Steam and Gas Power Systems

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Module No # 04
Lecture No # 18

Nozzles and Diffusers – Efficiency and Critical Pressure

Hello I welcome you all in this course on steam and gas power systems today we will discuss efficiency and critical pressure for a flow inside the nozzle and diffuser.

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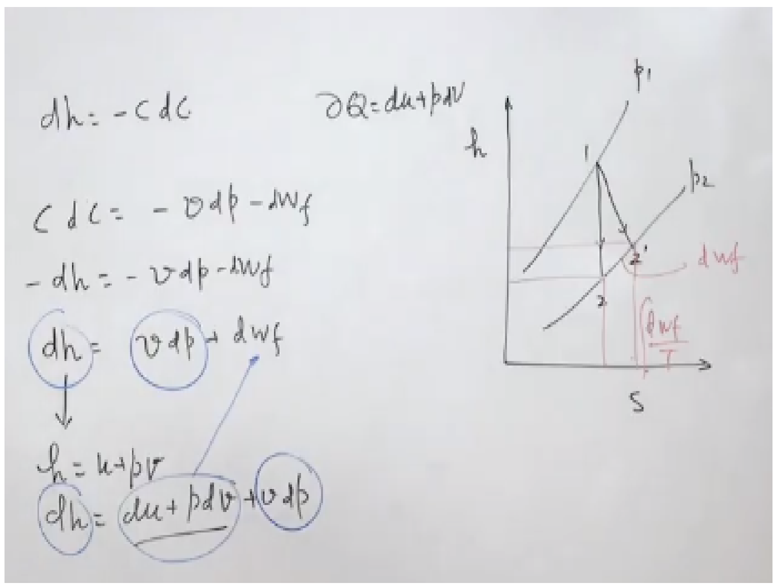

As we know that for the flow through a nozzle the change in enthalpy DH = - CDC change in kinetic energy and from momentum equation we have write that CDC = -VDP - WF. V is the specific volume W is the friction loss so if you compare this two equation that we get -DH = -VDP - WF or uses DWF right.

Or DH = VDP + DWF for H we already know that H = U + PV or DH = DU + PD V this is V + VDP. Now if we compare this two equations we will find that this VDP is in common and this 2 that this is going to be = this 1 deltaW DW and this is nothing but heat transfer del Q = DU + VDE. Now if you want to depict this on enthalpy entropy diagram this is enthalpy specific enthalpy and specific entropy.

There is two specific lines this is P1 and this is P2 expansion is taking place from state 2 to state 2 there is a heat transfer suppose friction is there is a heat transfer. So instead of following this isentropic line vertical line the process will follow this 2 dash. Now at this two dash in this difference this difference in enthalpy is nothing but DWF and there is a rise in enthalpy also right.

And the rise in enthalpy will be DWF by T so this is the rise in entropy due to friction and this is the loss in enthalpy drop. When there is a loss in enthalpy drop definitely the velocity of vapor or air coming out of the nozzle will be less in comparison to that the case when expansion is taking place from 1 to 2 here efficiency of the nozzle comes into the picture. Efficiency of the nozzle is 100 % when the expansion is isentropic expansion.

This total enthalpy drop is converted into the kinetic energy but here in this case what is happening only part of this is converted into the kinetic energy and this part is going in terms of increasing entropy of the fluid.

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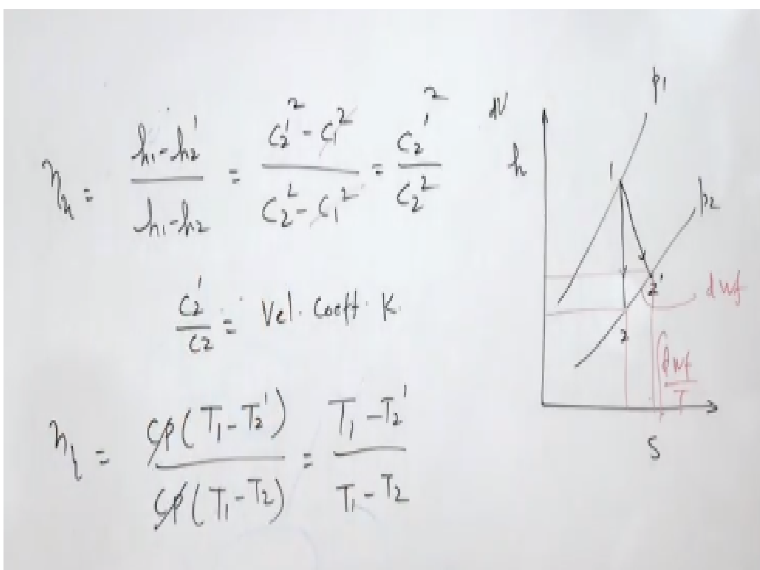

So the efficiency of the nozzle is going to be H1 - H2 dash divide by H1 - H2 right or we can write C2 dash square - C1 square divided by C2 square - C1 square. Always while doing the analysis of the nozzle we have neglected this so we can take always take as C2 dash square - divided by C2 square and this is this C2 dash by C2 is nothing but it is velocity co efficient.

We can say velocity co efficient K now in case of gas nozzles efficiency can also be expressed as CP T1 - T2 dash divided by CP T1 - T2. And there is CP and CP will be cancelled out so efficiency will the T1 - T2 dash divided by T1 - T2 right. There is another term in the nozzles is coefficient of discharge CD.

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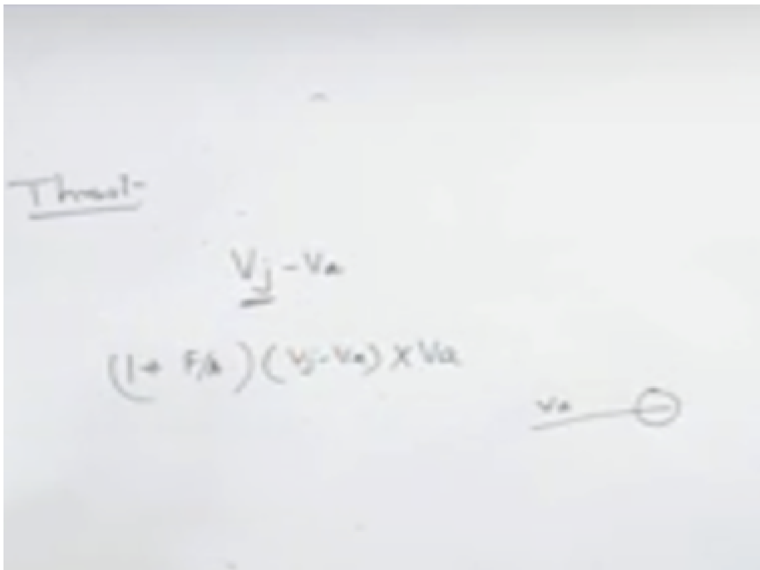

So co efficient of discharge is actual ratio of actual flow divide by the ideal flow for all passages co efficient of discharge any passages actual flow divided by ideal flow. Now let us take case of diffuser is pressure arranging is increased at the cost of kinetic energy. So one two this is two dash so efficiency of the diffuser will be H2 - H1 divide by H2 dash - H1 right.

Now we will derive and expansion for the mass of discharge for the nozzle how much discharge is taking place through the nozzle we do not have expression yet for this.

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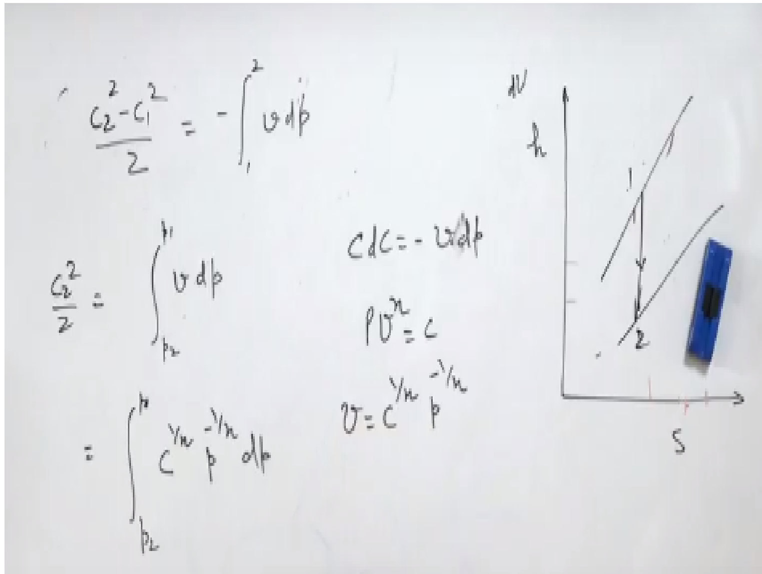

So as we know for the flow of the nozzles C2 square - C1 square by 2 = - 2 to VDP. This we have derive from VDC = -VDP right C1 we can always neglect so C2 square by 2 = integral P2 2 P1 VDP. We always know that for polytrophic this is polytrophic process not his one expansion through nozzle.

State one to state two this a polytrophic process so we can always say PV raise to power N = constant right or V = C raise to power 1 by N and P raise to power -1 by N. Now putting this value V here we will be getting P2 to P1 C raise to power 1 by N P raise to power 1 by N DP.

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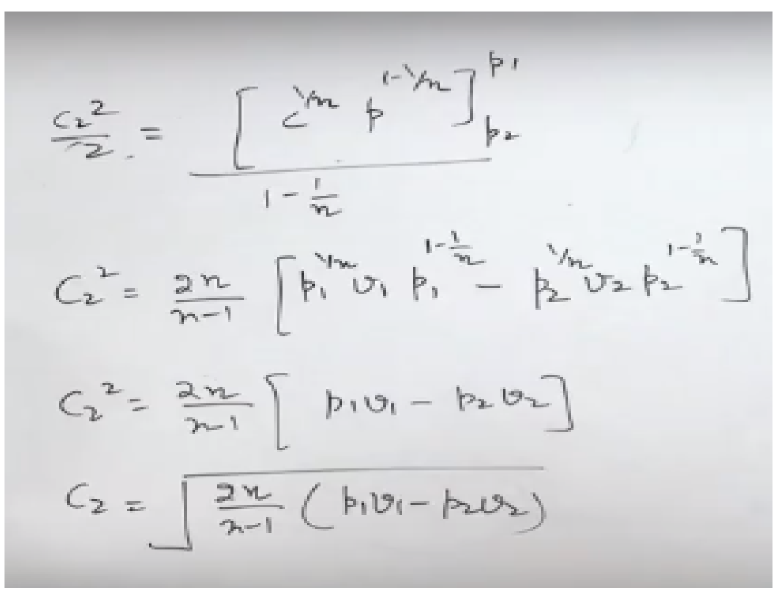

Now we can easily integrate this equation and we will be getting C2 square by 2 = C raise to power one by N P raise to power 1 - 1 by N divided by 1 - 1 by N from P2 to P1 right. Now C2 square by 2 or we will say that C2 square is 2N over N - 1 + C raise to power 1 by N.

T raise to power one by N = P raise to power 1 by N and V so here we can write P1 raise to power 1 by N, V1 P1 raise to power 1 by N - again C we can always write P2 raise to power 1 by N V2 P2 raise to power 1 - 1 by N right. If we further simply this then C2 square = 2 N over N - 1 this is P1 V1 - P2 V2 right.

We have velocity terms for the velocity 2 is under root 2N upon N - 1 P1V1 - 2V2 now we have find the mass flow rate.

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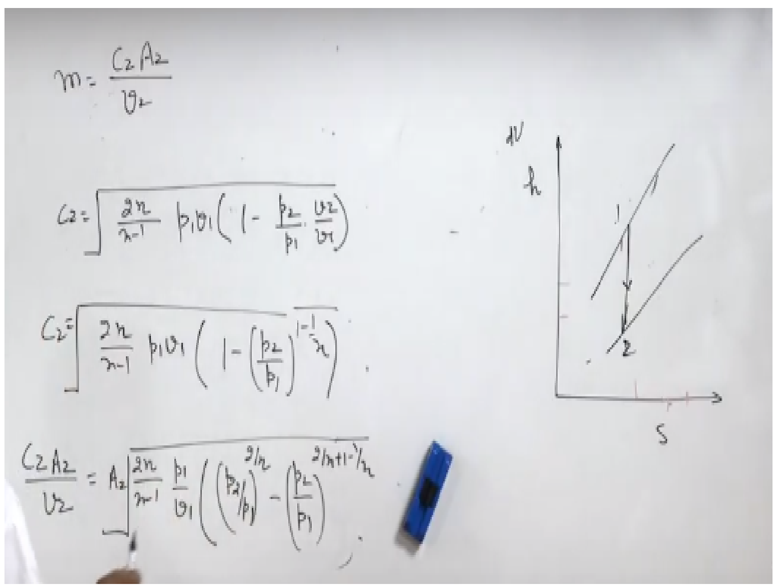

So mass flow rate is C2 at the exit A2 divided by V2 right now in order to achieve this what we can do we can take C2 = under root 2N upon N - 1 we can take out P1 V1 So we will be getting 1 - P2 by P1 multiplied by V2 by V1 fine now V2 by B1 = P1 by P2 power 1 by N or we can write P2 by P1 = P2 by P1 raise to power - 1 by N.

Now putting thus value here P2 by P1 here we will get C2 is equal to under root 2N upon N - 1 P1 V1 1 - P2 by P1 raise to power 1 - 1 by N. Now C2 multiplied by N ok so C2 multiplied by A2 by V2 will give us the mass flow rate so this is going to be = A2 now V2 is nothing but V2 =

V1 P1 by P2 by P1 raise to power - 1 by N. P2 we can take from here P2 by P1 raise to power - 1 by N multiplied by P1.

And if this goes inside then 2 N upon N - 1 P1 V1 because this V1 will get squared so this is P1 by V1 and this will take inside the bracket. So this is will become P2 by P1 raise to power 2 by N - P2 by P1 this 2 by N + 1 - 1 by N. Am repeating we have taken from here we have taken out P1 V1 we get the velocity C2. Now C2 velocity at the exit arial cross section at the exit divide by specific volume at the exit.

So velocity of the exit will get from here we have further simplified this equation we will we taken P1 out and this expression is modified by this expression then C2 is multiplied by A2 divided by V2 and V2 we have taken P2 by P1 raise to power - 1 by N multiplied by V1 this expression is taken inside so we are getting P1 by V1 and this expression.

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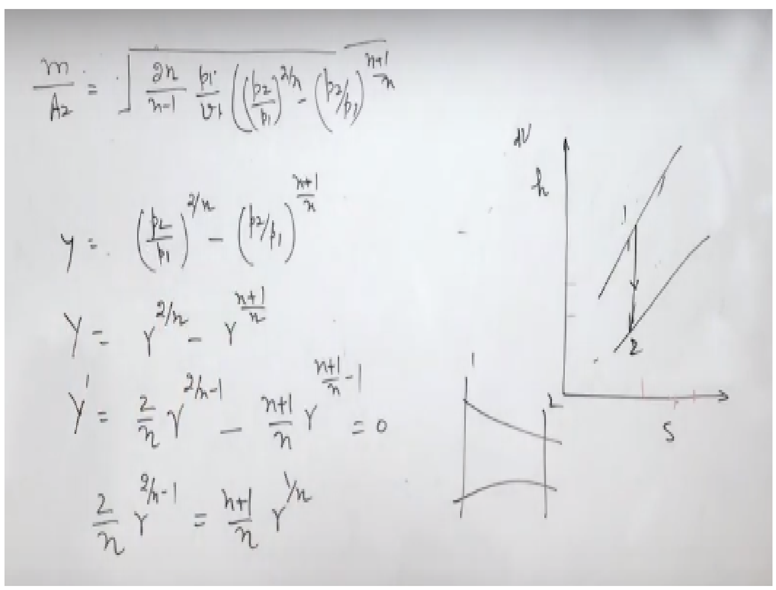

If you further simply this you will get M = A2 under root 2N upon N - 1 P1 by V1 P2 by P1 raise to power 1 by N - P2 by P1 raise to power N + 1 by N raise to power 1 by N is 1 by N. 1 by N + 1 by N now this is the mass flow rate we can take here also N by A2 mass flow rate per unit area is this right. Now here I want to have maximum this is about the discharge of the nozzle.

Now I want to have maximum discharge in order to have maximum discharge I should differentiate this equation this is normal practice so N then this term these terms are constants inlet pressure inlet specific volume nozzle is constant right and this constant right. We want to find for what pressure ratio the discharge is maximum when discharge this pressure is 1 discharge is 0.

Obviously when the leading side and the trading side if the pressure is same P2 and P1 is same there is no flow but when we start decreasing the P2 the flow the fluid id start flowing into the nozzle it does not mean that we if this we make this expression zero the flow become infinite. Normally what happens after attaining the certain value the flow becomes constant irrespective of the value of this pressure ratio that is known as choking of the nozzle.

So first of all we will differentiate this in fact we will take a function Y = P2 by P1 raise to power 2 rest are constant. So - P2 by P1 raise to power N + 1 by N. So we will differentiate Y this we can taken as for the sake of convenience R Y = R2 by N- R N + 1 by N Y dash is 2 by N R raise to 2 by N - 1 - N + 1 by N R raise to power N + 1 by N + 1 and this is = 0.

So 2 by N or raise to power tow by N - 1 = N + 1 by N R 1 by N.

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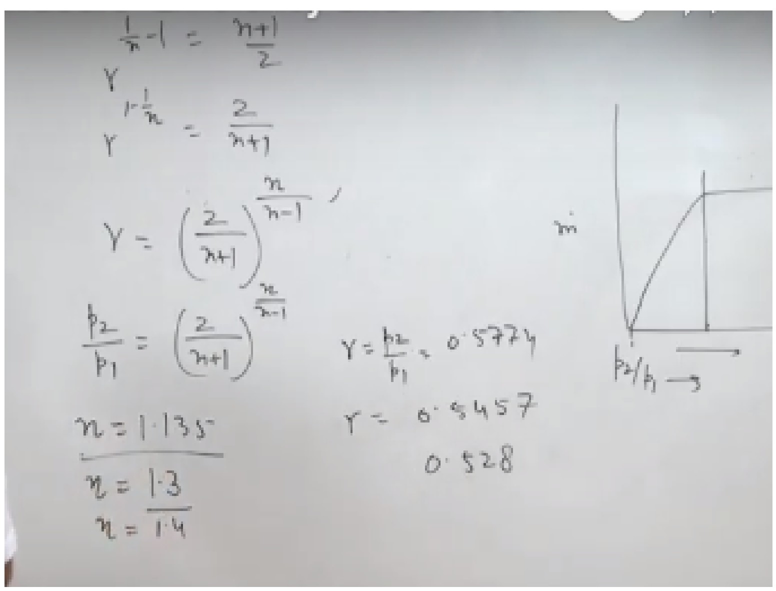

Now if you further simply this R raise to power 1 by N - 1 = N + 1 by 2. Or R 1 - 1 by N 2 by N + 1 or we can write this ratio R is 2 by N + 1 raise to power N by N - 1. So we have to maintain this pressure ratio P2 b P1 in order to have maximum flow through nozzle. If the pressure is less than this it will not increase so if we want to show on a graph it is flow is going to give something like this is P2 by P1 this is N this is decreasing in this direction right and this is mass flow rate.

So first of all it will increase and then it will become stagnant and this is known as critical pressure ratio. Now for steam saturated steam saturated steam is in that case the value of N = 1.135. If the value of N = 1.135 here in that case the R is going to be R = P2 by P1 is going to be 0.5 this is for saturated steam is getting expanded in a nozzle.

Suppose getting expanded in a nozzle suppose steam is superheated than N = 1.3. In that case R is going to be = 0.5457 simply just putting the value of N = 1.3 here we getting this expansion. Suppose it is a gas nozzle so N = gamma suppose it is air 1.4. In that case it is going to be 0.528 so for any value of N or we can find the pressure ratio for which the flow is maximum during flow through a nozzle.

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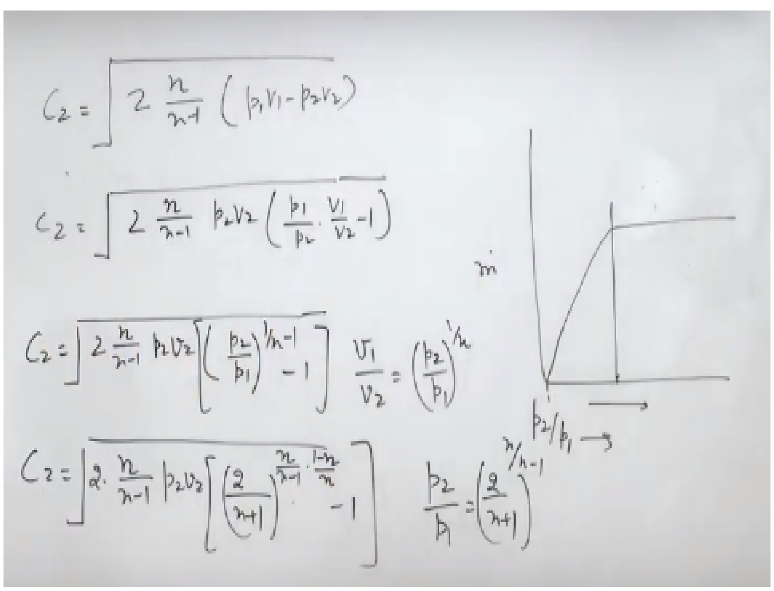

Now let us go back to the same equation right so we take P2 V2 common C2 here 2N over N - 1 P2V2 P1 by P2 V by V2 - 1 right. Now V1 by V2 = P2 by P1 raise to power 1 by N so we can write C2 = under root 2 N over N - 1 P2 V2 P2 by P1 right 1 by N - 1 because this will reverse then it will be - 1 and - 1.

Now again C2 = under root now we can put P2 by P1 here for the choking condition P2 by P1 = 2N + 1 raise to power N upon N - 1 we have already driven this. So two multiplied by N upon N - 1 P2 V2, P2 by P1 = 2 by N + 1 N upon N - 1 and this is 1 - N upon N - 1 right.

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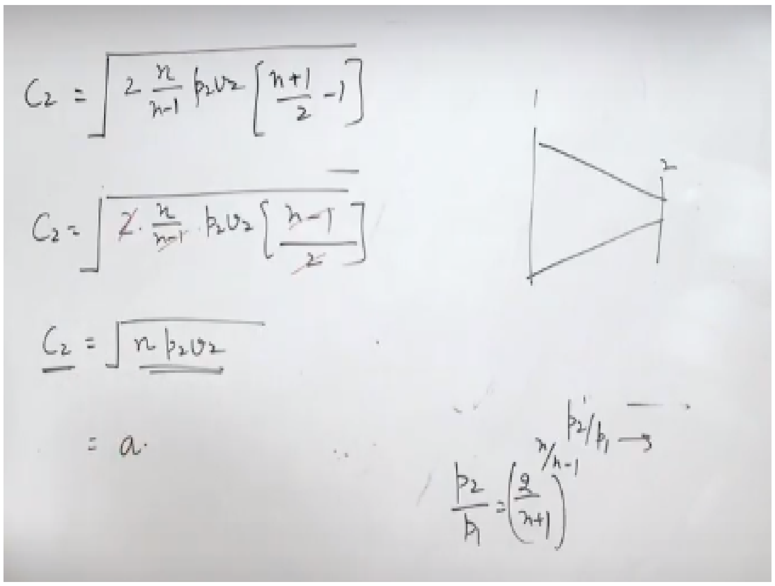

We can easily simplify this equation to find the value of C2 at the throughout C2 = now under root 2N upon N - 1 P2 V2 here this 1 - N, N - 1. So and this N and N will be cancelled out this is N - 1 this is 1 - N so this expression is going to be N + 1 by 2 - 1. Now C 2 is under root 1 N over N - 1 P2 V2 divide by 2 N - 1 now this N - 1 we will get cancel with this N - 1 this 2 will get will get cancel with this 2.

And the final expression is going to be C2 = under root N P2 V2 right so in a nozzle if a flow is adiabatic friction less ideal flow. This is one this is throat of the nozzle two right the velocity is going to be N P2 V2 and this is nothing but sonic velocity of the fluid N P2V2 I going to be sonic velocity of the fluid at this particular condition that is all for today thank you very much