C_{pg}(T_5 - T_4)$

$q_{in} = C_{pa}(T_3 - T_2)$

∴ $q_{in,r} > q_{in}$

Heat exchange cycle.



Heat balance,

$$\dot{m}_a C_{pa} (T_3 - T_2) = \dot{m}_g C_{pg} (T_5 - T_6)$$

effectiveness

$$\epsilon = \frac{\dot{m}_a C_{pa} (T_3 - T_2)}{\dot{m}_g C_{pg} (T_5 - T_2)}$$ max available heat.

$$\dot{m}_a C_{pa} = \dot{m}_g C_{pg}$$

$$\Rightarrow \epsilon = \text{Thermal Ratio} = \frac{T_3 - T_2}{T_5 - T_2}$$

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\# Improvements in WR is realised when modifications are done in high temp region. (Reheat)

\# Choice of pressure ratio (r)

\# Size of the plant

\# Highly advisable to have heat exchange cycle.

Gas Turbine System :-

Component Losses :

* Compressor, Turbine → Turbomachines

* High velocity Effect → Stagnation Parameters.

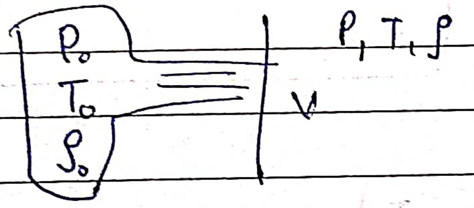
* Irreversible adiabatic

* Fluid friction at inlet and exit of duct.

* Variation in C_p and γ
* Mass flow rates are different ($\dot{m}_t > \dot{m}_c$)
* Bleeding arrangement.

Stagnation Parameters:-

Reservoir



SFEE (Steady flow energy equation)

$$q = (h_2 - h_1) + \frac{1}{2}(C_2^2 - C_1^2) + w$$

No work and No heat Transfer

$$h_2 + \frac{1}{2}C_2^2 = h_1 + \cancel{\frac{1}{2}C_1^2}^{\,0}$$

$$\boxed{h_0 = h + \frac{1}{2}C^2}$$

$$C_p T_0 = C_p T + \frac{1}{2}C^2$$

$$\boxed{\Rightarrow \underbrace{T_0}_{\text{Stagnation}} = \underbrace{T}_{\text{Static}} + \underbrace{\frac{C^2}{2C_p}}_{\text{Dynamic}}}$$

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Adiabatic compression work

$$\omega = -C_p(T_2 - T_1) - \frac{1}{2}(C_2^2 - C_1^2)$$

$$\Rightarrow \omega = -C_p(T_{02} - T_{01})$$

$T_{02}, T_{01} \Rightarrow$ Stagnation value

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Heating without work transfer

$$q = C_p (T_{02} - T_{01})$$

Stagnation to static pressure Ratio

$$\frac{T_0}{T} = 1 + \frac{c^2}{2C_p - T}$$

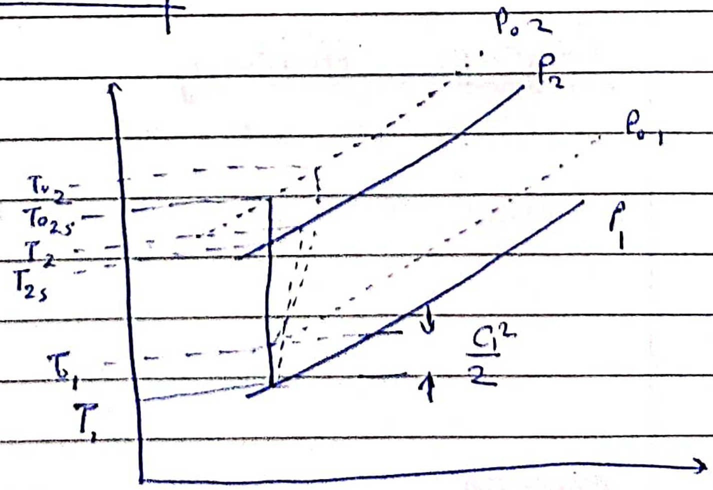
$$= 1 + \frac{c^2}{2\left(\frac{\gamma R}{\gamma - 1}\right) T} \quad \{R = \text{Gas constant}\}$$

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

$$M = \frac{c}{a}, \quad a = \sqrt{\gamma R T}$$

Isentropic, $\frac{P_0}{P} = \left(\frac{T_0}{T}\right)^{\frac{\gamma}{\gamma - 1}}$

$$\Rightarrow \boxed{\frac{P_0}{P} = \left[1 + \left(\frac{\gamma - 1}{2}\right) M^2\right]^{\frac{\gamma}{\gamma - 1}}}$$



Isentropic efficiency :-

$$\eta_c = \frac{w_c'}{w_c} = \frac{T_{02s} - T_{01}}{T_{02} - T_{01}}$$

$$(T_{o_2} - T_{o_1}) = \frac{1}{\eta_c}\left(T_{o2s} - T_{o_1}\right)$$

$$= \frac{T_{o_1}}{\eta_c}\left[\frac{T_{o2s}}{T_{o1}} - 1\right]$$

$$\boxed{T_{o_2} - T_{o_1} = \frac{T_{o_1}}{\eta_c}\left[\left(\frac{P_{o2}}{P_{o1}}\right)^{\frac{\gamma-1}{\gamma}} - 1\right]}$$

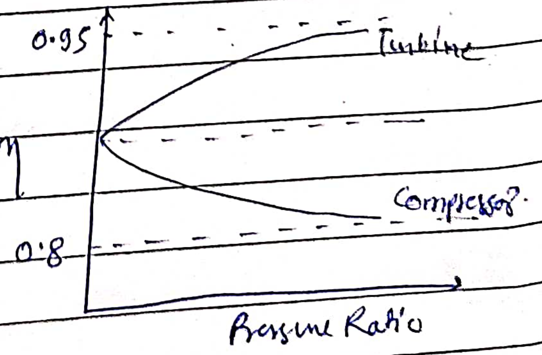
$$\eta_t = \frac{W_t}{W_t'} = \frac{T_{o3} - T_{o4}}{T_{o3} - T_{o4s}}$$

$$\Rightarrow T_{o3} - T_{o4} = \eta_t T_{o3}\left[1 - \frac{T_{o4s}}{T_{o3}}\right]$$

$$T_{o_3} - T_{o4} = \eta_t T_{o3}\left[1 - \frac{1}{\left(\frac{T_{o3}}{T_{o4s}}\right)}\right]$$

$$\Rightarrow T_{o_3} - T_{o4} = \eta_t T_{o_3}\left[1 - \frac{1}{\left(\frac{P_{o3}}{P_{o4}}\right)^{\frac{\gamma-1}{\gamma}}}\right]$$

Polytropic efficiency



Compressor

$$T_{o_2} - T_{o_1} = T_{o_1}\left[\left(\frac{P_{o2}}{P_{o1}}\right)^{\frac{n-1}{n}} - 1\right]\eta$$

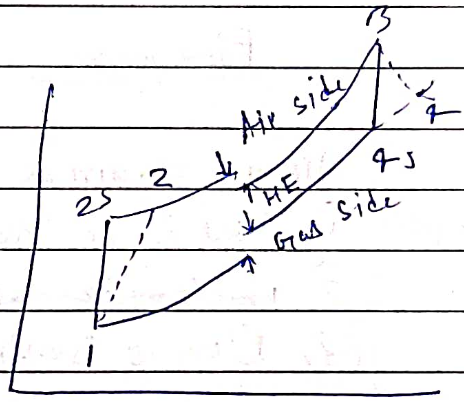
$$\frac{n-1}{n} = \frac{1}{\eta_{\infty,c}}\left(\frac{\gamma-1}{\gamma}\right)$$

Turbine

$$T_{03}-T_{04} = T_{03}\left[1-\frac{1}{\left(\frac{P_{03}}{P_{04}}\right)^{\frac{\gamma-1}{\gamma}}}\right]$$

$$\frac{n-1}{n} = \eta_{\infty,t}\left(\frac{\gamma_g-1}{\gamma_g}\right)$$

Pressure losses



$$P_{03} = P_{02}\left[1-\frac{\Delta P_b}{P_{02}}-\frac{\Delta P_{ha}}{\Delta h_g}\right]$$

$\frac{\Delta P_b}{P_0}$ → combustion chamber pressure losses

≈ 6 – 8% (aero engines)

≈ 2 – 3% (conventional gas turbines)

ΔP_{ha} → Pressure losses in air side

≈ 3% of P_{02}

Δh_g ≈ Pressure loss in gas side

= 0.04 bar

Combustion efficiency.

$$\eta = \frac{\text{Theoretical } f}{\text{actual } f}$$

Specific heat consumption

$$SFC = \frac{\dot{m}_f}{W_{net}}.$$

$$\eta = \frac{W_{net}}{f\,Q_{in}}$$

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Mechanical losses :-

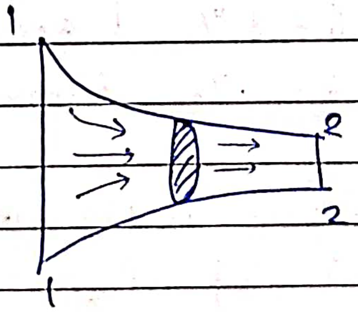
$$W_c = \frac{W_d}{\eta_m} = \frac{C_p (T_{03} - T_{02})}{\eta_m}$$

09/04/022

Flow nozzle

Assume steam as a compressible fluid.

Assumption
1. There is no heat loss.
2. ~~friction is absent~~ Frictional loss is negligibley small.
3. Flow is isentropic, PV^k = constant.
   K = index of the expansion of the isentropic process.
4. Flow is 1D



Area of the cross section normal to the flow direction = A
velocity = C
density = ρ
Sp. enthalpy = h
Pressure = P
sp. volume = v

mass continuity

$$\rho_1 A_1 C_1 = \rho_2 A_2 C_2$$

ρAC = constant

$$\Rightarrow \frac{d\rho}{\rho} + \frac{dA}{A} + \frac{dc}{C} = 0$$

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$p v^{k} = \text{constant}$

$\Rightarrow \dfrac{P}{\rho^{k}} = \text{constant}$

$\Rightarrow P\rho^{-k} = \text{constant}$

$\Rightarrow \boxed{\dfrac{d\rho}{\rho} = \dfrac{1}{K}\dfrac{dP}{P}}$

$Tds = du + pdv$

$\boxed{Tds = dh - vdp}$ applying this

$\cancel{Tds} = dh - vdp$ ($Tds \to 0$)

$\Rightarrow dh = vdp = \dfrac{dp}{\rho}$ — (1)

SSSF eq.

$\cancel{\dot{Q}} + \dot{m}_i\left(h_i + \dfrac{c_i^2}{2} + gz_i\right) = \cancel{\dot{W}} + \dot{m}_e\left(h_e + \dfrac{c_e^2}{2} + gz_e\right)$ ($\dot{Q} \to 0$, $\dot{W} \to 0$)

$h_i + \dfrac{c_i^2}{2} + gz_i = h_e + \dfrac{c_e^2}{2} + gz_e$

for two section

$h_1 + \dfrac{c_1^2}{2} + gz_1 = h_2 + \dfrac{c_2^2}{2} + gz_2$

$\Rightarrow (h_2 - h_1) + \dfrac{(c_2^2 - c_1^2)}{2} + g(z_2 - z_1) = 0$

Assuming nozzle is very short $\Rightarrow g(z_2 - z_1) = 0$.

$\Rightarrow (h_2 - h_1) + \dfrac{(c_2^2 - c_1^2)}{2} = 0$

$\Rightarrow \boxed{dh + cdc = 0}$

$\dfrac{dP}{\rho} + cdc = 0$ {from eq. 1}

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$$\frac{dP}{\rho} + c\,dc = 0$$

$$\Rightarrow \frac{dP}{\rho c^2} + \frac{dc}{c} = 0 \quad \text{— (2)}$$

$$M_{(\text{mach no.})} = \frac{c}{a} \qquad \{a = \text{acoustic velocity}\}.$$

$$\Rightarrow \rho c^2 = \rho m^2 a^2$$

$$a = \sqrt{\frac{KP}{\rho}}$$

$$= \rho m^2 \frac{KP}{\rho}$$

$$\boxed{\rho c^2 = KPM^2} \quad \text{— (3)}$$

Putting in eq. 2.

$$\frac{dc}{c} = -\frac{dP}{Km^2P}$$

So,
$$\frac{dA}{A} = \frac{-d\rho}{\rho} - \frac{dc}{c}$$

$$\boxed{\frac{dA}{A} = -\frac{1}{K}\frac{dP}{P} + \frac{dP}{KPm^2}}$$

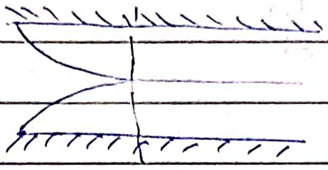
$$\Rightarrow \boxed{\frac{dA}{A} = \frac{1}{K}\frac{dP}{P}\left[\frac{1}{M^2} - 1\right]}$$

$$\boxed{\frac{dA}{A} = \frac{1}{K}\frac{dP}{P}\left[\frac{1-M^2}{M^2}\right]}$$

Case I :

Accelerated flow

accelerated → fully developed



density does not change significantly with pressure.

$$\frac{dP}{P} = \text{negative}$$

(a) when $M < 1$ {subsonic flow}.

$$\Rightarrow \frac{dA}{A} = -ve$$

⇒ flow through nozzle.

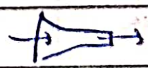
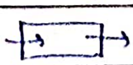
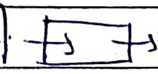
(b) when $M = 1$ {sonic flow}.

⇒ sonic state is reached and ~~area~~
Area = constant.

(c) $M > 1$ {supersonic flow}.

~~⇒ flow tl~~ $\Rightarrow \frac{dA}{A} = +ve$.

⇒ flow through divergent part of the nozzle.

type of flow	accelerated flow falling pressure	Retarted flow or Rising pressure.
Subsonic		
Supersonic		
Sonic		throttle of nozzle 

Case II

Retarted flow

$$\frac{dP}{P} = +ve$$

(a) $M < 1$

$\Rightarrow$ subsonic

$\Rightarrow \frac{dA}{A} = +ve$

$\Rightarrow$ ~~diverg~~ diverging.

(b) $M = 1$

$\Rightarrow$ sonic.

$\frac{dA}{A} = 0 \Rightarrow$ throttle.

(c) $M > 1$

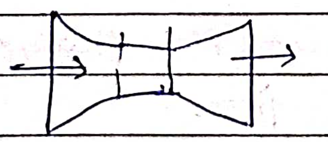
$\Rightarrow$ supersonic.

$\frac{dA}{A} = -ve$

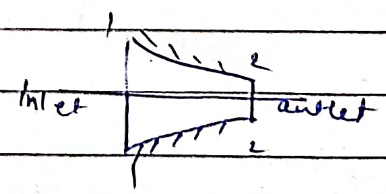
$\Rightarrow$ converging.

$\Rightarrow$ nozzle

Type of flow	Typeof duct	Typeof device.
Supersonic	convergent.	nozzle.
subsonic	convergent.	nozzle.
subsonic	divergent	diffuser
Supersonic	divergent	diffuser.



flow through a convergent divergent nozzle.



$\dot{m}_2 = \rho_2 A_2 C_2$

$\frac{P}{\rho^k} = \text{constant} \Rightarrow \rho_2 = \left(\frac{P_2}{P_1}\right)^{1/k} \rho_1$

$\int_1^2 C\,dc = -dh = -\int_1^2 \frac{dP}{\rho}$

$$\Rightarrow \frac{C_2^2 - C_1^2}{2} = -(\text{constant})^{1/k} \int_1^2 \frac{dP}{P^{1/k}}$$

$$\Rightarrow \boxed{\frac{C_2^2 - C_1^2}{2} = \frac{k}{k-1} \left(\frac{P_1}{\rho_1^k}\right)^{1/k} \left[P_1^{\frac{k-1}{k}} - P_2^{\frac{k-1}{k}} \right]}$$

when $d_1 >> d_2$

$\Rightarrow$ ~~$C_2 <<$~~ $C_1 << C_2$

$$\Rightarrow \boxed{\frac{C_2^2}{2} \simeq \frac{k}{k-1} \frac{P_1^{1/k}}{\rho_1} \left[P_1^{\frac{k-1}{k}} - P_2^{\frac{k-1}{k}} \right]}$$

$$\Rightarrow \dot{m}_2 = A_2 \left(\frac{P_2}{P_1}\right)^{1/k} \rho_1 \left[\frac{2k}{k-1} \left(\frac{P_1^{1/k}}{\rho}\right) \left(P_1^{\frac{k-1}{k}} - P_2^{\frac{k-1}{k}} \right) \right]^{1/2}$$

$$\Rightarrow \dot{m}_2 = A_2 \left[\frac{2k}{k-1} (P_1 \rho_1) \left\{ \left(\frac{P_2}{P_1}\right)^{2/k} - \left(\frac{P_2}{P_1}\right)^{\frac{k+1}{k}} \right\} \right]^{1/2}$$

max flow rate of steam per unit area

$$\frac{\dot{m}_2}{A_2} = \left[\frac{2k}{k-1} (P_1 \rho_1) \left\{ \left(\frac{P_2}{P_1}\right)^{2/k} - \left(\frac{P_2}{P_1}\right)^{\frac{k+1}{k}} \right\} \right]^{1/2}$$

{ k = constant and depends on quality of steam }

$$\Rightarrow \frac{\dot{m}_2}{A_2} = f\left(\frac{P_2}{P_1}\right)$$

$\frac{P_2}{P_1}$ = critical pressure ratio.

Camlin

11/04/22.

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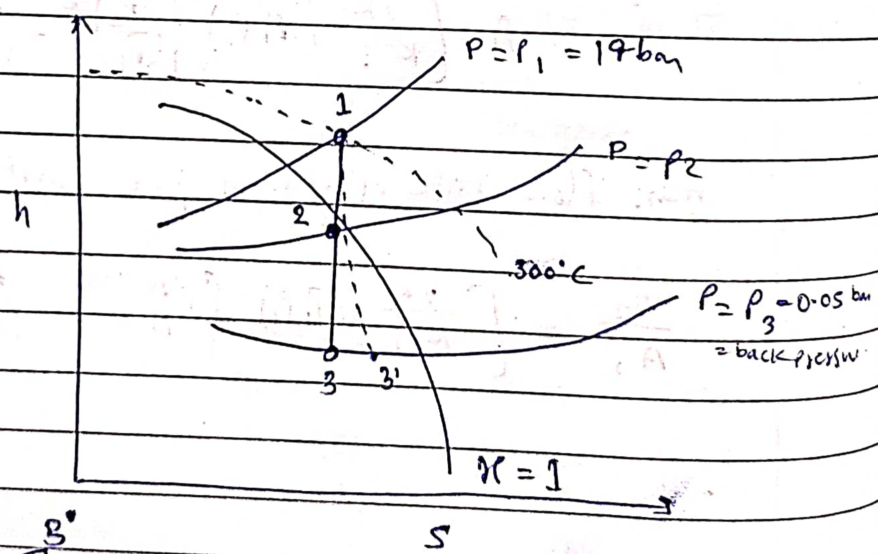
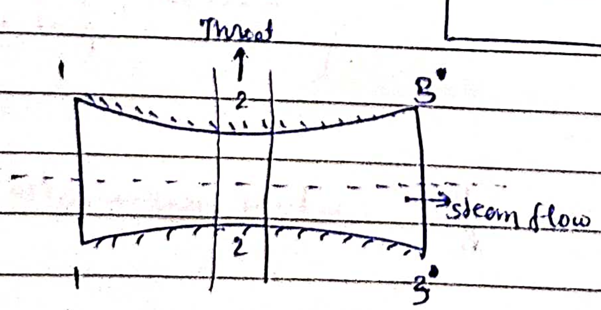
Prob1 Flow nozzle of a certain turbine.
Throat diameter = 0.6 cm each.
Power developed by the turbine = 150 kW
Steam consumption rate = 9.5 kg/kWh
Upstream pressure and temp are 14 bar and 300°C
Back pressure = 0.05 bar.
Assume flow is isentropic b/w entrance and exit.

{exam ~~wali~~ wali prob}

Find, no. of nozzles. = ?
Steam consumption rate. = ?
neglect velocity of approach.

Soln The expansion of steam in the nozzle is shown in the h-s diagram.





$h_1 = 3040.9 = 3041 \text{ kJ/kg}$. {from steam table}.

if inlet steam is superheated then $k = 1.3$.

$$\left(\frac{P_2}{P_1}\right) = \left(\frac{P_2}{P_1}\right)_{critical} = \left(\frac{2}{k+1}\right)^{\frac{k}{k-1}} = 0.5457.$$

$\Rightarrow P_2 = P_1 \times 0.5457$

$= 14 \times 0.5457$

$= 7.638$ bar.

$S_2 = S_1$ { isentropic process.

$S_2 = s_f + x_2 s_{fg} @ P_2$

So, $h_2 = h_f + x_2 h_{fg} @ P_2$

$\Rightarrow h_2 = 2882$ kJ/kg.

$S_{3'} > S_3$

but $S_3 = S_1$ & $P_3 = 0.05$ bar.

$h_3 = 2120$ kJ/kg.

$P_{cr} > P_{exit}$ [nozzle will be of convergent divergent type }.

$v_{3'} > v_3$

$v_{3'} = v_f + x_3 v_{fg} @ P_3$

* Max velocity will be at throat.

$$\frac{C_1^2}{2} + h_1 = \frac{C_2^2}{2} + h_2 \quad \{SFEE\}.$$

$$\Rightarrow \frac{C_2^2 - C_1^2}{2} = (h_1 - h_2)$$

$\Rightarrow C_1 \approx 0$ {velocity of approach}.

$$\rightarrow C_2 = \sqrt{2(h_1 - h_2)} = 563 \text{ m s}^{-1}$$

No. of nozzle :

$C_2 = 563\ ms^{-1}$

Throad dia $= 0.6 \times 10^{-2}$ m.

Throad area $= \frac{\pi}{4}(0.6 \times 10^{-2})^2$

$= 0.28279\ cm^2$

Steam consumption rate $= 9.5$ kg/kwh

$= \frac{9.5}{3600} \times 150$

$= 0.3958$ kg/sec

mass flow rate per nozzle.

$\dot{m} = \frac{A C_2}{v_2} = \frac{0.28279 \times 563 \times 10^{-4}}{0.2727}$

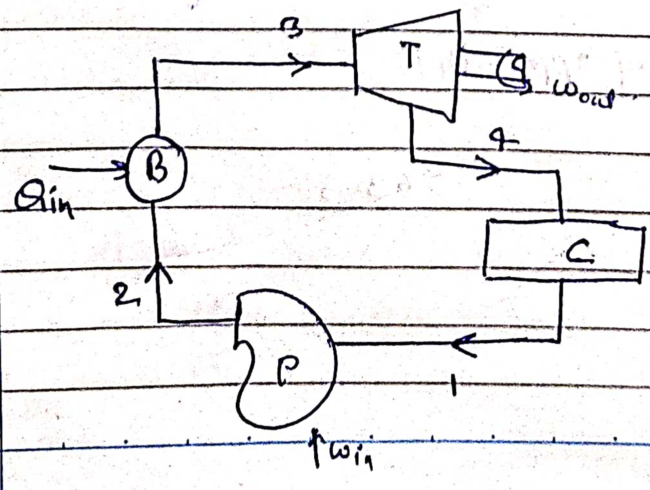
v_2 {from steam table at P_2 and h_2}.

or $\dot{m} = 0.05846$ kg/sec.

No. of nozzle ≈ 7. {6.7}.

Actual steam consumption rate $= 0.4092$ kg/sec.

12/04/022

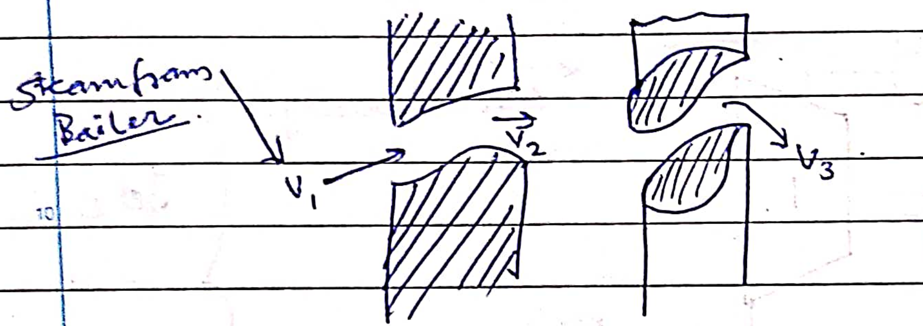


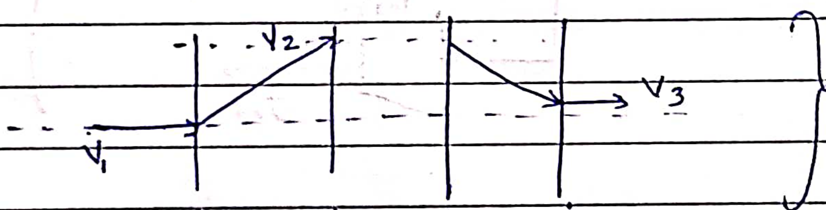
Thermodynamics sucks
Thermodynamics sucks ++1

Steam turbine
→ Impulse
→ Reaction.

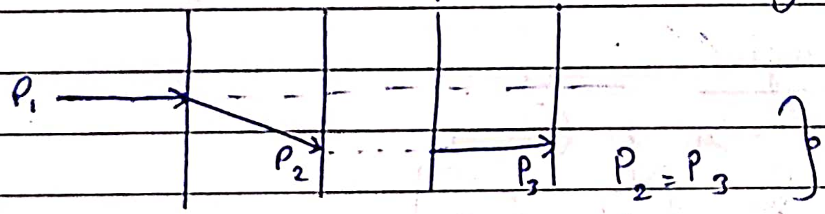
Steam turbine is the assemblage of nozzles and blades.

Nozzle Blade

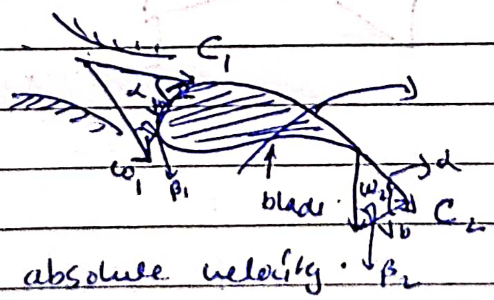




Velocity plot



Pressure plot.



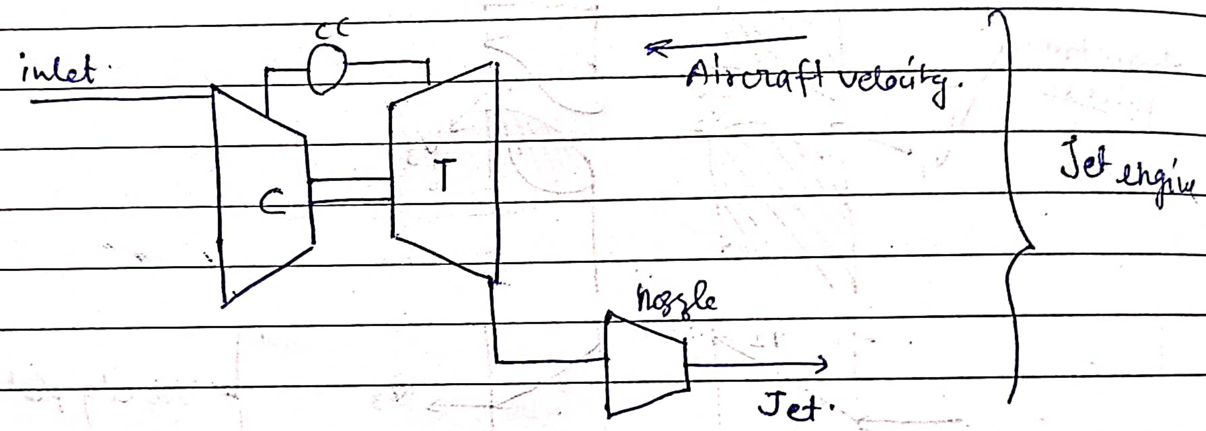
C_0 : absolute velocity.
V_b - blade velocity.
ω = relative velocity

α = flow angle.
β = blade angle.

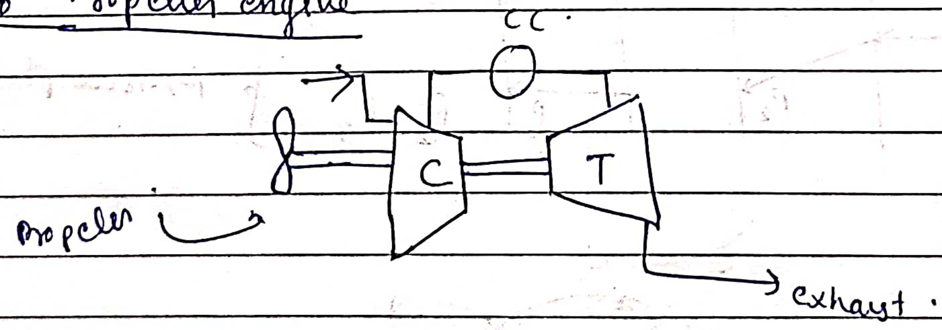
Suffices 1 and 2 ~~are~~ indicates inlet and outlet

Aircraft propulsion cycle :-

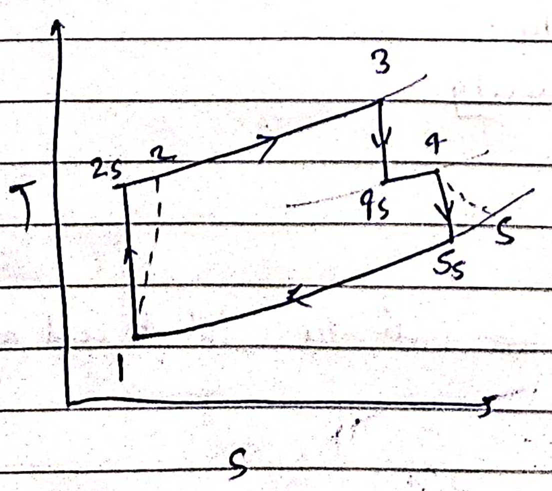
⇒ Power output → thrust
⇒ Intake and propelling nozzles.
⇒ Altitude effects/ Forward speed.
⇒ Power to weight ratio.
⇒ Low SFC, take off and landing speed.



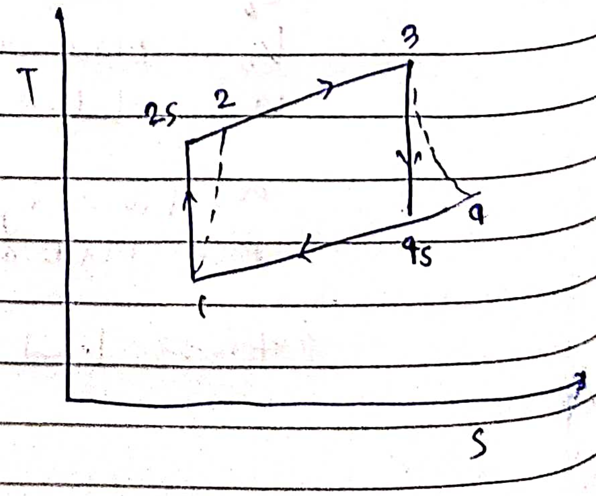
Turbo Propeller engine



Jet engine



Propeller.



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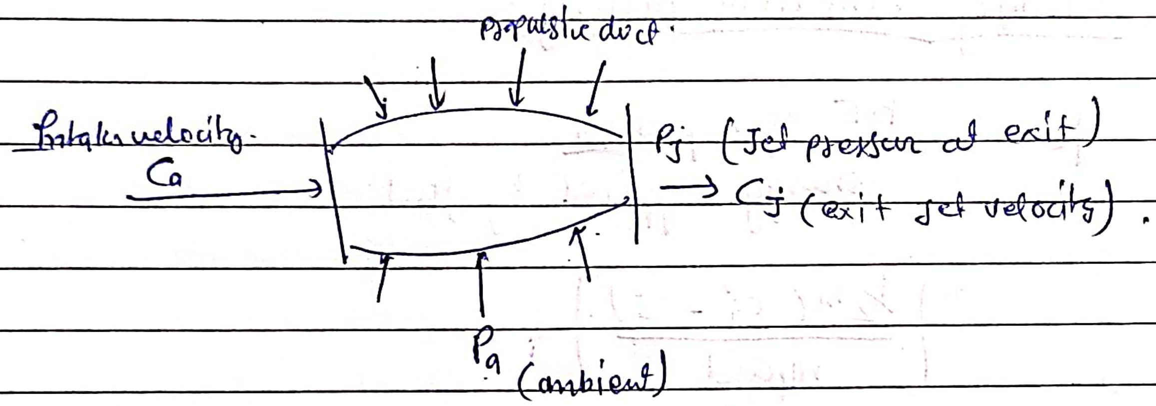
Performance criterion

→ Thrust → Momentum
→ Pressure.



Net thrust -

$$F = \underbrace{m(C_j - C_a)C_a}_{\text{(momentum thrust)}} + \underbrace{A_j(P_j - P_a)}_{\text{Pressure thrust}}$$

Propulsive efficiency:-

$$\eta_p = \frac{\text{Thrust power}}{\text{(used + unused) KE of jet}}.$$

$$= \frac{m(C_j - C_a)C_a}{\left[mC_a(C_j - C_a) + \frac{1}{2}m(C_j - C_a)^2\right]}$$

$$\eta_p = \frac{2}{1 + (C_j/C_a)}$$

$C_a \to 0 \Rightarrow F \to$ maximum, $\eta_p \to 0$

$C_a = C_j$, $\Rightarrow F \to 0$, η_p = max

~~$C_j \to C_j$~~ C_j

$C_j > C_a$, $(C_j - C_a)$ not too high.

→ Increase of jet velocity.

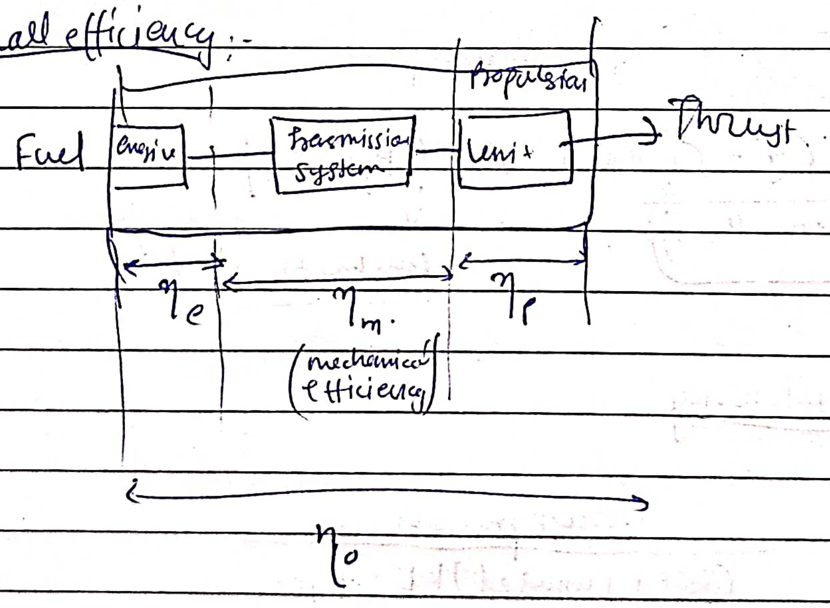
→ Decrease in SFC.

Energy conversion efficiency:

$$\eta_e = \frac{\text{KE of propulsion}}{\text{energy supplied by fuel}}$$

$$= \left[\frac{\frac{1}{2} m (C_j^2 - C_a^2)}{m_f Q_{net}}\right]$$

Overall efficiency:-



$$\eta_o = \frac{\text{useful thrust power}}{\text{energy supplied}}$$

$$\eta_o = \frac{m C_a (C_j - C_a)}{m_f Q_{net}}.$$

$$\eta_p = \frac{m C_a (C_j - C_a)}{\frac{1}{2} m (C_j^2 - C_a^2)}$$

$$\eta_p = \frac{\eta_o}{\eta_e}$$

$$\rightarrow \eta_o = \eta_p \eta_e.$$

$$\eta_o = \eta_p \eta_e \eta_m.$$

Engine classification

- → Piston engine
- → Turboprop engine
- → Turbojet engine.
- → Turbofan engine.
- → Ramjet engine.
- → Scramjet engine

} wave engines

Specific thrust:-

$$F_s = \frac{F}{\dot{m}}$$

SFC (Specific fuel consumption) $= \dfrac{\dot{m}_f}{F}$

$$F_s = \frac{f}{SFC}$$

{f = fuel air ratio}