Steam and Gas Power Systems
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Module No # 08
Lecture No # 38
Axial Flow Compressor Characteristics

Hello I welcome you all in this course on Steam and Gas Power Systems today we will discuss axial flow compressor characteristics.

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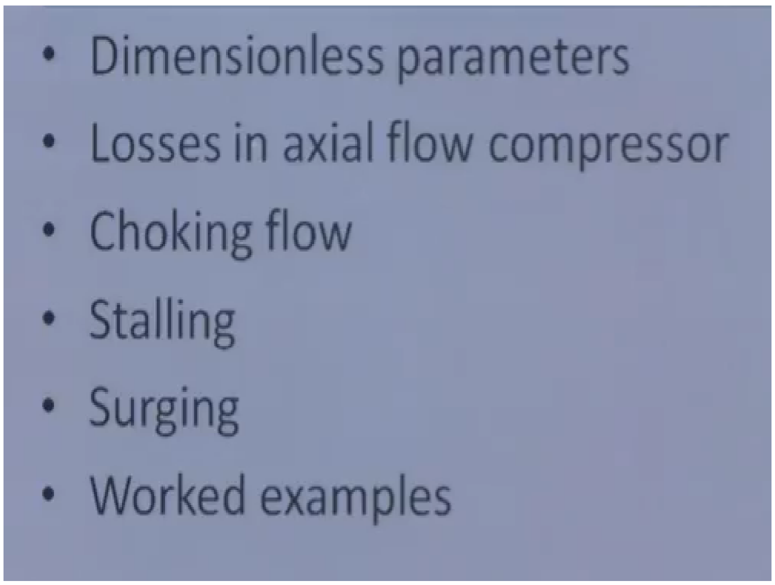

We will start with the dimensionless parameters, which are used for comparing the performance of axial flow compressors then losses and axial flow compressors, choking flow, stalling, surging and we will do some worked example. There are certain dimensionless parameters which are used in axial flow compressor in order to judge the performance of axial flow compressor.

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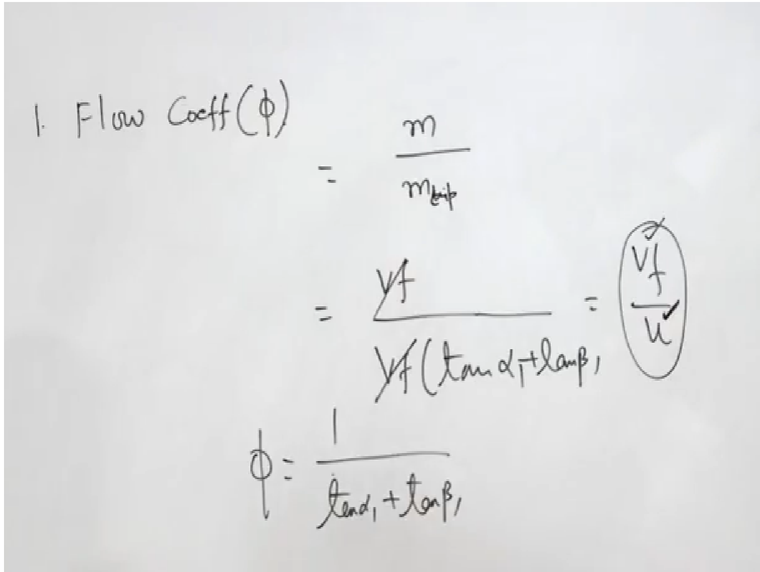

Number one is flow coefficient of an axial flow compressor is the mass flow rate and mass low rate and tip of the blade and this is VF where flow velocity. This is flow velocity Tan Alpha 1 + Tan Beta 1, it is nothing but VF by U because rest of the things for calculating the mass flow rate are going to remain same.

Only there will be a change in velocity actual mass flow rate and mass flow rate corresponding to thrift velocity. So we will be getting this expression, so flow coefficient is one by Tan Alpha 1 + Tan Beta 1, it is the dimensionless quantity.

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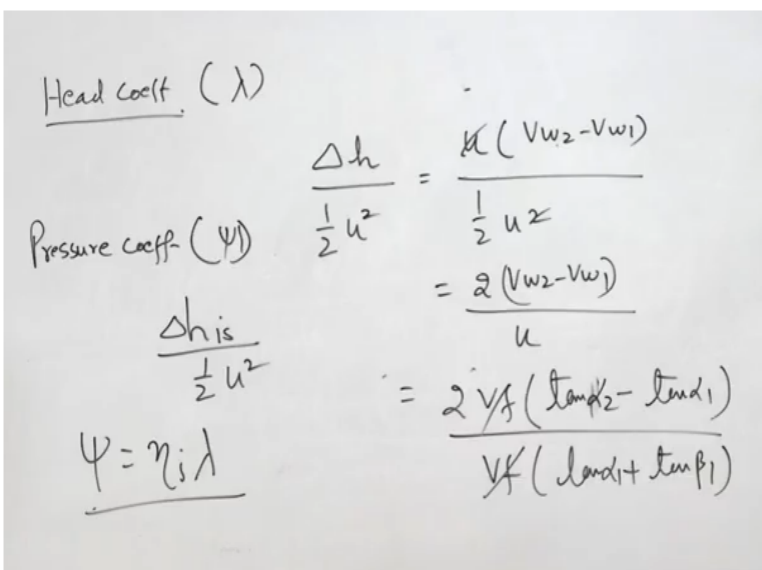

Another is head coefficient is denoted by Lambda right and it is enthalpy rise in a stage divided by enthalpy corresponding to peripheral velocity. This is kinetic energy at the tip of the rotor. Now enthalpy rise is UVW 2 – VW1 right and kinetic energy is half U square then U and this will be cancelled out and two VW2 - VW1 divided by U.

This is head coefficient and we can further write 2VFV W2 is VF Tan Alpha 2 - VF Tan Alpha 1 divided by VF Tan Alpha 1 + Tan Beta 1 or this VF will be cancelled out it will become dimensionless and after the head coefficient there is a pressure coefficient. In pressure co efficient the difference between these two is pressure coefficient the Delta H isentropic enthalpy rise is taken into the account okay.

And we can always say, that the pressure coefficient is isentropic efficiency multiplied by head coefficient like steam turbine. So impulse reaction, steam turbine axial flow compressors also do have degree of reaction.

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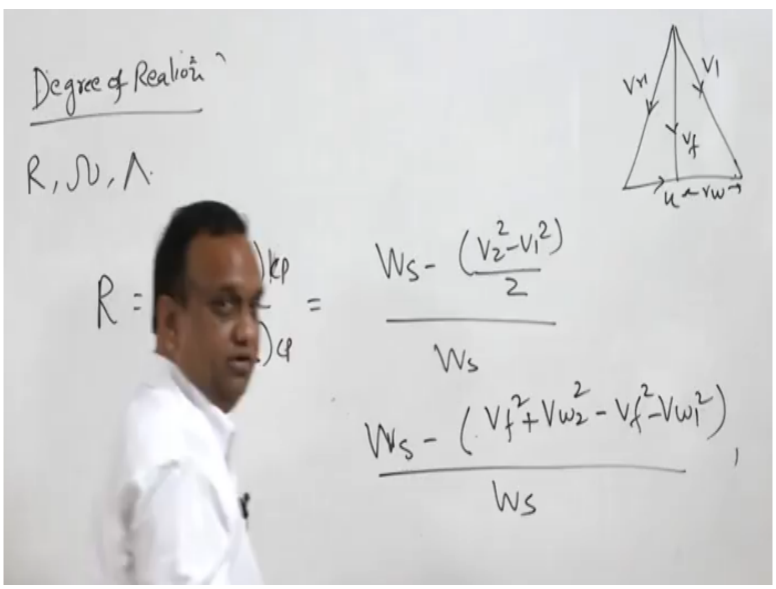

It is denoted by R, in some of the books it is denoted by Omega or capital Lambda. So the degree of reaction is again the temperature rise in rotor divided by temperature rise in stage or if you multiply by CP then energy imparted in rotor divided by energy imparted in stage or work in a stage or we can write work in a stage minus V two square minus V one square by two divided by work in a stage okay.

Now V2 square - V1 square is work in a stage minus, now in a velocity triangle velocity diagram, this is VR1 V1 and this is U and this is VF and this is VW right. So V1 square is nothing but VF square + VW1 VW2 square and V1 square is VF square - VW1 square divided by work in a stage.

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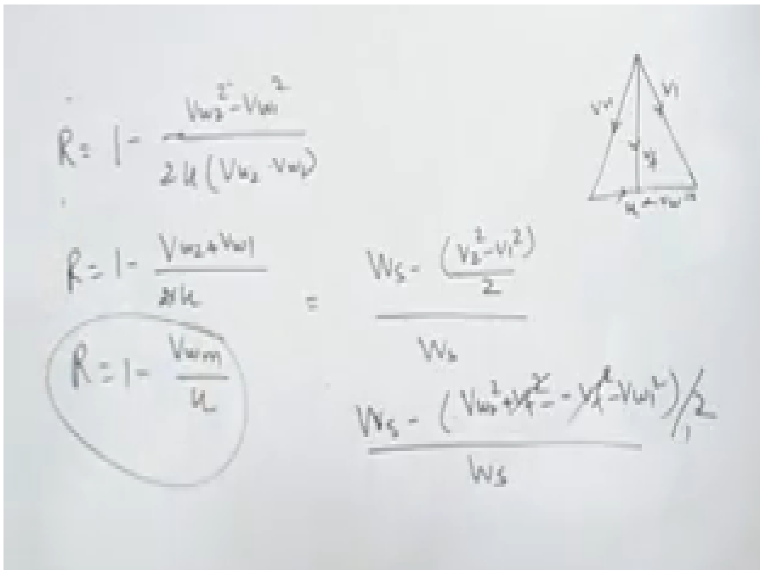

Now degree of reaction are is equal to, now instead of doing it here, we can write this is sorry V W two square + VF square - VF square. So this will be cancelled, so R is 1 - VW2 square - VW1 square divided by work in a stage. And the work in a stage is UVW 1 + V2 – VW1 VW2 - VW1 and this multiplied because this is 2 here this is divided by 2 and 2 will come here.

So R is 1 - VW2 + VW1 divided by 2 multiplied by U or R =1 - VWM divided by UVWM is mean will component. So this is how we can find the degree of reaction of an axial flow compressor. Now if we compare the centrifugal compressor with axial flow compressor

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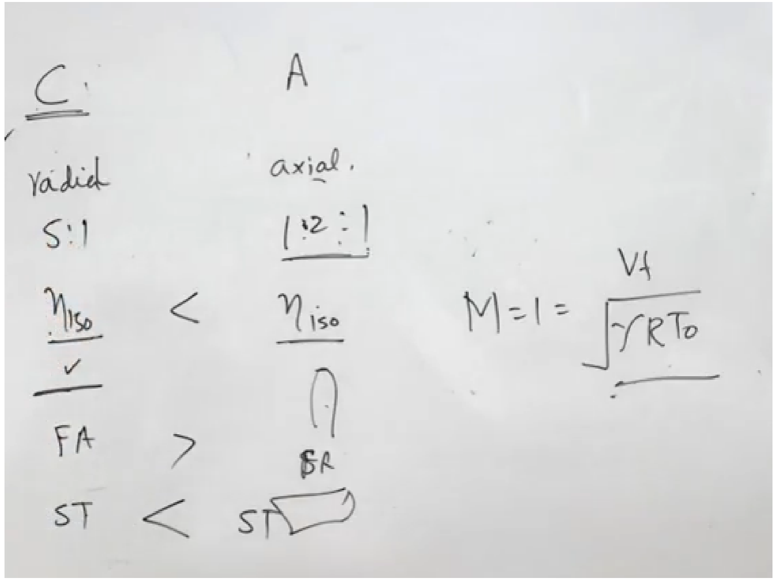

And axial flow compressor and centrifugal compressor, the flow is radial in the flow is axial as it implies from the name itself. Pressure ratio per stage is high 5 is to 1 or 6 is to 1. Here the pressure ratio per stage may be 1.2 is to 1. But in axial compressor we can have number of stages, it is very easy to add on stage in axial flow compressor. So per stage pressure is low but we can have number of stages in axial flow compressor.

Isentropic efficiency in centrifugal compressor is less than isentropic efficiency of axial flow compressor, the reason I have already told you because in centrifugal compressor there is change in direction okay which imparts losses in the during the flow of fluid, that is why isentropic efficiency of centrifugal compressor is less than isentropic efficiency of axial flow compressor.

We are not discussed here this choking and surging, so but we will discuss after this. So choking and surging the gap is quite substantial in case of centrifugal compressor but choking and surging stage, here the gap is not much the choking and surging. I will discuss after this, this as large frontal area, this is small frontal area so because axial flow compressor have small frontal area that is why they are very useful for jet propulsion or in aircraft applications right.

But when working with contaminated fluid, when in centrifugal compressor if the fluid is contaminated we can use centrifugal compressor but that is not the case of axial flow compressor. In axial flow compressor, the working fluid should not have any contaminations it should be clean starting tort to start the compressor. The starting tort in centrifugal compressor is less than the starting tort in axial flow compressor.

And this centrifugal compressor construction cost is less, it is less complicated. Here construction cost or fabrication cost is more and is a riddle, more complicated. If you compare with the centrifugal compressor, now before we start with the numerical, we will very short we will discuss the choke flow we have already discussed for centrifugal compressor during flow inside the compressor.

The velocity should not exceed M1, that is VF square VF dived by Gamma RTO. So this should not shock or flow should not become choke flow, otherwise if it becomes supersonic in the later stage some shock may take place and that will incur energy losses during the flow through a the compressor and it will affect the efficiency and it will also physically damage the compressor right. So it is ensured that choke flow does not take place inside the compressor there is a term stalling, now stalling it is due to the change in the direction of inlet.

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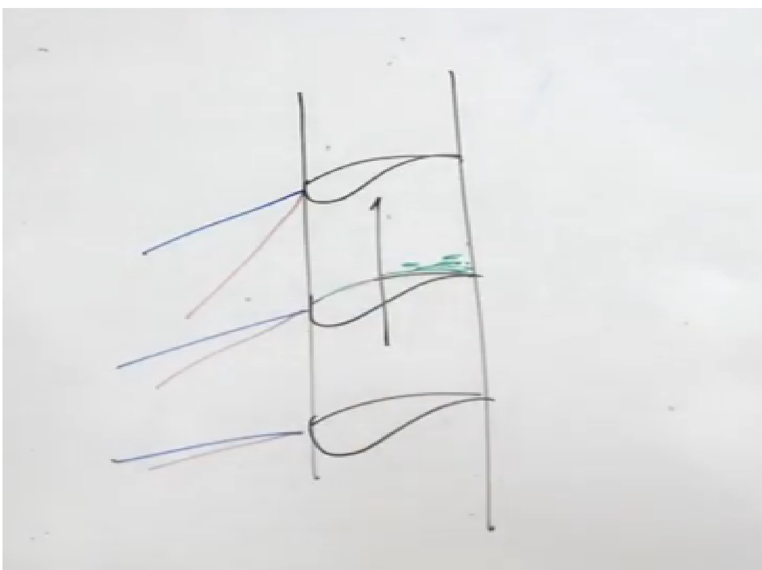

Suppose in a cascade there are number of blades let us take three blades and there is a different angle of incident changing and here at particular angle, the p and fag end he flow separation may take place. This is known as Stall and this is stall is not stationary it moves in opposite direction of the flow with half of the speed right and that is known as Rotating Stall.

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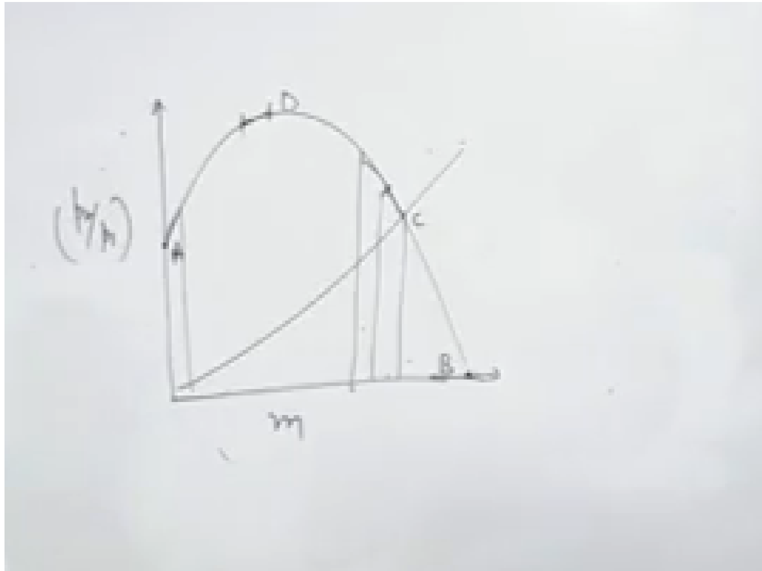

Now another phenomena is surging, let us draw the mass flow rate and pressure ratio and this is the surging curve. This is a characteristic curve and in this position there is a pressure ratio. But there is no mass flow rate it means the output valve is closed. Now in this position, mass flow rate is very high but pressure ratio is 0 it means the valve is fully opened, full throttle.

It is imaginary situation because if pressure ratio is not there will not be any flow so practically some pressure ratio has to be there right. Now there is a characteristic curve from here which cuts, this at state let us say this is A, this is B, this is C. Now when the flow is taking place at state C and we partially close the wall, when we partially close the wall the mass flow rate will reduce we further close the wall the mass flow rate will reduce.

When the valve is fully closed here when we slightly open the wall the pressure ratio will increase and mass flow rate will also increase it is reverse of this why it is happening the moment? We open the wall the flow will come with the certain velocity and this velocity will be converted into the admission pressure and that is how the pressure ratio is increasing but up to certain point only.

Now we are closing valve, we cross this point D and come to this side. When we come to this side, we further close the valve in that case pressure ratio will decrease. Initially when we are closing the valve the pressure ratio was increasing, now we are closing the valve the pressure ratio is decreasing it means pressure in the pipe at the exit of the compressor is more than at the exit of the pressure at the pipe so reverse flow will take place, so fluid will start flowing it is a arrest able type of flow.

The flue will start flowing backwards towards the compressor but the moment it enters the compressor the pressure will be neutralized and there will be interrupted flow or oscillating flow type of phenomena. So this is known as the surging in the flow and it is witnessed in both in centrifugal compressor and axial flow compressor as well.

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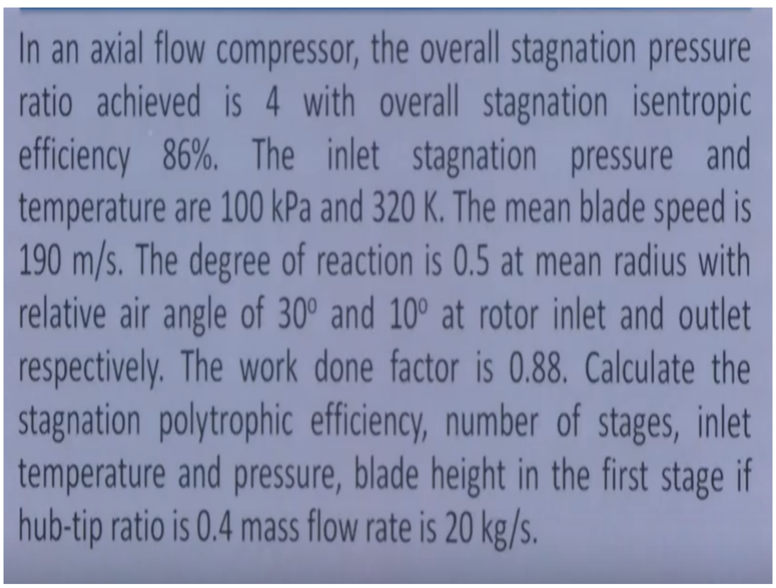

Now after this we will do a worked example now this numerical states that in an axial flow compressor the overall stagnation pressure ratio achieved is 4.

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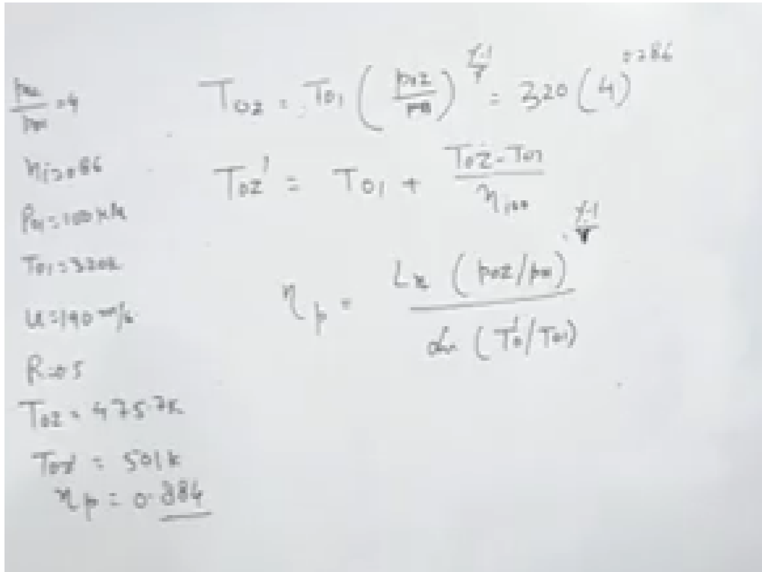

So pressure ratio is stagnation pressure ratio PO2 by PO1 = 4 and isentropic efficiency is 86 percent. The inlet stagnation pressure and temperature are PO1 = 100 kilo Pascal and TO1 is 320 Kelvin, the mean blade speed is 190 meter per second. So U = 190 meters per second, the degree of reaction is 0.5. The mean radius with radium angles air angle of 30 degree and 10 degree and rotor inlet and outlet respectively.

Work done factor is 0.88. Calculate the stagnation polytrophic efficiency. So here we will start simply TOZ = TO1. Now Z we are assuming, Z number of stages in axial flow compressor and in each stage is certain degree of pressure rise will take place and cumuli effect will be PO2 by PO1.

So TOZ is TO1 POZ by PO2 is to power gamma - 1 over gamma and that = 320 stagnation pressure at temperature at inlet is 320 pressure ratio is 4 and this is .286 and this TOZ = 475.7 Kelvin. This is the temperature at the exit of the compressor not at the exit of the stage TOZ dash will be calculated as TO1 + TOZ - TO1 divided by isentropic efficiency.

Now we have the value of TOZ TO1 isentropic efficiency TO1 is already with us. So TOZ dash will be is going to be 501 Kelvin. Now we will take polytrophic efficiency, small stage efficiency is natural lock POZ by PO1 raise to power 0.86 gamma - 1 over gamma divided by natural log of TOZ dash by TO1.

This is polytrophic efficiency, we have already done earlier this one right and now we will be putting the values. We have all the values with us and from here the polytrophic efficiency is going to be 0.884 okay. Now we will go for velocity diagram for the compressor now velocity diagram for the compressor, we can always take from the velocity diagram.

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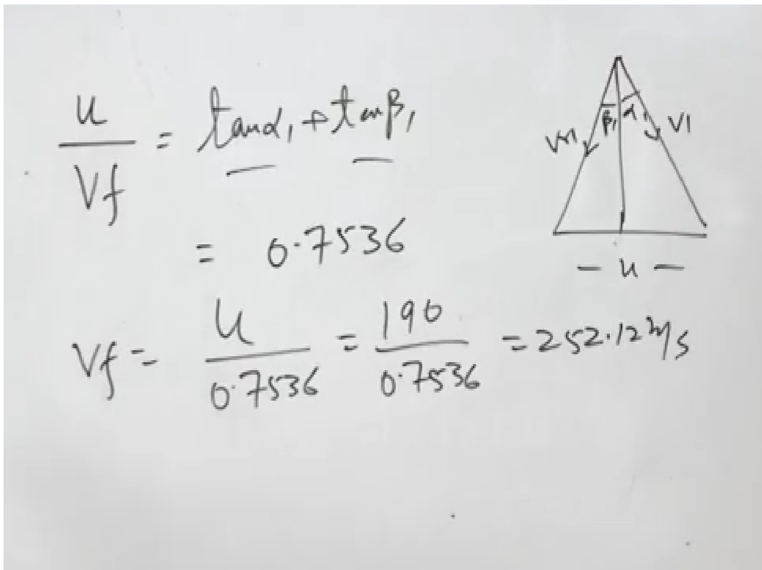

From compressor U upon VF = Tan Alpha1 + Tan Beta1. If we draw the triangle then this is V1 VR1 this is U alpha 1, beta1. Now alpha1 and beta1 are known to us calculate the relative air angles of 30 degree and 10 degree so for alpha 1 and beta 1 are known to us okay.

So Tan Alpha 1 + Tan Beta 1 that = 0.7536. So VF = U by 0.7536 = 130 by 0.7536 = 252.12 meters per second. So VF, we can note down because we will be frequently reading this 252.12 meters per second.

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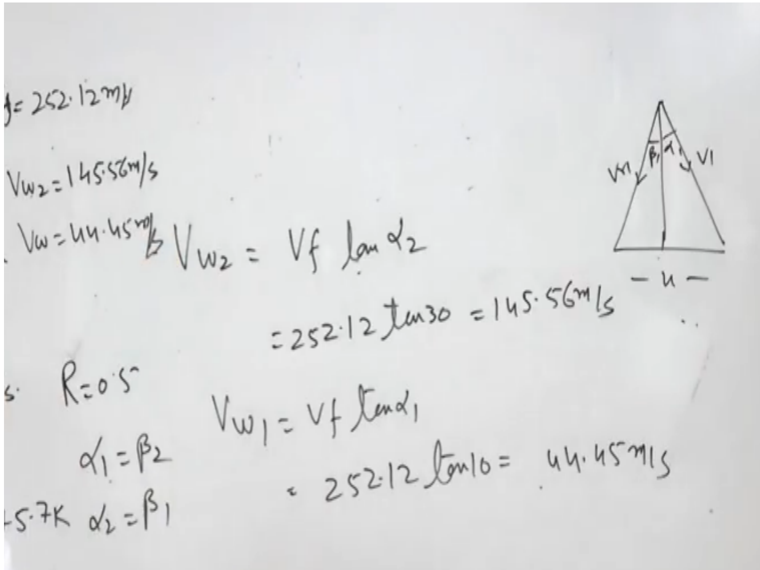

Now VW2 = VF 2 Tan Alpha 2 VF2 = Tan Alpha 2. Now here since, here since degree of reaction is 0.5. So Alpha 1 = Beta 2 and Alpha 2 = Beta 1 right. So now VW 2 = VF Tan Alpha 2 and that is = 252.12 Tan 30 and that is = 145.56 meter per second.

So this is CW VW2 = 145.56 meters per second. Similarly we can calculate VW1 = VF Tan Alpha 1 and that = 252.12 Tan 10 and that is going to be 44.45 meters per second. So V W1 = 44.45 meters per second.

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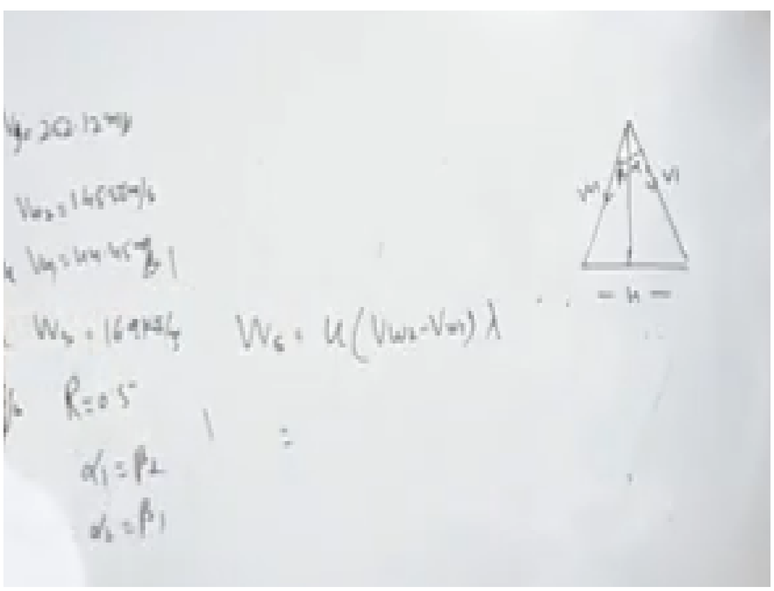

So work done per stage is UVW2 – VW1 multiplied by some work done factor is also given, so multiplied by Lambda U is with us, U is 190 VW2 and VW1. We have already calculated Lambda is 0.88 and this gives work done per stage as 16.9 kilojoules per kg right.

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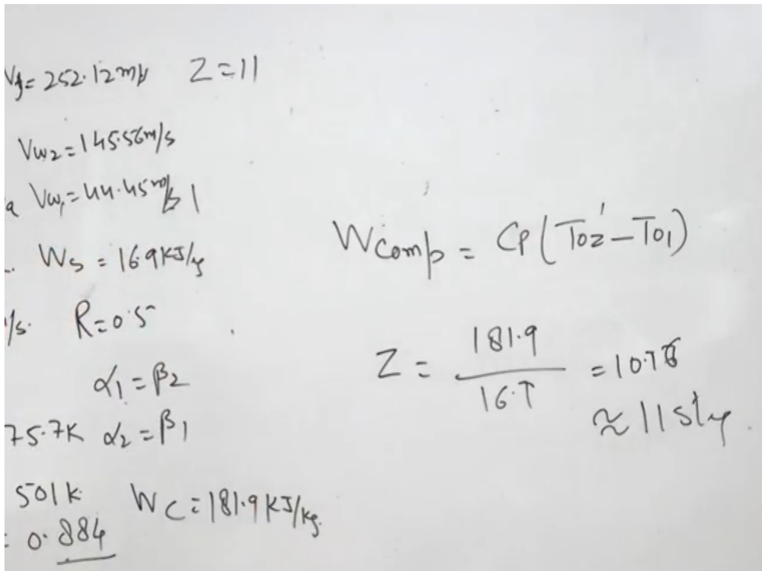

Work in compressor is work done in stage and total work done during compression is CP TOZ dash - TO 1. This is total compression and CP is already with us, 1.005. T O Z dash we calculated 501 Kelvin. TO1 is with us, this is 320 kelvin and from here the work of compression is calculated as 181.9 kilo joules per kg. So compression work is 181.9 stage work is this much if we take the ratio.

We can find out the stages, so number of stages Z = 181.9 divided by 16.9 = 10.76 or approximately eleven stages. So number of stages Z = 11 because we have to take the integer. We cannot take 10.76 stages. So eleven stages during compression stage axial flow compressor now once the stages are calculated, then inlet velocity V1.

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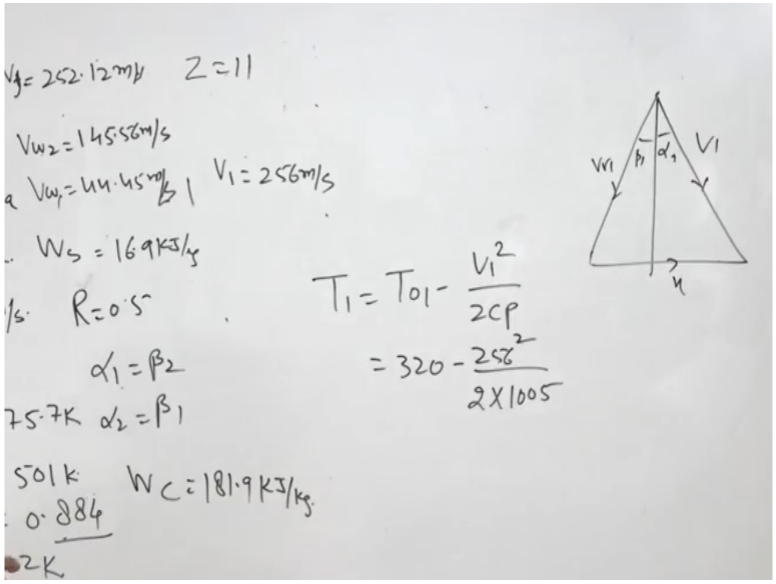

V1 = V1 Alpha 1 Beta1 VR1 U so V1 is VF by Cos Alpha 1. So V1, we are getting from here. We are getting V1 = 256 meters per second and temperature at inlet because we have only stagnation temperature. So temperature at inlet is going to be T1 = TO1 – V1 square by 2 C P.

This is stagnation temperature, so inlet temperature is going to be 320 K - 256 square by 2 into 1005. I have converted Kilo joules into Joules in specific heat and then this gives the value of T1 is, 302 Kelvin. Stagnation temperature is 320 and absolute temperature is 302 Kelvin.

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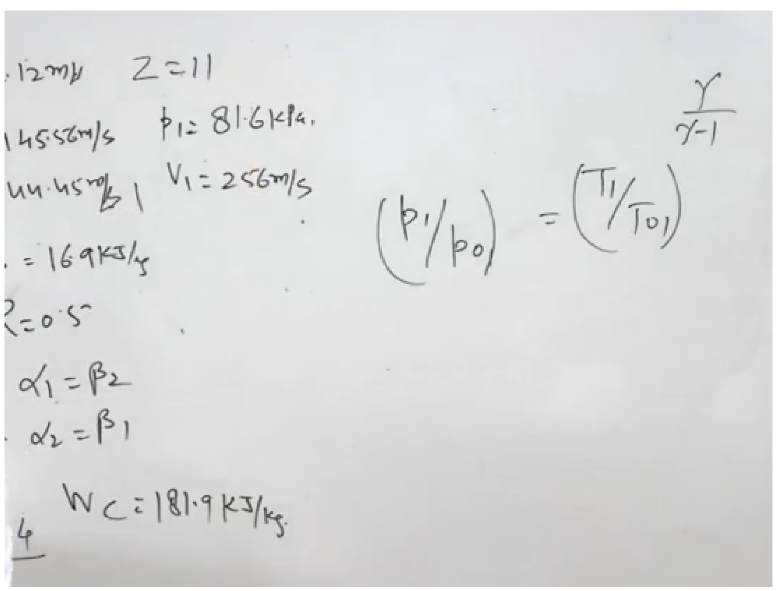

Now after this P1 by O1 = T1 by TO1 raise to power gamma over gamma- 1 right. Now here we have the value of stagnation pressure at inlet 100 kilo Pascal T1. We have calculated TO1 is also with us this will give the value of P1e as 81.6 kilopascal.

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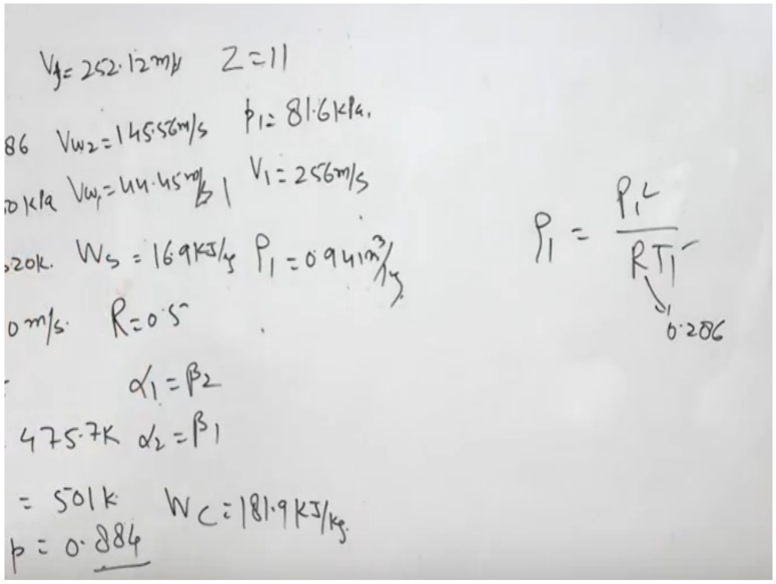

Now we need to calculate the density at inlet Rho1 is P1 V1 by P1 R T1 P1 R T1 right. Now P1 is these values are with us R = 0.286 and this will give the Rho1 as 0.941 meter cube per kg okay. Now the mass flow rate is 20 kg per second and blade to hub ratio is .4.

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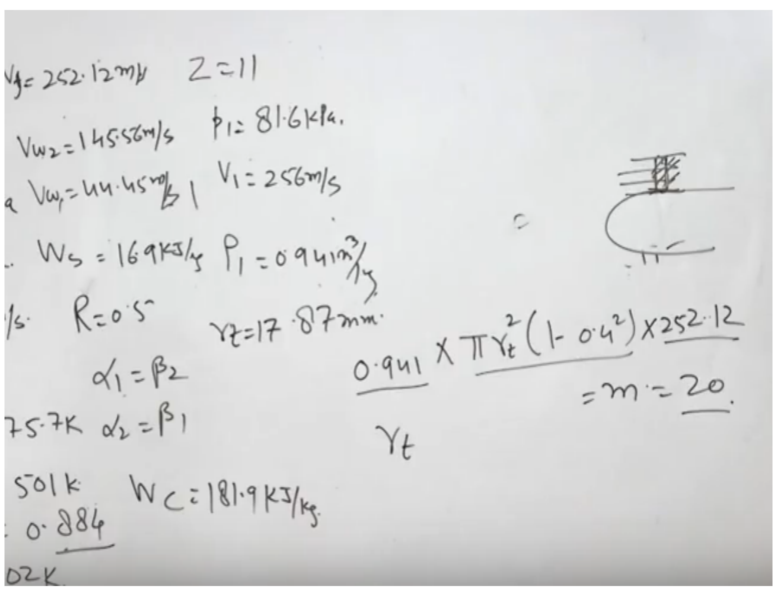

Blade to hub ratio means in axial flow compressor, this is hub the blades are mounted to the hub and this ratio blade to hub ratio is .4. So 0.941 density multiplied by Pi RT square tip square 1 -

0.4 square. This is area this is density area and velocity 252.12. This is the velocity of flow we will give the mass flow rate and that = 20.

This is density of air at inlet we have calculated Rho by RT 1, this is because mass flow rate is taking place between the hub and the tip. So this cross section area we have calculated here multiplied by the velocity and we are getting mass flow rate. From here we are getting the value of RT and the RT is 17.87 MM and when we multiply this 17.87 MM by .4, we will get the diameter of the hub.

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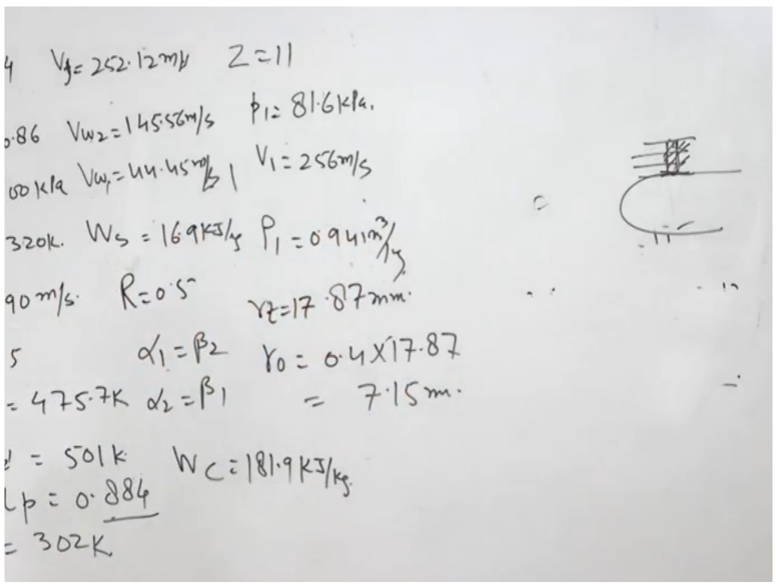

So tip diameter and RO = 0.4 into 17.87 = 7.15 MM. So now we have the diameter of the blade tip, diameter of the hub and rest of all the values. So that is all for today in the next class we will start with Jet Propulsion.