INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NPTEL
NPTEL ONLINE CERTIFICATION COURSE

Refrigeration and Air-conditioning

Lecture-05
Aircraft Refrigerator Cycles-2

with
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Hello I welcome you all in this course on refrigeration and air conditioning. Today we will continue our discussions on aircraft refrigeration cycles.

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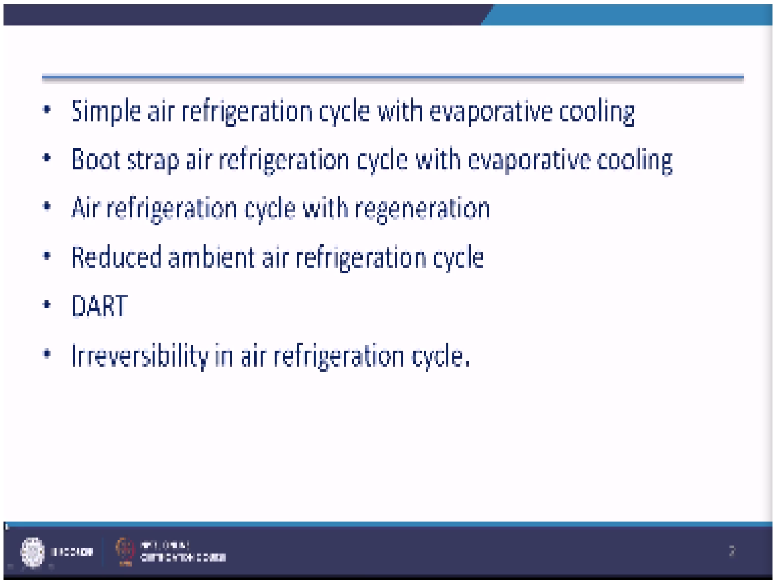

In this lecture we will cover the simple air refrigeration cycle with evaporative cooling. Bootstrap air refrigeration cycle with evaporative cooling. Air refrigeration cycle with regeneration. Reduced ambient air refrigeration cycle, DART irreversibility in air refrigeration cycle, where we start with simple air refrigeration cycle with evaporative cooler.

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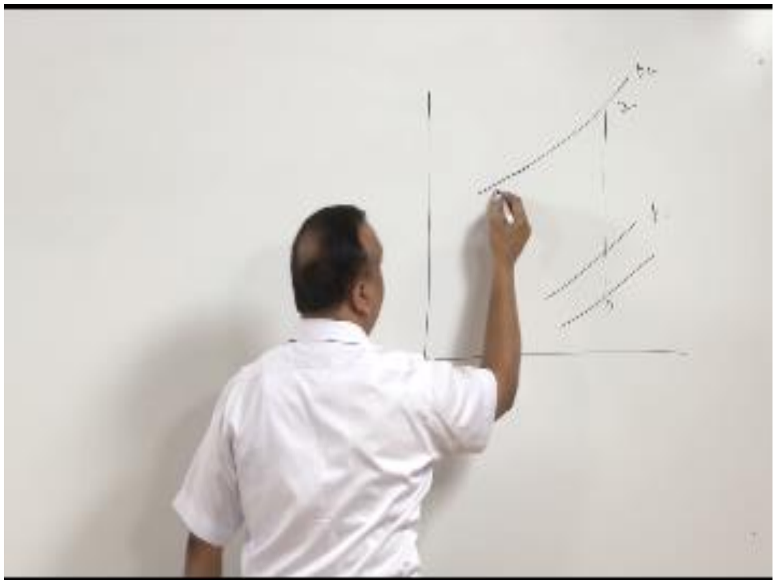

In previous lecture we have already discussed the simple air refrigeration cycle that is 0, 1 then compression 2 then cooling constant pressure cooling this is P1 this is P2 constant pressure cooling and then expansion in expansion turbine.

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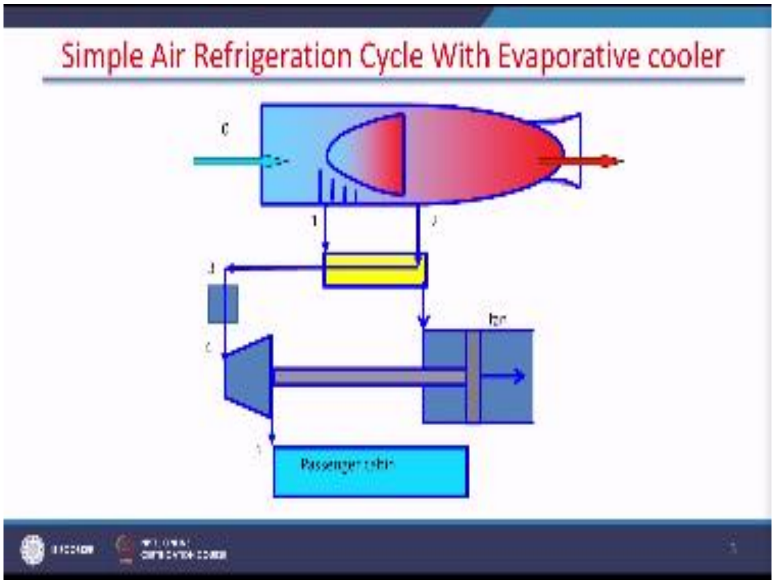

Now in this evaporative cooler in this cycle evaporative cooler is introduced just before the expansion turbine. This evaporative cooler further pulls down the temperature of air before the expansion and expansion turbine by providing evaporative cooler the gas is further pulled up to the state 5 and then expansion takes place and we get state 6 this is state 4. So you can see from here the temperature at state 6 is less than the temperature at state 4 we get in this case we get a cooler air entering the passenger cabin.

Or we can say the same amount of circulated air can take more refrigerating load, same arrangement is made in the bootstrap of a cycle. In bootstrap cycle you know there is a two time compression first, then second compression three, and then cooling four, and four to five expansion takes place, but in this case the gas will get further cool to six, and expansion will take place up to seven.

The evaporative cooler they provide additional cooling to the gas which is entering the expander by virtue of which we get cooler air at the exit of the expander or the turbine. Now evaporative cooling is attained either with the help of some refrigerant or liquid nitrogen and this evaporative cooling type of arrangement is very useful when the aircraft is moving with a very high velocity or supersonic velocity. Now we will discuss air refrigeration cycle with regeneration.

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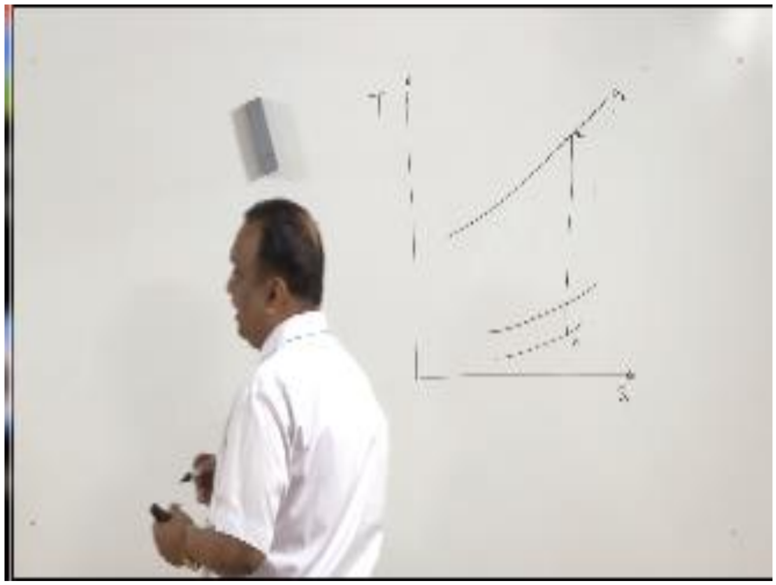

Now air refrigeration cycle with regeneration initially the processes are same due to running action the pressure and the temperature of the air is increased starting from state zero to state one, after the state one, the state two is attained in a compressor state two, the air coming out of the compressor is cool at a constant pressure this is the constant pressure line this is temperature on ordinate on abscissa there is entropy so at constant pressure the cooling of air takes place and state three is attained.

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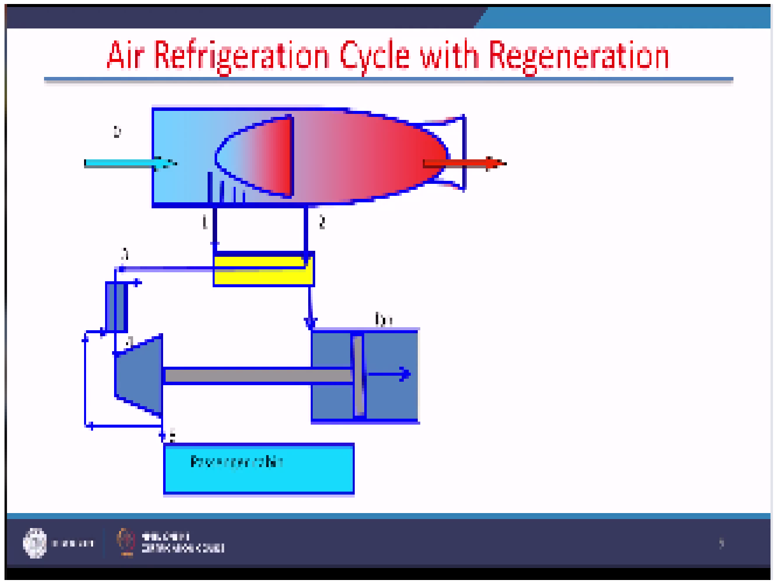

After the strain three there is a heat exchanger this heat exchanger as shown in the figure takes air after the expansion of turbine so part of the air after the expansion of turbine it is re-circulated through this heat exchanger so that the temperature of air is further cool to state four.

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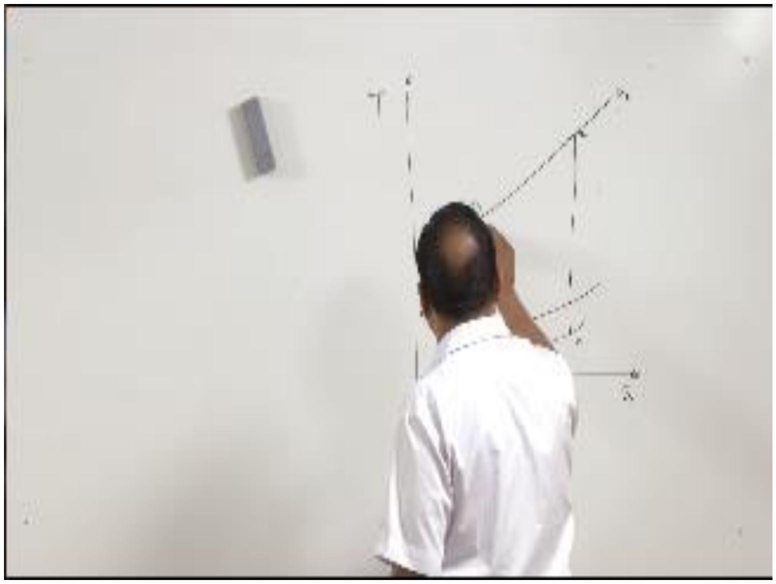

So due to this heat exchanger instead of containing this temperature three sorry 1, 2, 3 the gas is further or air is further cooled up to temperature 4 and further expansion takes place in this case also we get cooler air at the exit of the turbine now here the point is suppose 1 kg/sec is the gas circulation rate part of this air maybe 5% or 10% will be tapped at state 5 and this tribe air will be sent to the heat exchanger.

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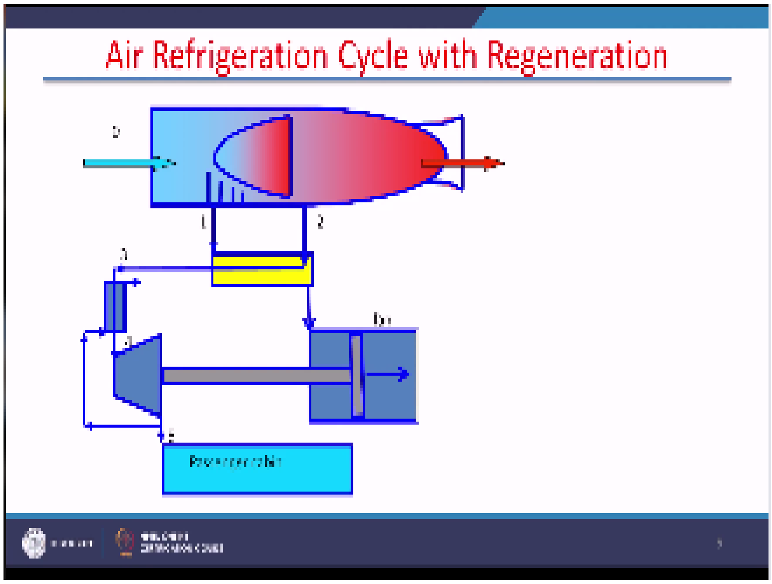

And in the heat exchanger this low temperature air will take heat from the air which is entering the turbine and it will further cool it so this type of arrangement is also possible in air refrigeration cycles now the last one is a reduced ambient air refrigeration cycle in a reduced ambient air refrigeration cycle before entering the compressor the air is trapped and it is passed through a turbine which produces work and the pressure of air is reduced because it is an adiabatic process reversible adiabatic process.

So if you look at this state 5 we say at state 1 the air may be I will never let us say – 20 degree centigrade but after the extension the temperature of air will further reduce so this low temperature air will now be used for cooling the gas coming from the compressor so definitely this will also improve the performance of the cycle and whatever work is produced in this auxiliary turbine during process 1 to 5 this work is added to the frame work because in this cycle if an run is run by the auxiliary turbine this is expansion turbine the fan is run by the expansion turbine and the air circulated by this fan is used to take away heat in that cooling heat exchanger.

Now these are the 4 cycle 6 type of cycles which are used for air refrigeration systems now if we compare these cycles if you have compare these cycles with each other I have taken on the x-axis Mac number on y-axis.

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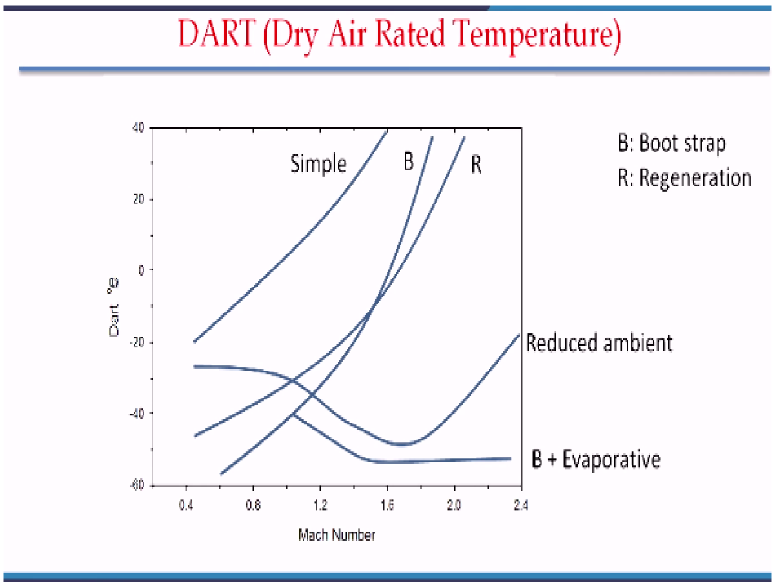

It is the dart is dry air rated temperature, dry air aerated temperature is the temperature of air at the exit of expansion domain or temperature at state here in the state five or State six so dart if you look at the dart and with the help of tried if we try to compare the performance of all these cycles if you look at the simple air refrigeration cycle dart keep on increasing if we increase the velocity of the aircraft.

The dart keep on increasing so this cycle cannot be used for very high velocity aircraft and if we look at the bootstrap, bootstrap is much better than the simple refrigeration cycle and we can go for the bootstrap even the supersonic aircraft it is because if let us say Mac number is 1.2 the value of dart is -40 in bootstrap cycle and further we can go up to 1.2 1.4 upto 1.6 but for further increasing the Mac number the regeneration type of regeneration type of cycle is recommended.

For high Mach numbers if you look at 1.6Mac number here you can see that the value of dart is close to 0 but value of dart for bootstrap is on positive side of temperature positive temperature some 10 or 20 degree centigrade temperature, now for very high velocity aircrafts for very high velocity aircrafts we can go for reduced ambient type of cooling system you can see the reduced ambient type of cooling system is very stable up to.

Let us say 2 or 2.2 MEK we can comfortably go with the system but the aircraft has to fly on very high speed let us say to 2 Mac or 2.5 Mac in that case the best one is bootstrap with erupted evaporative cooling, so bootstrap air refresher cycle in combination to evaporative cooling is best suited for high velocity aircrafts. Now irreversibility's in a refrigeration system because till now we have considered all processes as a reversible process.

But in actual practice none of the process is a reversible process almost all the processes are irreversible process.

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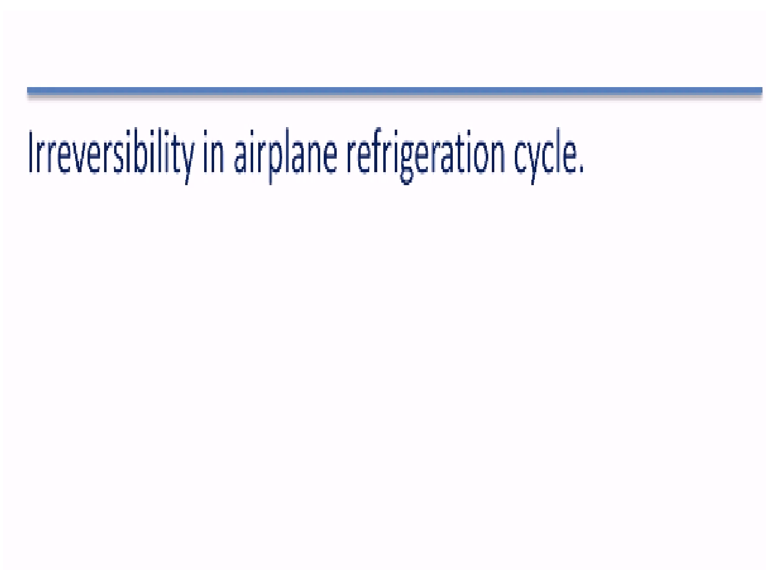

Let us start with the state 0.

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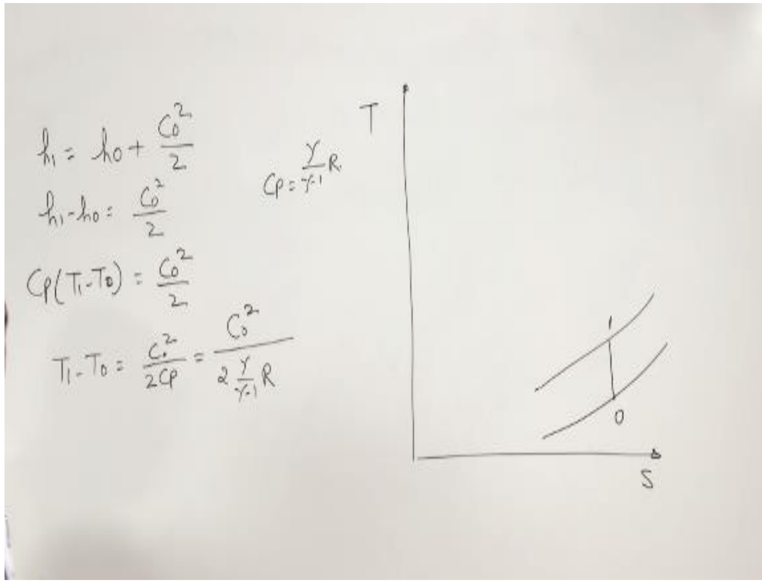

Where air is coming with a very high velocity towards the aircraft state 0 and it get compressed to state 1 during ramming action, if we apply the first law for open system thenh1 = ho+$Co^2/2$, h1 – ho = $C0^2/2$, now as you know the change in enthalpy in sensible heating or sensible cooling is because here it is a adiabatic compression and we have already derived in adiabatic compression the change in enthalpy is CP(T1 – T2) sorry T1 – To CPDT is equal to $C1^2/2$, now T1 - TO = $C^2/2CP$ or we can write as $Co^2/2$ γ/ γ – 1. R because CP = γ / γ -1.R the further if we divide the entire equation by T goes so T1 by Tu.

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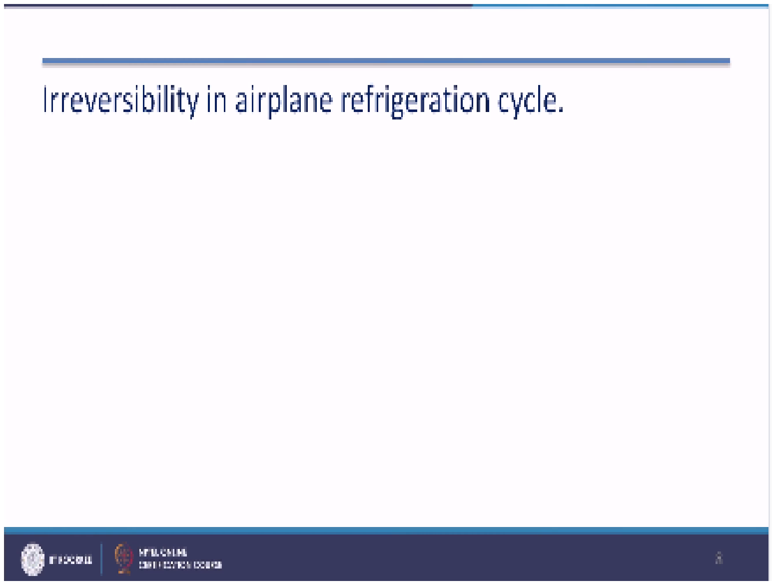

Shall be equal to.

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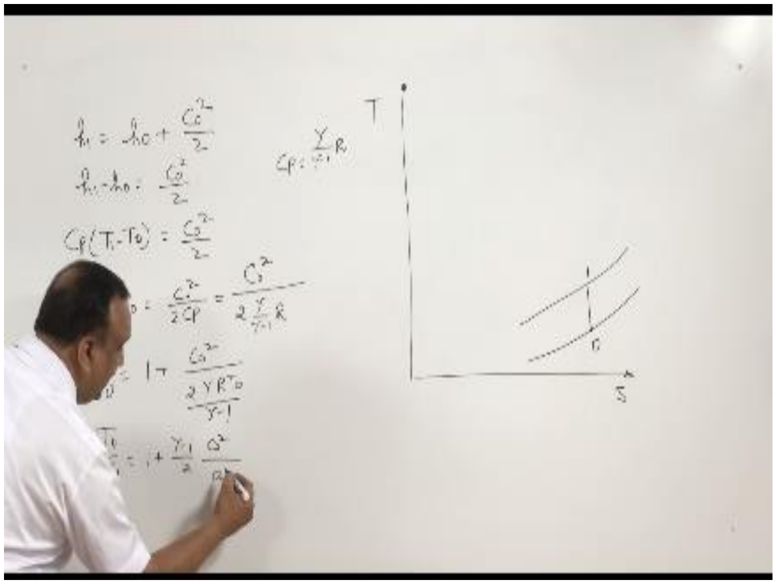

1 + Cu^2 two γRTo divided by γ - 1 right and then To by T1 is equal to 1+ γ - 1 by 2 and this γRT can always take as can always be taken as sonic velocity at this particular temperature and this ratio will give you.

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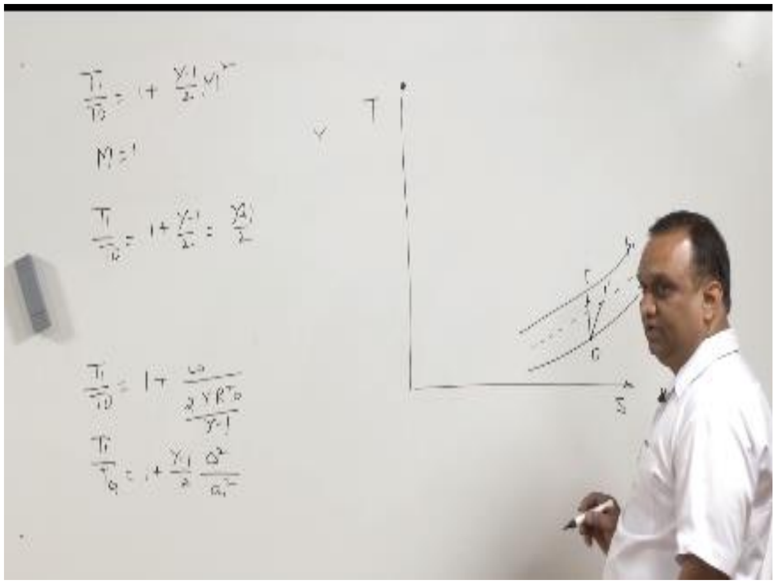

To by T1 sorry T1 by T1 this is T1 by To so here also it is T1 by T o is equal to 1 + γ - 1 by 2 M^2 from this equation if we know the value of Mac number suppose the aircraft is moving with M is equal to 1 let us say the Sonic aircraft M is equal to 1 so immediately we can find that T1 by To is going to be equal to 1 + γ - 1 by 2 or it is going to be γ + 1 by 2 but in actual practice this process does not take place instead of pressurizing up to P once from Po to P1 the pressure rises up to P1 - only so entire stagnation pressure is not retained but part of the stagnation pressure is attained.

But the temperature at this point this is 0.1 so instead of getting point 1 in the process in the irreversible process we get point 1 - now temperature of point 1 dash is equal toT1 so T1 dash is equal toT1.

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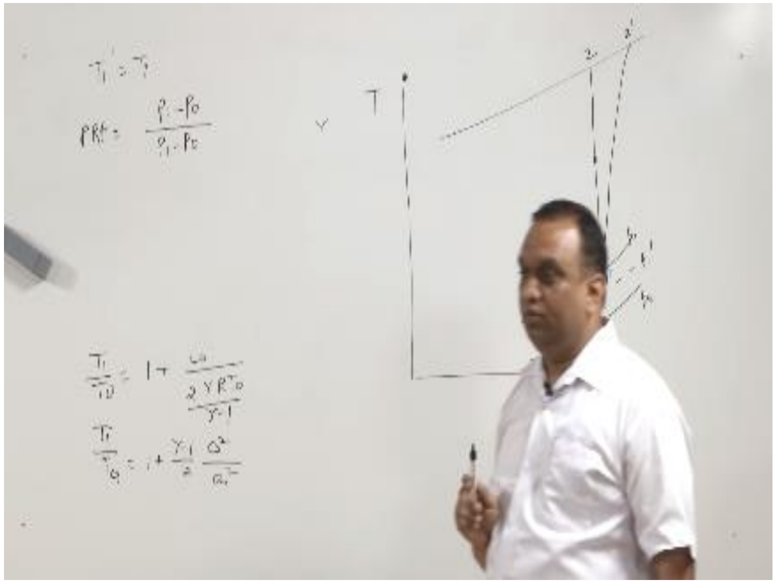

But the pressure of at this state is less than the pressure of it the state 1 and there is a pressure recovery factor pressure recovery factor PRF pressure recovery factor is P1- - Po divided by P1 -Po after in stating state 1′ the air goes to the compressor now inside the compressor ideally there is an isentropic process or reversible adiabatic process there is no heat transfer during this process and we get state 2 when in actual practice it is a irreversible process due to irreversibility it is no longer a vertical line or entropy does not remain constant there is a change in the entropy and we get state 2′.

If you look at here the temperature at state 2′ is greater than temperature at state 2 this is due to irreversibility in the process and there is a term which is known as polytrophic efficiency, so polytrophic efficiency of the compressor can be expressed as.

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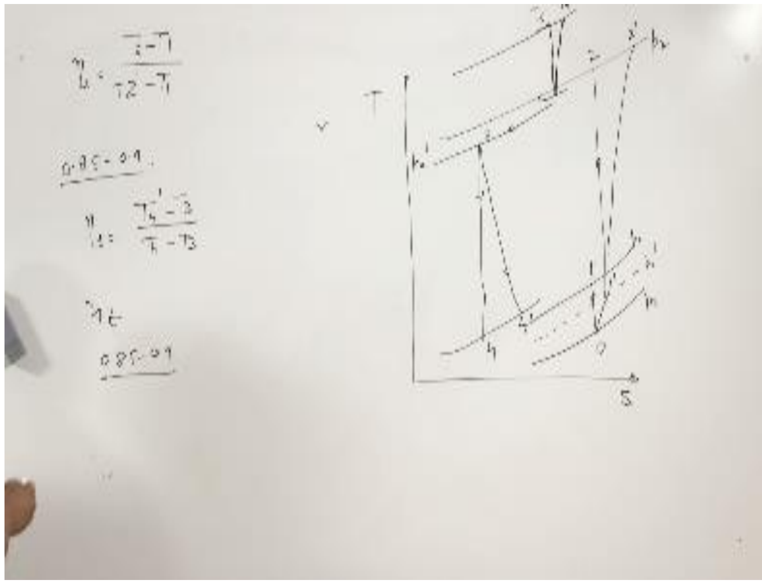

$T_2-T_1/T_2'-T_1$ definitely in this process, process 1 to 2 energy consumption is less in comparison to the process 1′ to 2′ in process 1′ to 2 the energy consumption is less in comparison to the actual process that is 1′ to 2′ this polytrophic efficiency for a rotary compressor is approximately of the order of 90% it varies in fact but normally it is between 85 to 90% after the process attaining process 2′ cooling of air takes place it is supposed to be at a constant pressure p2 but in actual practice there is always a pressure drop.

So instead of p2 there is the pressure p2′, p2′ and temperature let us say temperature 3 is attained this is state 3, so state 3 is attained at a constant it is supposed to be a constant pressure process. But since the gas passes through the heat exchanger and it passes through the pipes also there is a certain there pressure drop during this process so instead of getting temperature in state 3 at pressure 2 we attain it at the pressure 2′ which is slightly later than which is slightly less than the pressure 2.

After attaining the state 3 the expansion takes place I am taking the simple cycle expansion takes place and during this expansion also if the expansion takes place inside the turbine so this is an ideal process but in actual practice it is no longer a vertical line it is no longer a constant entropy process again the during this process the entropy increases they increase in entropy during this process due to irreversibility is present during this process.

And instead of getting state 4 we get state 4 - and temperature of state for - is higher than the temperature of a state 4 or after expansion the temperature is higher in case of irreversible process in comparison to the reversible expansion and here also the efficiency of the turbine poly tropic efficiency poly tropic efficiency of the turbine can be expressed as P 4 - - T 3 /T4 – T3, so it is if you look at these two equations this is ideal temperature drop in compressor ideal temperature rise actual temperature rise this is ideal temperature rise actual temperature rise.

Ratio of these two will give the poly tropic efficiency of the compressor in case of turbine it is reverse actual temperature drop divided by ideal temperature drop so this is the this expression is for the poly traffic efficiency of the turbine if you are using bootstrap cycle in case of bootstrap cycle again some pressure drop will be here and again during the compression process there will be in reverse abilities or they will be rise in entropy so in bootstrap cycle also again the same type of phenomena takes place.

So in a bootstrap cycle again the pressure this compression is the secondary compressor again it is a it is not a reversible process and change in entropy takes place that is why temperature at this state may be let us say the state is 5 t5 and p5 _ so t5_ >T 5 and in this case also the efficiency of turbine is in the range of 85 to 90%, so while dealing with the real-life problems we have to we have to take into the consideration with the efficiency of all the components in an air refrigeration system.

Normally the efficiency of the rotary machines because in the air efficient system rotary machines are used so normally the efficiencies poly tropic efficiencies of the rotary machines are higher than the efficiency of reciprocating machines, for example if I take reciprocating compressor, so for a reciprocating compressor, the 80% efficiency is very high efficiency.

Normally it lies between 70%and 80%, the reason being that if let us take example of axial flow turmoil or axial flow compressor, in axial flow compressor there is no change in the direction of the fluid, straightaway passes through the compressor since there is no change in the direction of the fruit flow, that is why the losses are minimum.

So highest efficiencies attain with the axial flow compresses, now if we replace axial flow compressor and it is always close to 90 % or greater than 90 %, if we close replace the axial flow compressor with the centrifugal compressor, in the centrifugal compressor the direction of the flow of the fluid is like this, there is an axial entry of the fluid in the centrifugal compressor and there is a real exit.

And change in the direction of the fluid is approximately 90 degree, approximately 90 degree that is why in centrifugal compressors the losses during the flow are more than in the case of axial flow compresses, and efficiency of this compressor is slightly less than the efficiency of an axial flow compressor, and if you go to the recalculating compressor the efficiency is minimum.

However in most of the cases in air refrigeration system, axial flow compresses are used because in air refrigeration systems high bulk of fluid has to be handled, if very high bulk of fluid has to be handled, the axial flow compressor are the best kind of compressors, so here with this I and the discussions on the air refrigeration cycles, in the next class we will try to solve one numerical on a refrigeration cycle.

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