Steam and Gas Power Systems
Prof. Ravi Kumar
Department of Mechanical & Industrial Engineering
Indian Institute of Technology – Roorkee

Module No # 08
Lecture No # 39
Jet Propulsion

Hello I welcome you all in this course on steam and gas power system today we will discuss about the jet propulsion.

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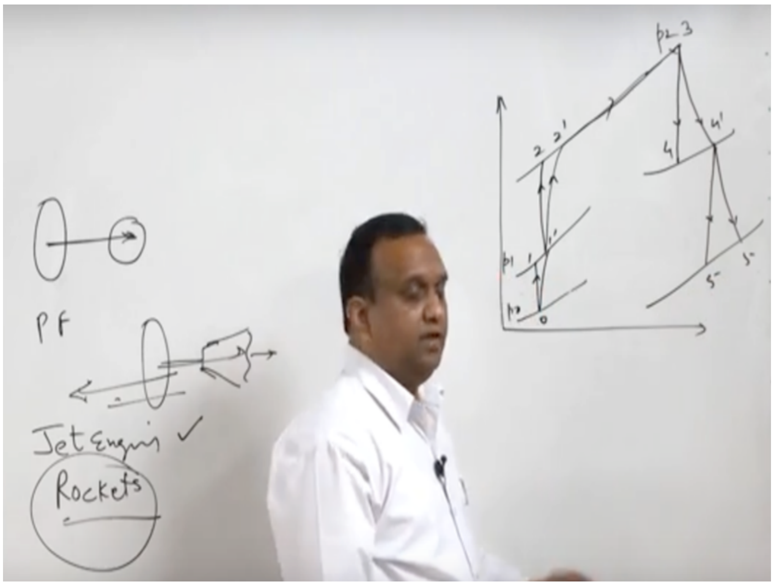

Now jet propulsion is something like, if you provide or if you impart the momentum to the fluid, in such a manner that reaction to this momentum gives the thrust to a body. So that is known as jet or a propulsive force the momentum gives the propulsive force to the body then it is known as jet propulsion right. Now the momentum of a gas can be imparted. How the momentum to the gas can be imparted?

Now one thing is we compress the gas right and then we release the gas then the momentum can be imparted and release thru a nozzle. Suppose there is a body, at the back side of this body if I put a nozzle and pass pressurized gas thru this nozzle right. And this when the gases leave the nozzle due to reaction of that, this body will move in this direction right. But in practice how it is realized if you draw a temperature interpret diagram of an arrangement, in a jet propulsion system there is a diffuser.

Because the body itself is moving with suppose let us take this type of system is used in the jet engines and another is rockets right. Jet engines they do air breathing they take air from the surroundings and air is used for burning the fuel. And high velocity jet they leave the engine, and reaction to that causes propulsive force on jet engine.

But rocket does not breath it has its own oxidation mechanism, which creates the jet out of the body of the rocket right. So in a jet engine because the body itself is moving with a very high velocity. So when the air is sucked in so there is a diffuser fixed in the engine. So diffuser, let us say atmospheric air is atmospheric conditions are O. So in the diffuser, the pressure is increased to state 1.

And since it has its own efficiency it so instead of state one state one dash will be attained right. After the diffuser in jet engines, there is a compressor where compression of and normally it is an axial flow compressor. So in this compressor the further pressurize takes place. So this is state 2 and this is state 2 dash I am taking both ideal and real processes simultaneously. Now at state 2 has happens in the case of gas turbines in jet engines also.

The fuel burns and constant pressure heat addition this is P2 and this is P1 and this is P0. Constant pressure heat addition takes place, and we attain the state 3 and when state 3 is attained a turbine is used. The purpose of turbine in jet engine is not to produce power the purpose of turbine is to run the compressor right and output of the turbine is used for running the compressor.

Now at the exit of the turbine, still the temperature and pressures are very high right. And this high temperature and high pressure fluid is expended in the nozzle. And which produces propulsive force so this is three this is four, four dash, five, five dash. So this is the entire process of, it is very similar to the arrangements in the gas turbine right. Only thing is, in the gas turbines the output of the turbine is used for power generation or you that is a high-grade energy so it is used for the variety of the purposes.

But here the main purpose of this gas turbine is to run the compressor. And the gases available at the exit of the turbine which are at high pressure in temperature, they are expended in the nozzle. And very high velocity gas leaves the nozzle and that causes the propulsive force. Now jet engines if you do the energy balance between this state o and state 1 right.

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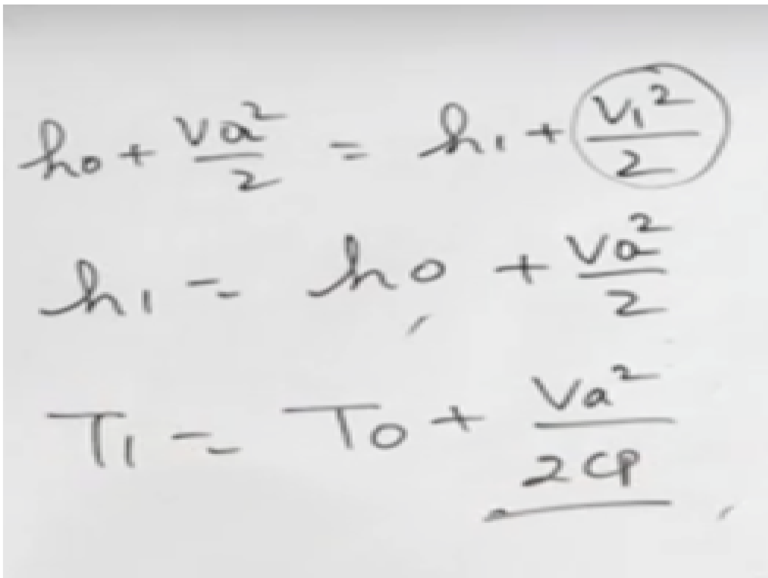

So HO + VO square by 2 = H1 + V1 square by 2, ok. And this gives H1 is equal to, because this is almost I mean 0, or if you compare with the VO, it is negligible right. So we write H1 = HO + VO square by 2, ok. Because VO depends upon the speed thru which the object the jet is moving right. Or we can say it is VA in order to avoid any confusion ok.

And then it is T1 = TO + VA square by 2 CP. So these are normal equation for diffuser we will be using frequently using in the analysis of gas this jet propulsion system. Now there are certain terms which are used for uh jet propulsion.

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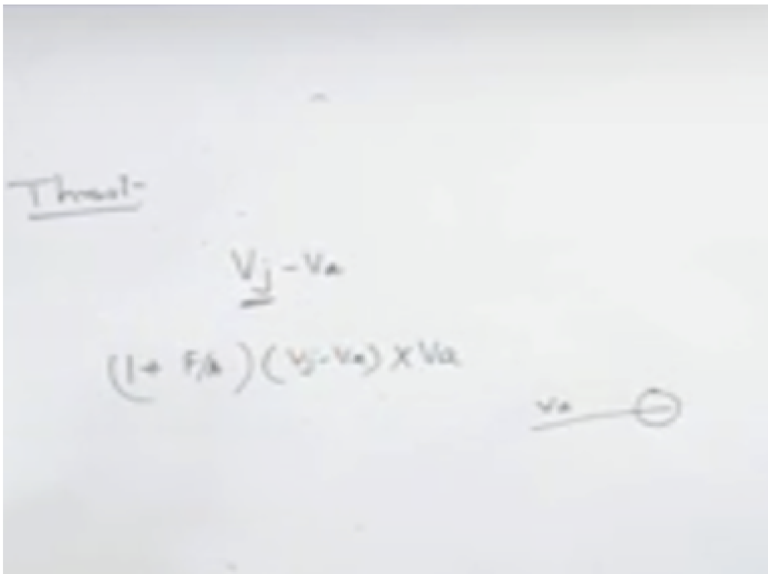

First is thrust. Thrust is for per kg of mass flow rate it is the velocity of the jet minus velocity of VA, that is VJ - VA. The jet is moving at a certain velocity VA in this direction right. And then the jet is the velocity through which the fluid is leaving the jet right. So thrust will be VJ - VA if we take mass of the fuel into the account then it is going to be 1 by F by A, flue air ratio, VJ - VA right.

Now thrust power is going to be, this is the, thrust is force and in order to find the power you just multiply this by VA you will get thrust power.

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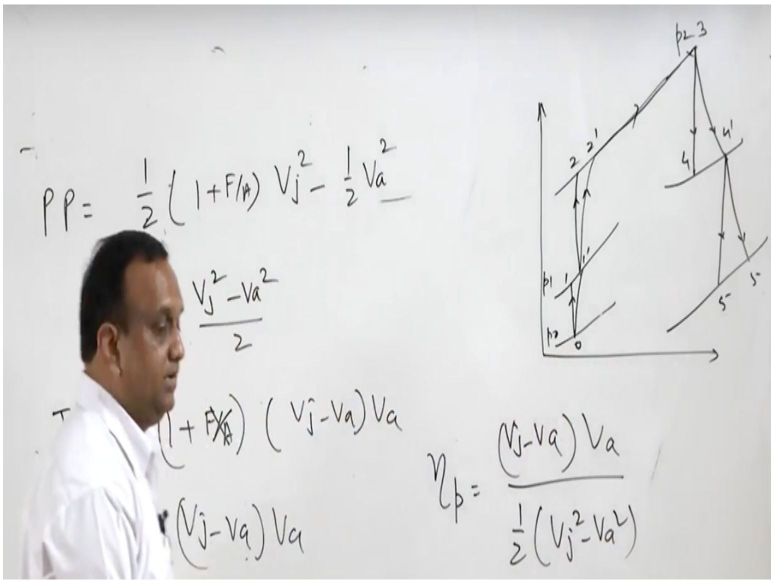

Now another term is propulsive power is nothing but change in kinetic energy, half 1 + fuel by air V jet square - half VA square. So if we neglect this F by A, then it becomes VJ square - VA square by 2. That is propulsive power.

Thrust power we have already calculated, 1 + fuel by A VJ - VA multiplied by VA right. Or if we neglect this, then it becomes VJ - VA multiplied by VA. Now ratio of thrust power and propulsive power is propulsive efficiency. So that propulsive efficiency is thrust power divided by propulsive power. So thrust power is VJ - VA multiplied by VA divided by half VJ square - VA square.

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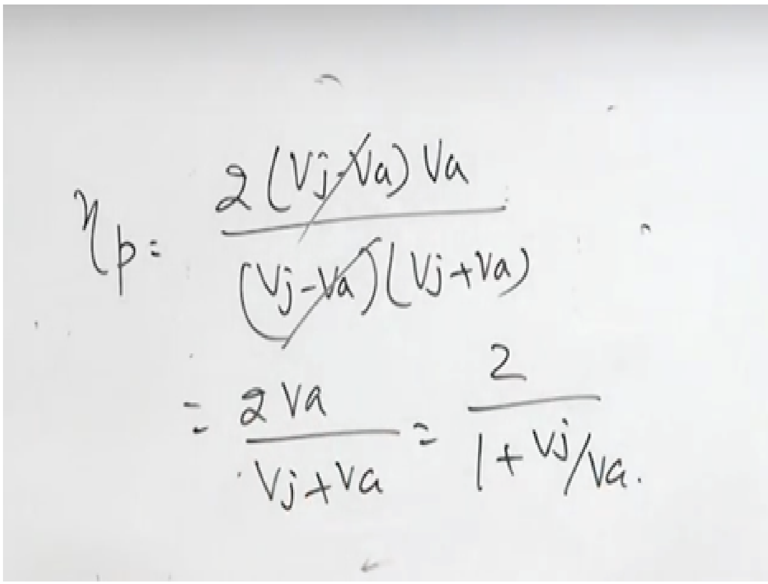

And then we rearrange the terms then we get propulsive power as, propulsive efficiency as, two VJ - VA, VA divided by VJ - VA, VJ + VA and this will be cancelled out, 2 VA VJ + VA. Or it is 21 + VJ by VA ok and this is known as propulsive efficiency.

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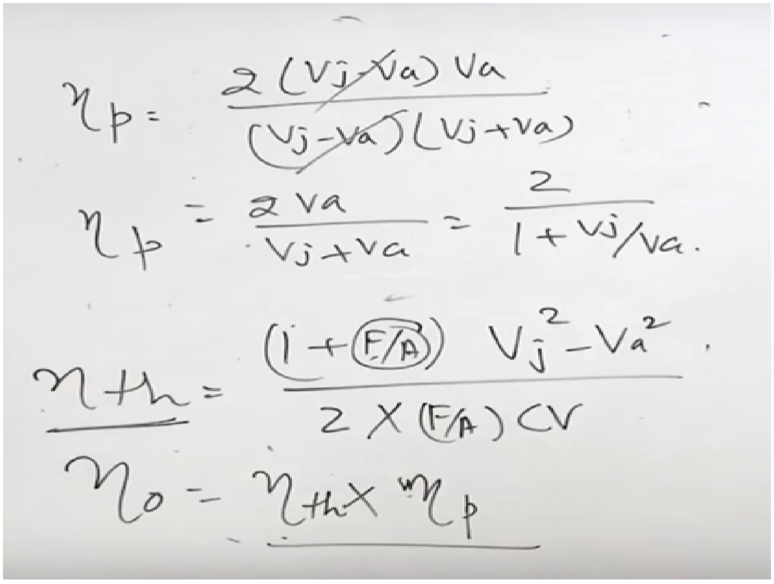

Now every power generating machine has thermal efficiency also. So a jet engine has thermal efficiency. And thermal efficiency is again, 1 + fuel VJ square - VA square divided by 2, that is the change in the kinetic energy. Multiplied by N calorific value of the fuel, or this is the mass of the fuel associated per kg of air. And this will give the thermal efficiency of jet engine. And overall efficiency is thermal efficiency multiplied by propulsive efficiency. And that will give the overall efficiency of the jet propulsion system.

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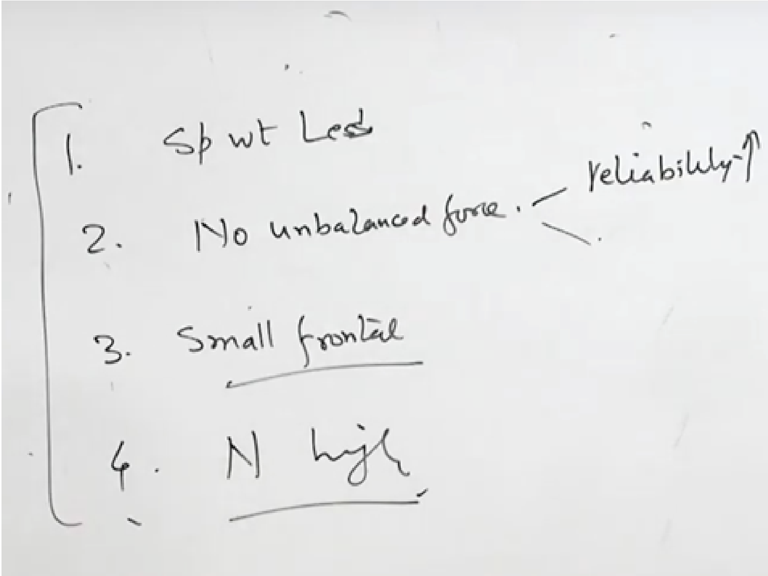

Now the there are certain advantages of jet propulsions over other methods or other technologies. So there are certain advantages of jet propulsion system. First of all, specific weight is less specific weight means mass per unit of power generation it is less. So that is why it is used for it is suitable for the aircrafts or air aviation. Unbalanced force is no unbalanced force there is no unbalanced force in jet propulsion system.

So when unbalanced force is not there, reliability is high reliability is high when there is no unbalanced force because chances of failure are less and we can go for higher thrust right. Third is small frontal area so a small frontal area means it is suitable for uh the purpose of for aviation purpose because it has a small front frontal area which will produce lesser drag during the movement in the air.

There is no restriction in the power output. In IC engines, if you use, in aircrafts we use IC engine detonation is the limiting parameter. But here detonation the no detonation takes place so detonation is not a limiting parameter in case of jet engine. It can go for a very high speed. Speed is high and lubrication is IC, if you use IC earlier in in in aircrafts IC engines were used.

But IC engines because it is a sliding type slider crane type mechanism is used in IC engines, substantial lubrication is required. In jet engines that much lubrication is not required so that is also benefit. At higher altitude where pressure is very low, their efficiency is better than other engines. So for higher altitude because these aircrafts they normally navigate at the height of then kilometers or twelve kilometers at that height its efficiency is better than the other engines right and there are no pressure fluctuations in this engine also.

So there are certain benefits that is why this engine is used for aircrafts or air navigation. But there are certain disadvantages also. First of all noise level is very high in jet engines the noise level is very high. So that is why normally though it is always said that the gas turbines having high very high thermal efficiency if you compare with the uh IC engines. But they are not used for surface transportation. So noise is also one of the criteria.

There are other things also like power load efficiency of these turbo machines is very poor if you compared with the reciprocating machines or reciprocating engines like petrol engine or diesel engine. Their power load efficiency is much much better than power load efficiency of gas turbines. Because when we run the vehicle on the road, we do not run the vehicle on the designed condition.

When you are driving a scooter you are driving in the first gear in the crowded area. When you are highway you are driving your car or scooter exceeding the optimum design parameters. So we rarely drive our vehicles on optimum design conditions or design condition. So when we deviate, we always deviate from the design conditions.

And if you use the gas turbine engine or the jet engine for these type of applications, because they have very low power load efficiency so they are unsuitable for such type of applications. But noise is also one of the criteria why these engines are not used for surface transportation. So now after this we will solve one numerical on jet propulsion. We have already discussed the jet propulsion, thrust, thrust power, propulsive efficiency, propulsive power, propulsive efficiency, advantages of jet propulsion.

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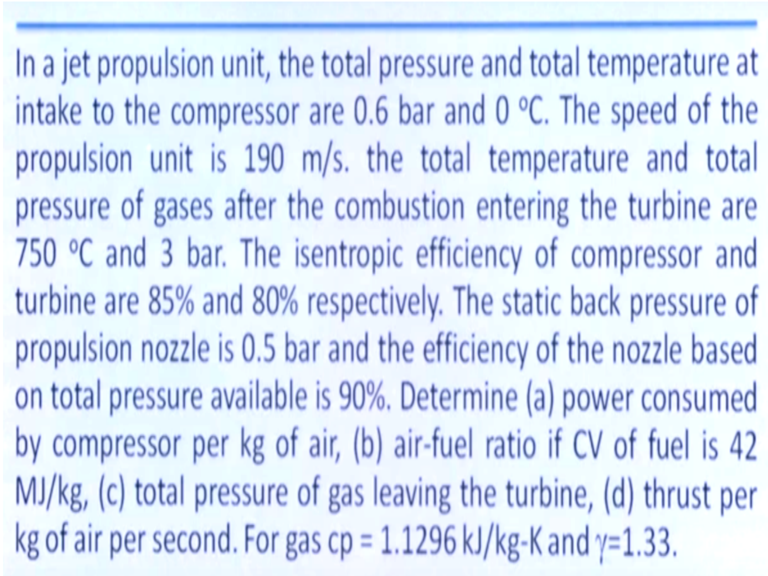

In a jet propulsion unit, the total pressure and total temperature at intake to the compressor are 0.6 bar and 0 °C. The speed of the propulsion unit is 190 m/s. the total temperature and total pressure of gases after the combustion entering the turbine are 750 °C and 3 bar. The isentropic efficiency of compressor and turbine are 85% and 80% respectively. The static back pressure of propulsion nozzle is 0.5 bar and the efficiency of the nozzle based on total pressure available is 90%. Determine (a) power consumed by compressor per kg of air, (b) air-fuel ratio if CV of fuel is 42 MJ/kg, (c) total pressure of gas leaving the turbine, (d) thrust per kg of air per second. For gas cp = 1.1296 kJ/kg-K and γ=1.33.

Now we will do one example on jet propulsion now here, in a jet propulsion unit, the total pressure and total temperature at intake to the compressor are .6 bar and 0 degree centigrade.

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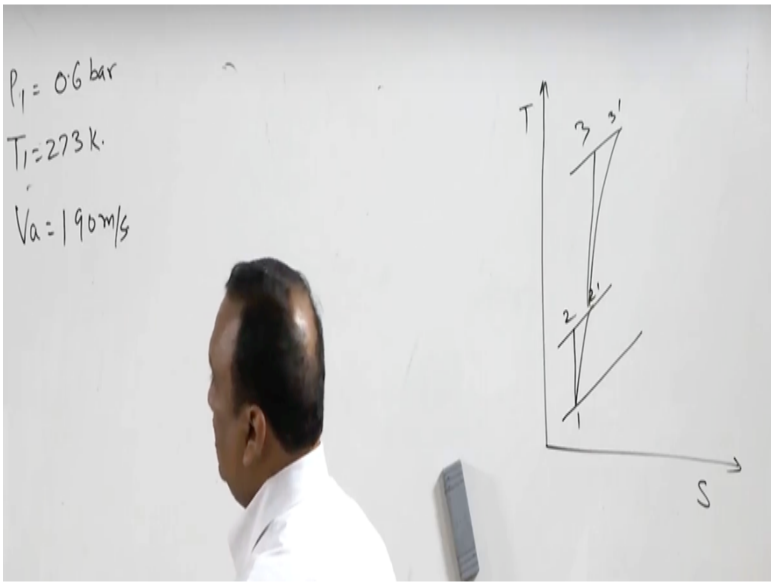

So P1 or is equal to or let us say P1, P0 it is confusing with the stagnation so we will start with P1. So P1 is 0.6 bar and T1 is 273 kelvin. The speed of the propulsion unit is 190 meter per second ok. So VA = 190 meters per second.

The total temperature and total pressure of gas is after the combustion entering the turbine are 575 degree centigrade and three bar so we will write on the figure itself. So this is temperature and entropy diagram for jet propulsion. This is this place takes place in diffuser, one, two, two dash then three, three dash sorry, diffuser is there or not?

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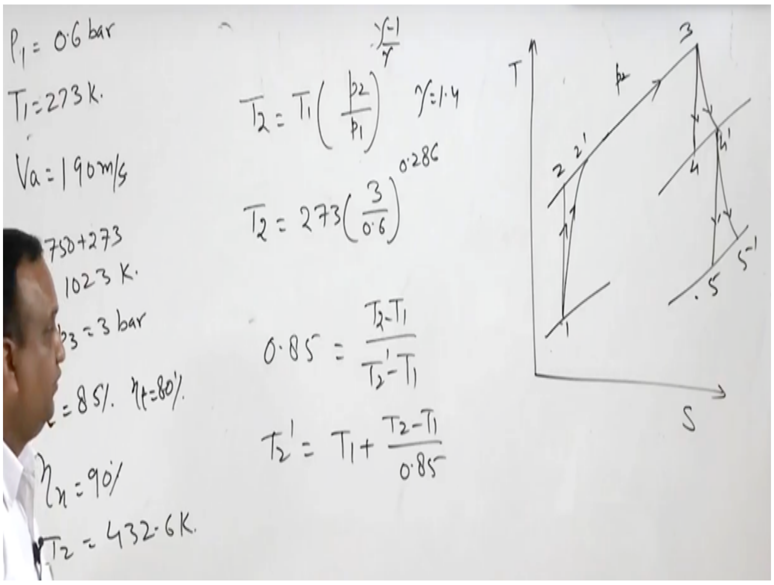

Diffuser, they have not taken into so we will not take diffuser into account. So simply compression is taking place, 1 to 2, 2 dash right. Now two to three, heat addition constant pressure heat addition this is P2 and then expansion in a turbine, four, four dash and then expansion in a nozzle 5, 5 dash. So the temperature is 750 degree centigrade.

So T3 is 750 + 273 and that is going to be 1023 kelvin and pressure is P3 is 3 bar. So P2 or P3 is 3 bar so compression is taking place from this .6 bar to 3 bar. The isentropic efficiency of compressor and turbine are 85% and 80% isentropic efficiency of compressor and turbine.

So compressor is 85% efficiency of the turbine is 80%. The static back pressure of propulsive propulsion nozzle is .5 bar and the efficiency of the nozzle based on total pressure available is 90%. So efficiency of the nozzle is 90%.

And back pressure of the nozzle is .5 bar this back pressure is .5 bar. Determine power consumed by compressor per kg of air. So let us assume that 1 kg per second of air is circulated in the system. So first of all in order to find the compressor power, we will calculate the value of T2, T2 = T1 P2 by P1 raised to the power gamma.

Gamma is given or? Okay this is air so gamma is gamma - 1 over gamma. So here it is fixed, 1.4 gamma = 1.4. So T2 is 273 divided by 0.6 raised to the power .286 and this will give T2 as 432.6 kelvin right. Now we have to find the value of T2 dash, T2 dash.

So T2 dash is so in order to find T2 dash we will use the efficiency. Now the efficiency of the compressor is 85 %. So 0.85 = T2 - T1 divided by T2 dash - T1. So T2 dash = T1 + T2 - T1 divided by 0.85. So here we will get the value of T because T1 and T2 are known to us now. So we will get the value of T2 dash = 457.2 kelvin.

Now we have the value of temperature two and two dash as well. We have the temperature at state three also which is 1023 kelvin right. Now with the help of these we can find how much mass of fuel has been added, because we have the calorific value of the fuel also, it is 42 mega joules per kg. So we can find how much fuel has been added or has been burned with the help of one kg of air right.

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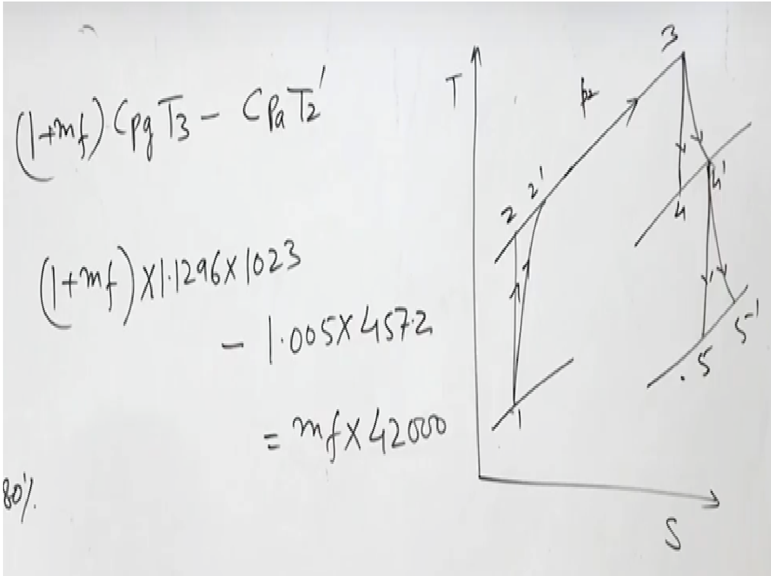

So 1 + MF, mass of the fuel, CPG T2 this is enthalpy of fuel gases is here, minus enthalpy of oh sorry enthalpy of air at two dash. So CP air T2 dash, because mass of the air is one kg here. Now we will take 1 + MF, mass of the fuel, CPG is1.1296, T3 is 1023 – 1.005 into 2 T2 dash is 457.2.

Now if you solve this and this is equal to mass of the fuel multiplied by calorific value of the fuel that is 42000 kilojoules per kg because here we are dealing with the kilojoules. Now from this equation we will get the mass of the fuel and mass of the fuel is 0.017 kg per kg of air right.

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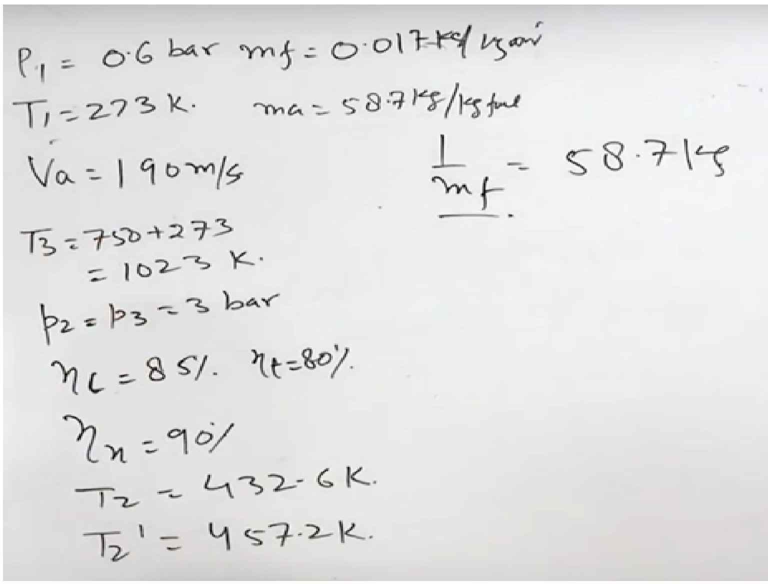

Or we can say that for burning one kg of fuel the air required is one by MF and that is equal to 58.7 kg. So for burning one kg of fuel we need 58.7 kg of air per kg of fuel, air fine. Now here power of the turbine the output of this turbine is used for running this compressor.

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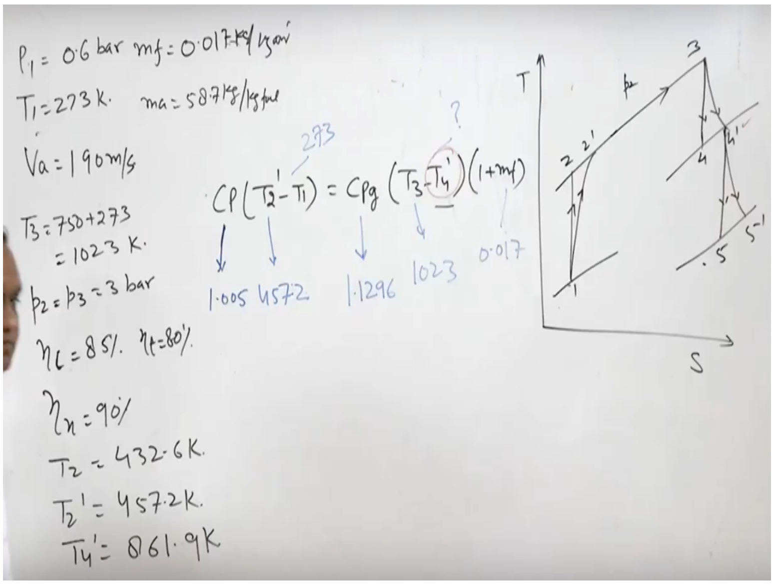

So CP T2 dash - T1, this is the work consumed by the compressor is equal to CPG T3 minus T4 dash 1 + MF. Mass of the fuel we have already calculated, T3 is with us and what about T4 dash? T2 dash is with us, T1 with us. We can from here we can get the value of T4 dash. Mass of fuel we have already calculated. We will put here, mass of the fuel, CP of air is known to us.

The CP of the air is 1.005 kilojoules per kg, T2 dash is 447.2 kelvin. T1 is 273 kelvin, CPG is also there. We did which is 1.1296, T3 1023. T4 dash is not known to us, MF is 0.017 right. So from here we will get the value of T4 dash this T4 dash and T4 dash is 861.9 kelvin.

And once we have the value of T4 dash and we know the isentropic efficiency of turbine, it is 80 percent.

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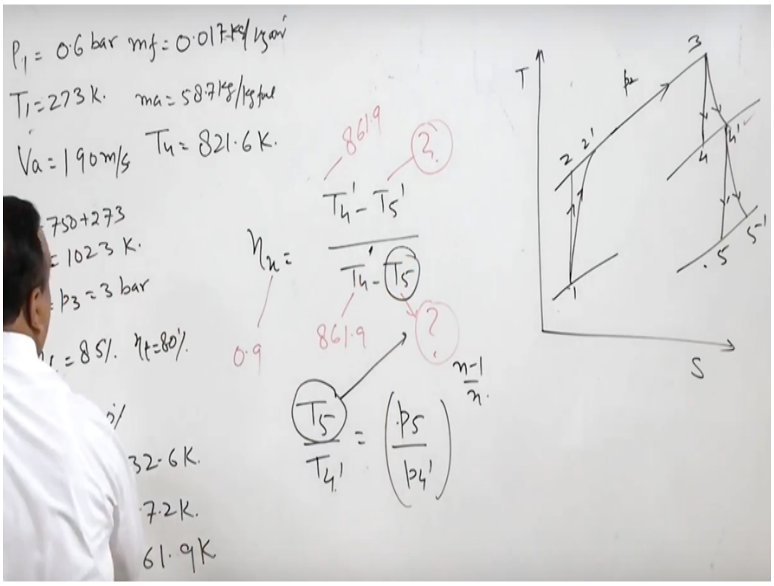

So isentropic efficiency of the turbine is T3 - T4 dash divided by T3 - T4. Or we can say T4 = T3 -T3 - T4 dash divided by efficiency of the turbine ok. Now here again T3 is 1023,T4 dash we have just calculated 871.9 kelvin this is 0.8.

Now out these we will get the value of T4 as 821.6 kelvin. We have efficiency of this nozzle also that is 90% right. And efficiency of the nozzle is T4 dash - T5 dash divided by T4 - T5 ok. And here also sorry T4 dash it is not T4 - T5, T4 dash because expansion is taking place from here. So T4 - T5 dash divided by T4 - T5.

Now here also this is 90%, 0.9, T4 dash 861.9. T5 dash we have to find yes T5 dash is not with us right now T4 dash is 861.9 and T5 is T5. We have calculated T5 or not? T5 we have not calculated yet T5 also we have not calculated yet. But T5 we can always calculate as T5 by T4 dash = P5 by P4 dash raised to power gamma - 1 gamma.

Sorry this is fuel gas, so it is N - 1 over N, N -1 upon N ok. From here we will calculate the value of T5. And this T5 value because T4 dash is with us, P5 is with us, P4 dash is with us right and from here we will get the value of T5 right. And from once we have the value of T5 we can calculate the value of T5 dash.

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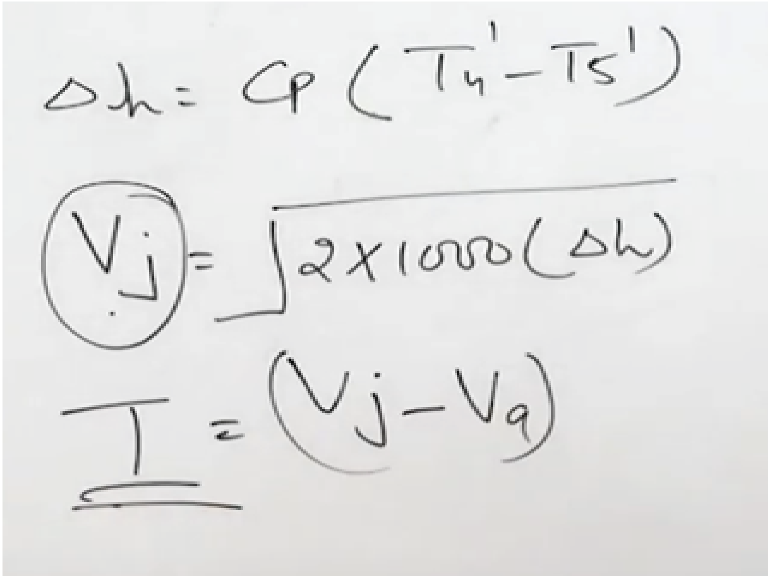

And now T5 dash can be calculated and T5 dash is six thirty-five. No T5 632 kelvin right. Now after calculating T5 dash, we can calculate delta H, enthalpy drop. Now this is a nozzle related problem so enthalpy drop in the nozzle will be delta H = CP T4 dash - T5 dash.

Once we have enthalpy drop in the nozzle, we can calculate the velocity of jet it is under root two into one thousand delta H. Now we have jet velocity. Once we have the jet velocity we can calculate what? Thrust total pressure of gas leaving the turbine thrust per kg of thrust per kg. So thrust we have to calculate thrust right. So in order to calculate thrust is equal to jet velocity - VA. This is thrust per kg, per kg of air right. And VJ we have taken from here and VA is already given, 190 meters per second.

We can calculate the thrust. This you can do by yourself in this question part C, total pressure of gas leaving the turbine. So I missed that part, actually I have taken the value from the solution that is 1.44 bar right.

I that I have taken from the solution that is P4 = 1.44 bar. But we can easily calculate here because we know the value of P3. So P4 by P3 = T4 by T3 raised to power N over N -1 right. From here because we have all other values, we can always calculate the value of P4 and it is coming 1.44 right. And now subsequent solution, I have directly used this value, P4 = 1.44 bar.

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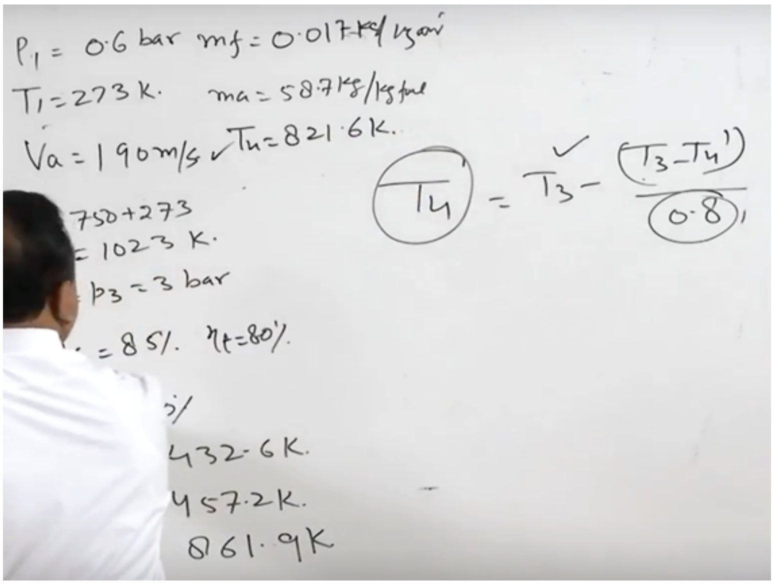

There is uh one thing I missed here I have directly calculated the taken the value of T4. So T4 is T3 - T3 - T4 dash divided by 0.8. From here we can get the value of T4 because T4 dash is already with us. Efficiency of turbine it is 80%. It is given here, T3 is also available with us and this will give the value of T4 as 821.6 kelvin.

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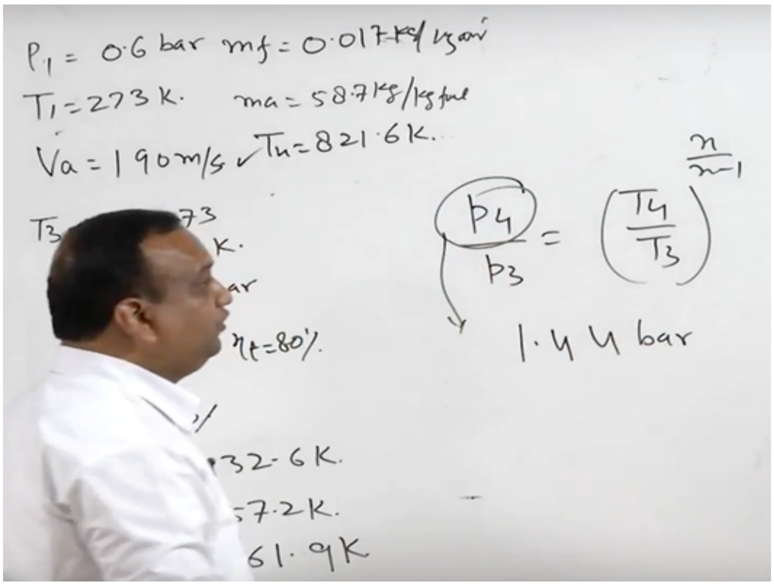

Now once we have the value of T4, then we have to find the pressure ratio so the P4 by P3 = T4 by T3 raised to power N over N - 1 right. From here, we will get the pressure P4. And P4 we have calculated as 1.44 bar which is also used in subsequent solution. And this 1.44 bar is the solution for total pressure of gas leaving the turbine that is part c of this problem right.

That that is all for today in the next class we will solve some more work example on this steam and gas power systems. Thank you very much