REFRIGERATION

REFRIGERATION: It's a process of creating or maintaining lower temperature than surroundings.

CLAUSIUS STATEMENT: It's impossible to construct a device which operates on a cycle and transferring heat from low temperature body to high temperature body without any external work input.

REFRIGERATOR: Refrigerator is a device which must operate on cyclic process and creates and maintain low temperature than surroundings continuously by some external work input. $COP_R = Q_2/W$

REFRIGERATION EFFECT:
It's the amount of heat which is to be extracted from storage space in order to maintain at lower temperature. Q_2

HEAT PUMP: It's device which must operate on cyclic process and creates and maintain high temperature than surroundings continuously by some external work input. $COP_{HP} = Q_1/W$

REFRIGERATION CAPACITY: $RC\ (KW) = \dot{m}Q_2$

UNIT OF REFRIGERATION	
$1\ tonne\ (British) = 1000\ kg$	$1\ ton\ (US) = 907\ kg = 2000\ Pounds$

1 TON OF REFRIGERATION: It is the amount of heat which is to be extracted from 1 ton of water at $0\ °C$ in order to convert into 1 ton of ice at $0\ °C$ in 24 hours. $1\ ton = 3.5\ KW$

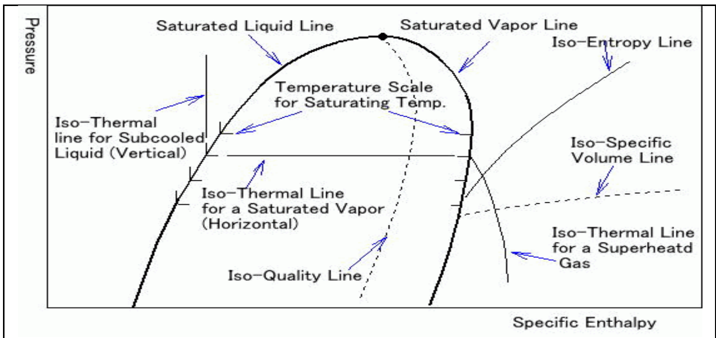
REFRIGERANT: these are the heat carrying medium in a refrigeration system.

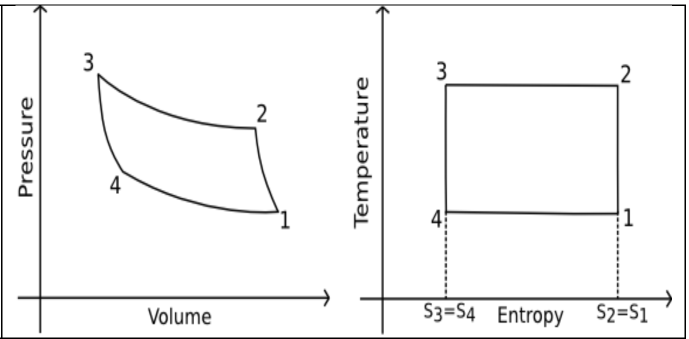
1. **Primary Refrigerant:** These are refrigerant upon which compression and expansion take place and undergoes a cycle to produce lower temperature. E.g. NH3, R12, R22, R134a, Etc…
2. **Secondary Refrigerant:** These are refrigerant upon which are first cooled by the primary refrigerant and then used for cooling at the desired place. E.g. Water, Air, Etc…

TD Cycles						
Power Cycles		Refrigeration Cycles				
Vapour Power Cycle	Gas Power Cycle	Gas Refrigeration Cycles	Vapour Refrigeration Cycles			
Rankine cycle	Gas Turbine	Reversed Carnot (Ideal)	Ideal Carnot	VCR	VAR	

In vapour cycle Working fluid undergoes Phase change.

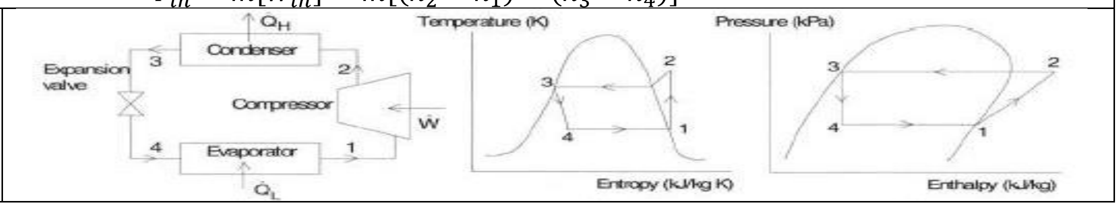
IDEAL/ CARNOT REFRIGERATION CYCLE:





$Q_l = h_1 - h_4$	$Q_h = h_2 - h_3$	$W_{in} = W_C - W_{exp} = (h_2 - h_1) - (h_3 - h_4)$	
$COP_R = \dfrac{Q_l}{W_{in}} = \dfrac{T_l}{T_h - T_l} = \dfrac{CE}{P_{in}}$		$COP_{HP} = \dfrac{Q_h}{W_{in}} = \dfrac{T_h}{T_h - T_l} = \dfrac{HE}{P_{in}}$	
$W_{in\ R} = \left[\dfrac{T_h - T_l}{T_l}\right] Q_l = \left[\dfrac{T_h - T_l}{T_l}\right](h_1 - h_4)$		$W_{in\ HP} = \left[\dfrac{T_h - T_l}{T_h}\right] Q_h = \left[\dfrac{T_h - T_l}{T_h}\right](h_2 - h_3)$	
$T_h = T_{sat}@P_h$	$T_l = T_{sat}@P_l$	$h_2 = h_g@P_h$	$h_3 = h_f@P_h$
$Capacity\ of\ Ref. = \dot{m}Q_l = \dot{m}(h_1 - h_4)$		$Capacity\ of\ Heating = \dot{m}Q_h = \dot{m}(h_2 - h_3)$	
$P_{in} = \dot{m}[W_{in}] = \dot{m}[(h_2 - h_1) - (h_3 - h_4)]$			

VAPOUR COMPRESSION REFRIGERATION SYSTEM:



VAPOUR COMPRESSION REFRIGERATION SYSTEM:

1-2: Reversible Adiabatic Compression, $\boldsymbol{h_1} = h_g@P_l\ (At\ Evaporation\ Pressure)$ $\boldsymbol{h_2} = h_{sup}@P_h\ \&\ T_{sup}(At\ Condention\ Pressure)$ $\boldsymbol{Or}\ h_2 = h_g@P_h + C_{P\ vap}(\boldsymbol{T_{sup}} - T_{sat})$ $\boldsymbol{Or}\ s_1 = s_g@P_l = s_2$ From property table, $h_2 = h_{sup}@P_h\ \&\ s_2$ $\boldsymbol{Or}\ w_{in} = \left[\frac{n}{n-1}\right](P_2v_2 - P_1v_1)$ From the 1st Law, $h_2 = h_1 + w_{in}$	**2-3:** Constant Pressure heat Rejection, $\boldsymbol{h_3} = h_f@P_h(At\ Condention\ Pressure)$ From the 1st Law, $q_R = h_2 - h_3$ **3-4:** Throttling process (Reversible Adiabatic Expansion), From the 1st Law, $\boldsymbol{h_4} = h_3$ 4-1: Constant Pressure heat Addition, From the 1st Law, $q_{in} = h_1 - h_4 = Ref.Eff.$ $COP_R = \frac{q_{in}}{w_{in}} = \frac{h_1 - h_4}{h_2 - h_1} = \frac{h_1 - h_3}{h_2 - h_1}$
$Capacity\ of\ Refrigeration = \dot{m}q_{in} = \dot{m}(h_1 - h_4)$	$Capacity\ of\ Heating = \dot{m}q_{out} = \dot{m}(h_2 - h_3)$
$P_{in} = \dot{m}[w_{in}] = \dot{m}(h_2 - h_1)$	

PERFORMANCE PARAMETER FOR VCR:

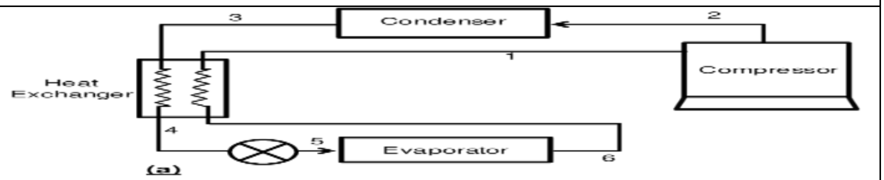
Volumetric Efficiency of reciprocating compressor	$\eta_{vol.} = 1 - C\left[(r_p)^{1/n} - 1\right]$

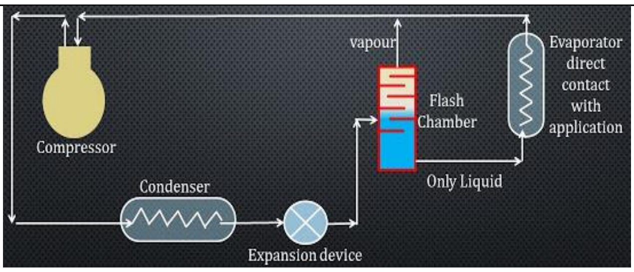
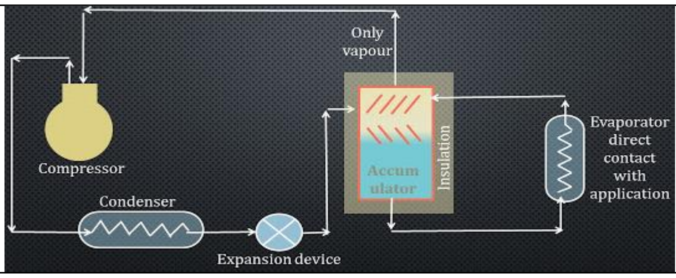
DECREASING IN EVAPORATOR PRESSURE	INCREASE IN CONDENSER PRESSURE
• Ref. Effect decreases • w_{in} increases • COP Decreases • Volumetric Efficiency decreases • Evaporator pressure depends on desired lower temperature.	• Ref. Effect decreases • w_{in} increases • COP Decreases • Volumetric Efficiency decreases • Condenser pressure depends on surrounding temperature.
NOTE: The condenser pressure should be in such a way that corresponding saturation temperature must be grater than surrounding temperature.	

SUPERHEATING	SUBCOOLING
• Ref. Effect increases • w_{in} increases • COP may increases or decreases depends on refrigerant. In case of NH3 it decreases and In case of R12 it increases. • Volumetric Efficiency remains same	• Ref. Effect increases • w_{in} remains same • COP may increases. • Volumetric Efficiency remains same

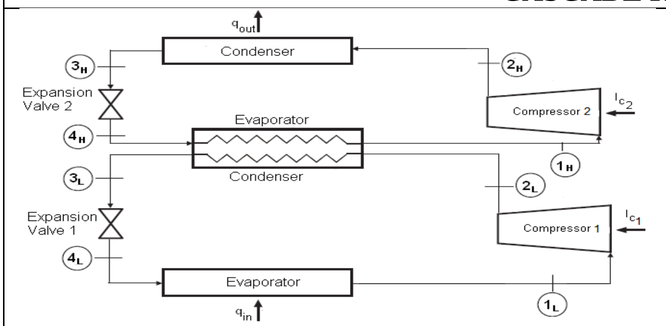
SUPERHEATING & SUBCOOLING

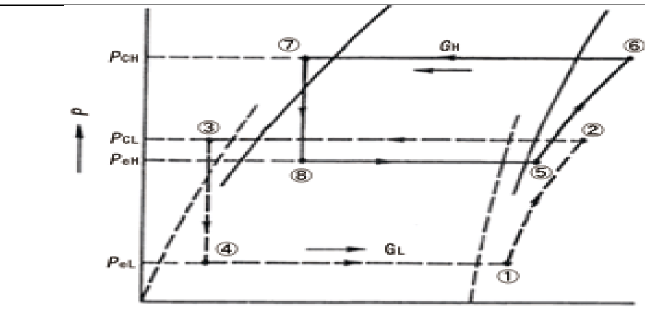
- Ref. Effect increases.
- w_{in} increases.
- COP may increases.
- Volumetric Efficiency remains same



USE OF FLASH CHAMBER	USE OF ACCUMULATION
	
Size of Evaporator Reduce	Size of Evaporator Reduce as well as pump is more safe.

CASCADE REFRIGERATION



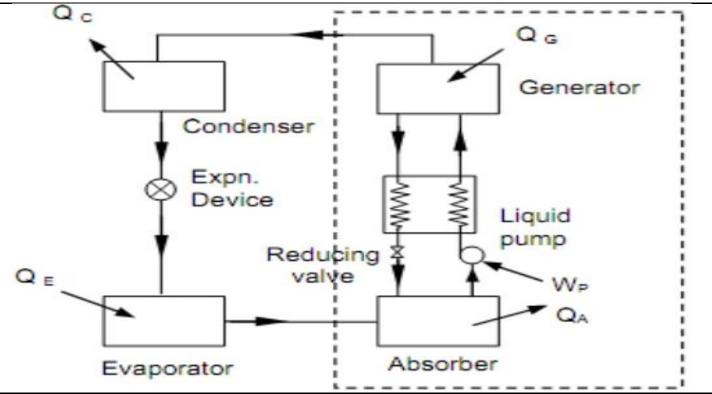


For Cascaded System, $COP_{Cascade} = [COP_1 COP_2]/[1 + COP_1 + COP_2]$

DESIGNATION OF REFRIGERANT $(C_m H_n F_p Cl_q)$	
CASE-I: SATURATED HYDROCARBON	**CASE-II: UNSATURATED HYDROCARBON**
$R - (m-1)(n+1)p$ $Where, n + p + q = 2m + 2$	$R - 1(m-1)(n+1)p$ $Where, n + p + q = 2m$
CASE-III: INORGANIC REFRIGERANT	
$R - (700 + Molecular\ Weight)$	E.g. NH3 = R-717, CO2 = R-744, Air = R-729, SO2=R-764

- Cl atom contain in chemical formula is responsible for the depletion of ozone layer.
- If chemical formula does not contain Cl then it's eco-friendly refrigerant. E.g. R-134a is eco-friendly refrigerant.
- The F atom in the molecules of refrigerant make it physiologically more favourable.
- The H atom in molecules impacts degree of flammability.

VAPOUR ABSORPTION REFRIGERATION SYSTEM: Useful when capacity system is high. Work with low grade energy. So, it's useful when high amount of waste energy available.



T_G			T_G		T_o
$Q_G \downarrow$			$Q_G \downarrow$		$Q_2 \uparrow$
VAR	$\rightarrow Q_o - Q_a$	T_o	HE	$\rightarrow W \rightarrow$	$Ref.$
$Q_e \uparrow$			$Q_1 \downarrow$		$Q_e \uparrow$
T_e			T_o		T_e

Where, Q_e = Energy absorbe by evaporator,
Q_G = Energy Supplied for heating,
Q_a = Energy Rejected from absorber chamber,
Q_o = Energy Rejected from Condensor.
According to 1st Law, $\sum Q = \sum W$

$$Q_e + Q_G - Q_a - Q_o = -W_P$$

According to 2nd Law, $\oint \frac{dQ}{T} \leq 0$,

$$\frac{Q_G}{T_G} + \frac{Q_e}{T_e} - \frac{Q_o + Q_a}{T_0} \leq 0 \Rightarrow \frac{Q_e}{Q_G} \leq \left(\frac{T_G - T_o}{T_G}\right)\left(\frac{T_e}{T_o - T_e}\right)$$

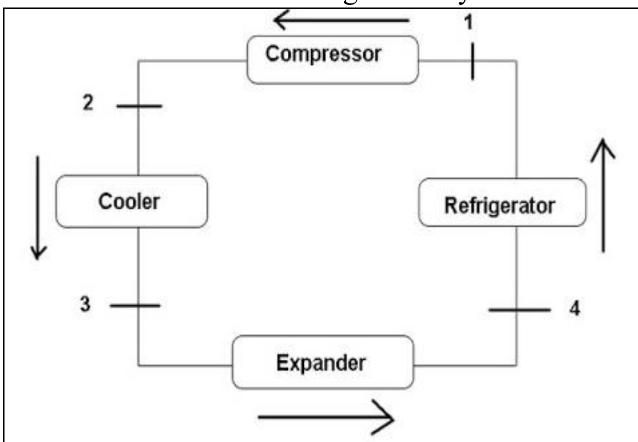
$$\therefore (COP_R)_{max} = \frac{Q_e}{Q_G} = \left(\frac{T_G - T_o}{T_G}\right)\left(\frac{T_e}{T_o - T_e}\right)$$

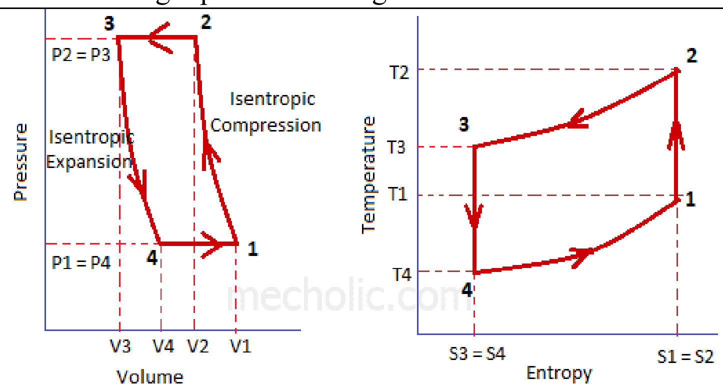
GAS REFRIGERATION SYSTEM (AIR REFRIGERATION SYSTEM):

- Air is used as refrigerant which is treated as ideal gas (No phase change).
- It's based on reversed Brayton cycle also known as "Bell Coleman Cycle"

BELL COLEMAN CYCLE:

- It's used for aircraft refrigeration system because of it's low weight per ton of refrigeration.





(a) P-V Diagram

(b) T-S Diagram

- If any ideal gas undergoes throttling process, there will be no temperature difference after throttling process. Hence, we can't use throttling process in this cycle.
- Isentropic expansion gives some work whereas isenthalpic expansion (Throttling) is not giving work. But in actual case, isentropic work is really very small, hence the enthalpy remains almost same hence, COP also remains almost same.

1-2: Rev. Adiabatic Compression	**2-3:** Constant Pressure heat Rejection.
From 1st Law, $W_c = h_2 - h_1 = C_P dT = C_P(T_2 - T_1)(For\ Ideal\ Gas)$	From 1st Law, $q_h = h_2 - h_3 = C_P dT = C_P(T_2 - T_3)(For\ Ideal\ Gas)$
3-4: Rev. Adiabatic Expansion	**4-1:** Constant Pressure heat Addition
From 1st Law, $W_e = h_3 - h_4 = C_P dT = C_P(T_3 - T_4)(For\ Ideal\ Gas)$	From 1st Law, $q_l = h_1 - h_4 = C_P dT = C_P(T_1 - T_4)(For\ Ideal\ Gas)$
$W_{net} = W_c - W_e = C_P(T_2 - T_1) - C_P(T_3 - T_4) = C_P(T_2 - T_1 - T_3 + T_4)$	
$COP_R = \frac{Q_l}{W_{in}} = \frac{T_1 - T_4}{T_2 - T_1 - T_3 + T_4} = \frac{1}{\frac{T_2 - T_3}{T_1 - T_4} - 1} = \frac{1}{(r_p)^{\frac{\gamma-1}{\gamma}} - 1}$	$r_p = \frac{P_h}{P_l} = \frac{P_2}{P_1} = \frac{P_3}{P_4} = \left[\frac{T_2}{T_1}\right]^{\frac{\gamma}{\gamma-1}} = \left[\frac{T_3}{T_4}\right]^{\frac{\gamma}{\gamma-1}}$
$(r_p)_{min} = 1$	At $(r_p)_{min} = 1, COP_R = \infty$
$P_{in} = \dot{m}C_P[(T_2 - T_1) - (T_3 - T_4)]$	$Capacity\ of\ R = \dot{m}C_P(T_1 - T_4)$

REQUIREMENT OF REFRIGERATION OF AIRCRAFT:

- Pressure and Temperature are very low at higher altitude.
- Due to ramming effect pressure and temperature increases because of high velocity of air craft.
- Instruments generates heat and human passengers also generate heat.
- **Why Air Refrigeration only not other?** Cheap and easily available and no leakage issue. Their weight per ton is low. And no other additional instrument required due to engine system used in refrigeration. $COP_{R\ AirCraft} \approx 0.4$

<table>
<tr><th colspan="2">TYPES OF AIR CRAFT REFRIGERATION SYSTEM</th></tr>
<tr><th>Simple system</th><th>Boot Strap System</th></tr>
<tr><td>It's good for ground cooling. & Use At low Speed.</td><td>Used in Transport type aircraft to get more lower temp.</td></tr>
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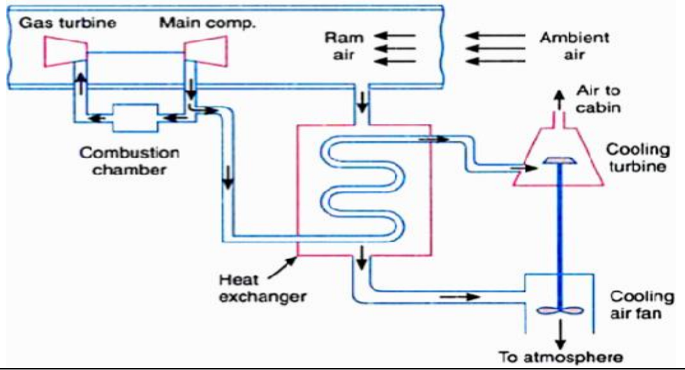

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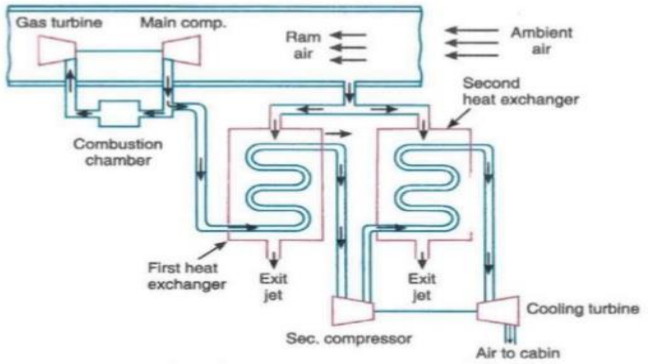

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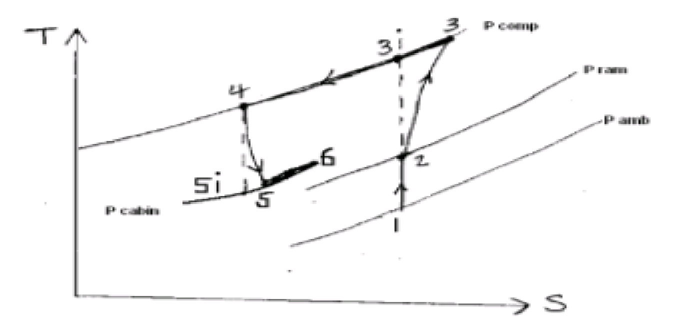

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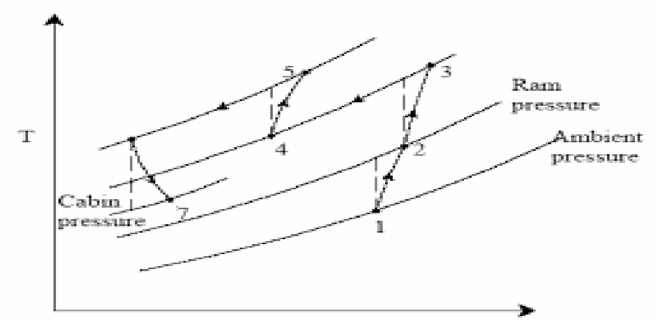

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<tr><td></td><td>Can't use for ground application.</td></tr>
<tr><th>Regenerative System</th><th>Reduced Ambient System</th></tr>
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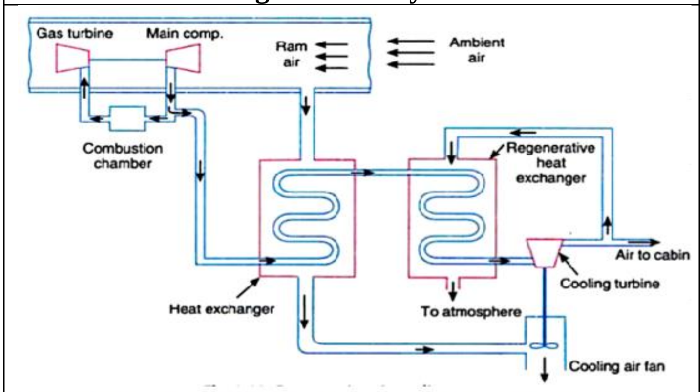

Used for both ground cooling as well as high speed aircrafts also for supersonic aircrafts and rockets.
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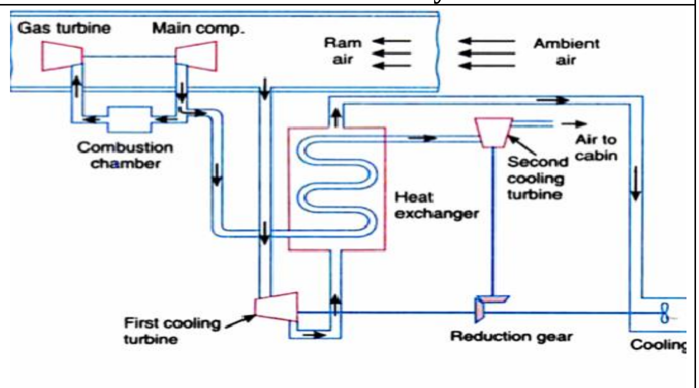

This system is used for exceptionally high speed aircraft when the ram air temperature is too high.
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