Fluid Machines.
Professor Sankar Kumar Som.
Department Of Mechanical Engineering.
Indian Institute Of Technology Kharagpur.
Lecture-38.
Axial Flow Compressors Part III and Fans and Blowers Part I.

Good morning and welcome you all to this session of the course. Now today we will be solving some problems relating to axial compressors. Last class we discussed in brief the principle of operation and the degree of reaction of an axial compressor. Now today we will see that how we can solve problems, so that our understanding becomes much better. Now let us concentrate on one problem.

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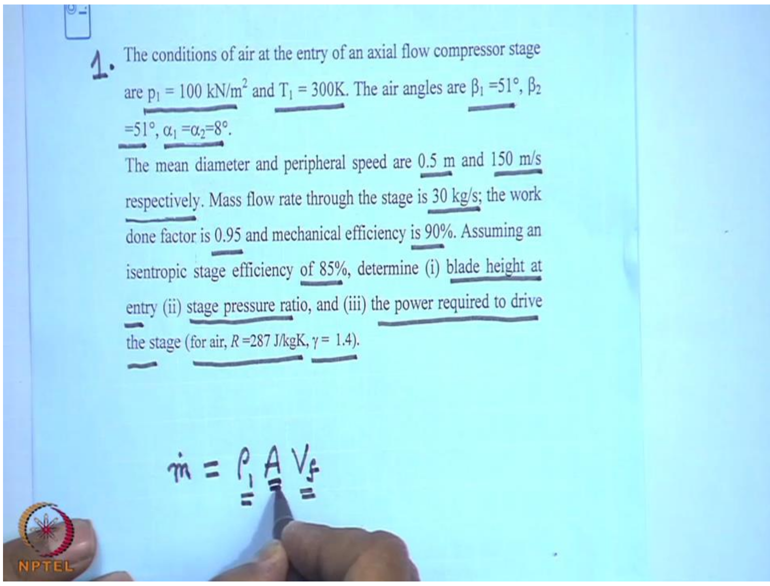

This is the problem number 1, which we will be solving. The conditions of air, let me read out the problem 1st. The conditions of ad at the entry of an axial flow compressor stage are P1 is given, the inlet pressure and temperature is given. The air angles are beta-1, so this nomenclature is known to us, this is the blade angle at inlet and beta-2, the blade angle at the outlet, that is a rotor blade angle at the inlet and outlet, that is 51 degree, both are 51 degree. And alpha-1 is Alpha 2 is 8 degree, this is given.

Alpha 1 is the angle of the absolute velocity at the inlet and alpha-2 is the angle of the absolute velocity at the outlet of the rotor blade. The mean diameter and peripheral speed are 0.5 metre is the mean diameter and this is the peripheral speed respectively. That means the peripheral speed in the mean diameter. The mass flow rate through this stage is 30 KG per second, the work done factor is 0.95, all these things are known to us. Mechanical efficiency is 90 percent.

Assuming an isentropic stage efficiency of 85 percent, what are to be found out, we have to find out blade height at entry, stage pressure ratio and the power required to drive the stage. This is given for air, the characteristic gas constant, 287 joule per KG K and the ratio of specific heat, 1.4. Now, sorry, to find out the blade height at entry, 1st of all you have to understand that it is the geometry, blade height. Which is basically related to the area at the inlet.

So therefore if we write the equation of mass flow rate, that thing we can, we have to select this equation to find this, we can write that Rho 1 inlet density and the area at inlet, and the velocity of flow which is same throughout. Now here, 1st of all we have to find out A, rho 1. Now A, within A, that is the annulus area, the blade height is there. The blade had can be found out from the annulus area A.

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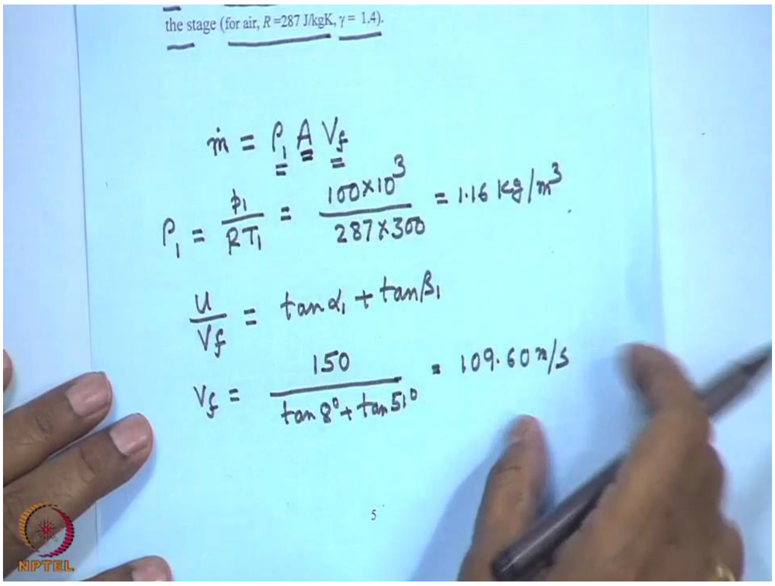

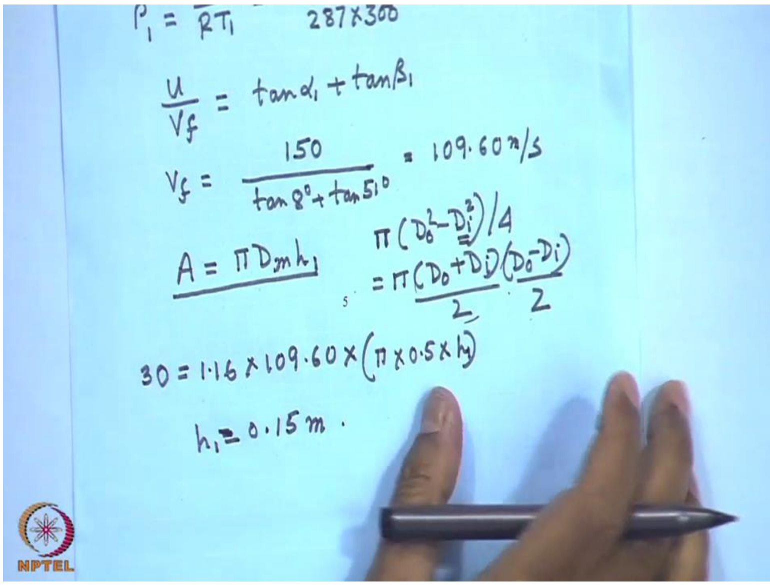

Now let us find out rho 1. So rho 1 at the inlet can be found out from the equation of stage as P1 by RT one. Well. So P1 is what? P1 is given as 100 kilo Newton per metre square. So therefore 100 into 10 Newton per metre square. 100 kilo Newton so into 10 to the power 3 and deep-fried the value of R 287 and T is 300, we get the value of rho 1 and rho 1 comes out to be 1.16 KG per metre cube. Alright, we get rho one. How to get VF, the flow velocity?

Is it given, assuming isentropic stage air, the flow velocity is not given but we can find out the flow velocity from the expression we developed earlier that U by VF is what tan alpha-1 +… Because we choose this expression. Flow velocity is not given but beta-1 and alpha-1 is given so that we can find out the flow velocity at U. What is U, U is given 150 metre per second. So 150 divided by tan alpha-1 + tan beta-1. That means tan of 8 degree + tan of 51 degree. And if you solve for it, you will get a velocity 109.60 metre per second.

So therefore you can get the annulus area. But before that you put annulus area in terms of this, blade height. Annulus area is Pie into the mean diameter into blade height. True. Where from does it come? It comes from annulus area is pie into outer diameter square - inner diameter square. If you consider the inner diameter as the diameter of the drum of this, and the outer diameter A the diameter of the casing, then this is the annulus area.

This can be written as pie into D0 + DI, sorry by 4. D0 + D I by 2 and D0 - D I by 2. Now it is, this is the mean diameter, D0 + D I by 2 and this is the blade height. So therefore this can be expressed in terms of the mean diameter and blade height, that area. So therefore now if I substitute here, we can write M dot, M dot is given 30 KG per second is equal to rho1 1.16

into VF, 1st I write VF because I have found out VF 109.60 into pie, what is that DM, DM is given as 0.5 metres, 0.5 metres, okay, it is given.

So therefore 5 into 0.5, so only unknown is your blade height H. Which gives H equals to, rather H1, the blade height at the inlet, so I write H1, blade height at the inlet, so H1 is 0 equals to 0.15 metre.

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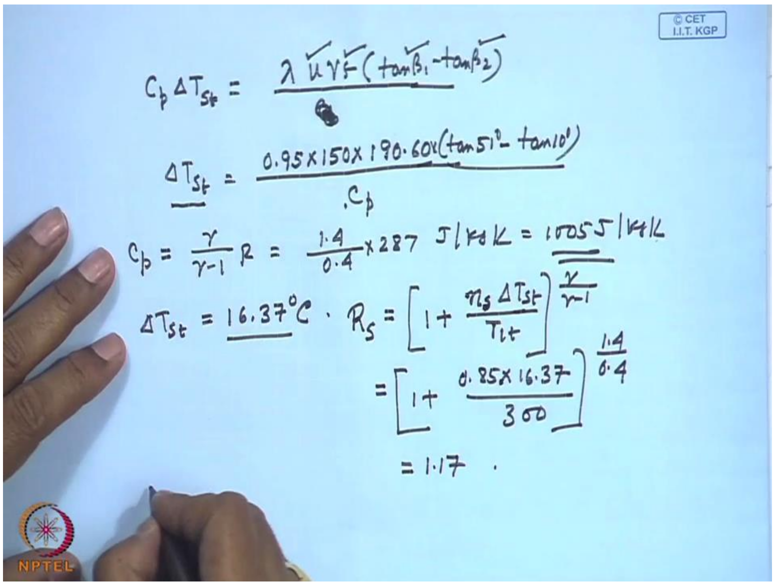

So the 1st part is over, the H1, blade height at entry. How to find out the stage pressure ratio? Stage pressure ratio is simple to find out, stage pressure ratio to find out, what we have to do, we have to find out the static temperature, the stagnation temperature ratio of the stagnation temperature difference, otherwise you cannot find out the static pressure ratio. So H1 is known. Now let us find out, write this formula.

That CP into Delta P ST, that is the stagnation temperature is equal to, today last class we discussed that it is the work done factor into U VF by CP, CP is always there, U VF into tan beta-1 - tan… Wherefrom it comes that this is the work done per unit mass, this is equal to CP Delta T S T. So therefore this is multiplied with a work done factor. So here what we have, we have U, we have VF, we have beta-1, we have beta-2. So we can find out delta TST. We can write this, what is the value of lambda here?

Lambda is 0.95, it is given, well then the U is 150 metre per second, VF we have calculated just now, 190, I am sorry, VF is 109, VF will come out as 109, yes, yes, VF is 109.60. So this is lambda U into VF, VF is 109.60, that is the VF, we have calculated. And tan, into tan of 51 degree - tan of 10 degree divided by CP. Now CP value, you can calculate here. Here CP is not given. Even if it is not given, you can take that. In this problem gamma and characteristic Constant is given. CP can be found out as gamma by gamma -1.

That means 1.4 divided by 0.4 into 287, that is the joule per KG k. That means if you find out CP, it will be 1005 joule per KG K, this is the standard value of CP for air. So CP, then you can find out delta TST and that becomes delta TST, becomes equal to, if you calculate it, I will tell you the value, 16.37 degree Celsius. Then you can find out the pressure ratio RS as I have told this is the nomenclature and this is the formula, again and again we tell, this will be 1+, the isentropic stage efficiency, that is Eta S, the isentropic stage efficiency, delta this formula, I have told inlet temperature divided by gamma by gamma -1.

Okay. So this can be written as 1+, substitute the values, if you can substitute the values, delta TST is 16.37 divided by 300 and if you put the value of gamma, then you get the value of stage pressure ratio as 1.17. 3rd one is that, what is the 3rd one?

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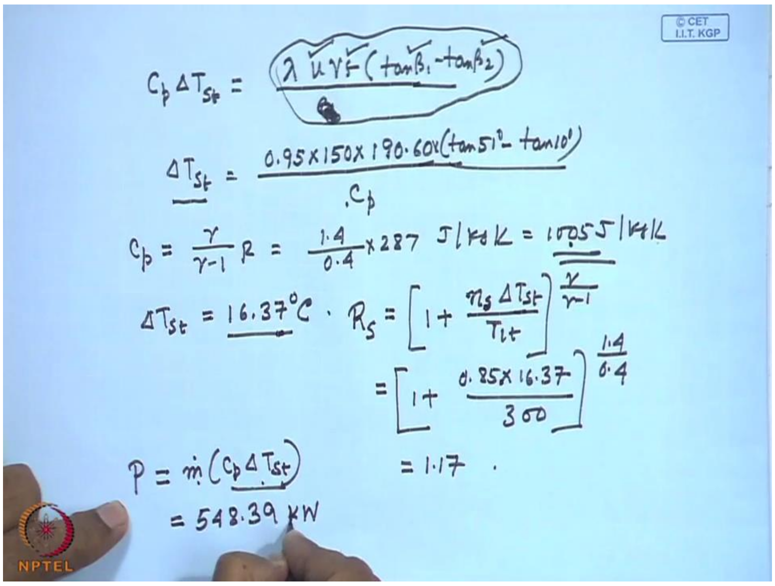

The power required to drive the stage. The power required is very simple because this is the the CP delta TST, power required is what, power per unit mass into the mass flow rate. Mass flow rate into CP delta TST. So delta TST we know, this already we have found out, multiplied with the CP, that means this part. That is actually this part. So this part we know and mass flow rate already we know 30 KG, given in the problem, 30 KG per second, so therefore if you put the value CP, this one, the delta TST 16.37 degrees Celsius and mass flow rate 30 KG per second, you get the value of 548.39 kilowatts.

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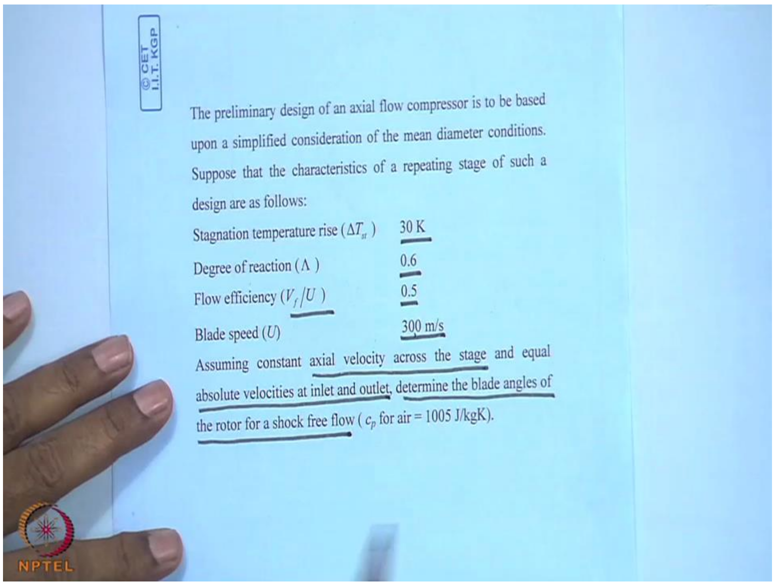

If you consist the unit finally you will get this, this is the power. So this is one example that we can work with. Next, another problem, I will tell you where you have some idea about the degree of reaction. Okay. So this problem is this. The preliminary design of an axial flow compressor is to be based upon a simplified consideration of the mean diameter conditions. Suppose that the characteristics of a repeating stage of such a design are as follows. That means a particular stage, these are repeated for different stages.

Stagnation temperature rise is given, that means indirectly the work done on the fluid is given. Degree of reaction is given, flow efficiency is given, 0.5. But this is actually not flow efficiency, I think it will be better if you write it as flow number, VF by U is actually flow number, sometimes they write the flow efficiency, however flow number, blade speed, that means it is the ratio of flow velocity to the peripheral speed. Peripheral speed is also separately given, 300, that means we get VF, multiply 0.5 with that.

Then what is the problem, assuming constant axial velocity across the stage and equal absolute velocity at inlet and outlet, that means V1 is equal to V3, that we have already done. Determine the blade angles of the rotor for a shock free flow. That means there is no incidence loss. So how to find, workout this problem. Now this problem if your workout, you see that degree of reaction is given. Now 1st of all we know the stagnation temperature rise.

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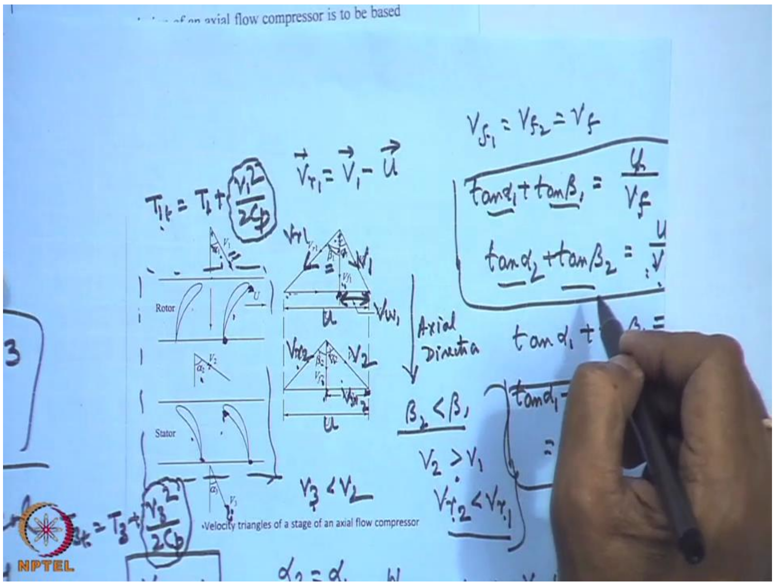

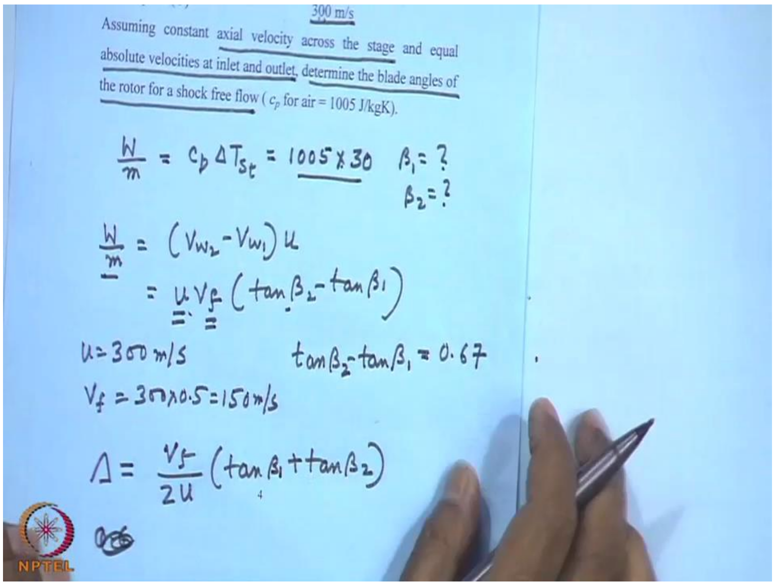

So 1st of all we find out the work per unit mass is equal to, is known. That is what, that is CP into Delta TST. And what is CP, CPAs 1005 joule per KG K and that is 30 and finally this becomes equal to your work per unit mass. Now how to find out beta-1 and beta-2? So what we have to find out, we have to find out beta 1, we have to find out beta 2, the 2 angles. Okay. So you remember beta-1, beta-2. So I tell you again that this one, we have to find out. We have to find out beta-1, beta-2.

So what we will do, we will take some of these relationships, tan beta 1 - tan beta-2 is equal to work done. Where you will get that formula? That VF, okay, I am coming to it again, it was done earlier. If you remember that W by M is VW2 - VW 1 into U and that becomes is equal to U into VF into tan beta-2 - tan beta-1. Now we know U, we know VF, VF is 300 into 0.5, U is 300, U is 300 metre per second. Well and you can see, I think you can see very well and VF is 300 into 0.5, that is 150 meter per second, tan beta-2, tan beta-1, beta-2 and beta-1 we have to find out.

W by M we know. So therefore if we put this here and this value here, we get a relationship tan beta-2 - tan beta-1 equals to what? Tan beta-2 - 0.67 you get, everything is known. Now we have to get another relationship relating beta-2 and beta 1, that will come from the relationship of degree of reaction. Now degree of reaction if you remember is given by U by VF, degree of reaction is VF by U. VF by 2U, if you remember that, that today we have done in last class, we have done it, tan beta-2 beta-1 + tan beta-2.

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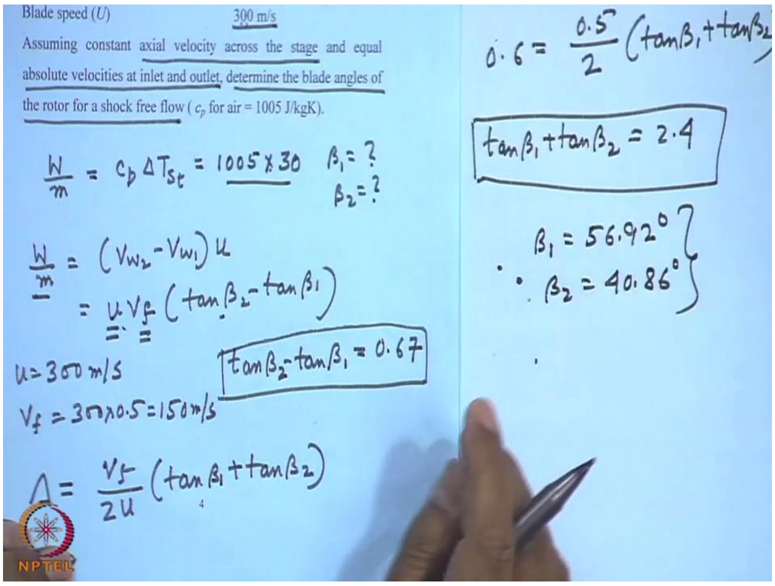

So we have done this thing, so here also we know VF by U, VF by U is 0.5. That means 0.6, rather I write here, I write here, this will be better. 0.6, 0.5, VF by U is 0.5, it is given in the problem by 2 into tan beta-1. So it is a simple problem which gives the relationship tan beta-1 + tan beta-2, it is what, 1.2 to 2.4. It is very simple. So this is one relation and this is one relation. So as simple as this and finally if you solve for tan beta-1 and tan beta-2, finally you get beta-1 as 56.92 degree and beta-2 is 40.86 degree, these are the answers you can check.

So therefore with the degree of reaction you get, that is only that we have to deal with equations, which equations will be required depending upon the parameters given. So these are the problems which make concepts more clear. Now, after this, I will start the fans and blowers. The fans and blowers, there is nothing much different from that of compressor. The difference is like this, as I told earlier at the beginning of my fluid machines class that the, when the output for a compressible flow for example, that handling air at the outlet of a machine where energy is given and we get the fluid at the outlet of the machine having higher energy, acquired, stored energy.

If that is mostly in the form of high pressure, static pressure but less velocity, we call it as compressor, was it a centrifugal or it is axial. But when the basic purpose is to have fluid with very high velocity, where we have to deliver high rate of flow with high velocity of flow, therefore, there the machine must deliver the fluid with higher energy by absorbing energy from outside, mostly in the form of the kinetic energy with high velocity but relatively much less pressure, static pressure.

Those machines are known as fans and blowers. So fans and blowers and compressors are of same kind, in the sense that they take energy from outside and the fluid flowing through it gains its internal energy. But for fans and blowers, this energy is mostly in the form of kinetic energy rather than pressure, static pressure. It is more of velocity rather than static pressure. Now amongst fans and blowers, fans are those machines where the static pressure at the outlet of the machine is few millimetre of water gauge.

You can understand that atmospheric pressure is 10 meter of water gauge, it is so less, few millimetre of water gauge. Whereas in case of blower, it is something more than 1000 millimetre of water gauge, still it is very less, 10 meter of water gauge is the atmospheric pressure. So this is the pressure, gauge pressure, that means above the sphere at the outlet. Why this pressure is so low and why the pressure is required?

1st of all pressure is required because these machines deliver air for some purpose, that means the air has to flow, it may be required that to make a, to supply the air through a duct. So therefore we have to overcome the friction of the duct, that means this flow has to take place through a duct, it has to overcome the frictional resistance, not only through a duct, through a room. So therefore downstream resistance has to be, frictional resistance has to be overcome to deliver that flow.

So these machines develop that pressure sufficient to overcome the resistance. Now in case of lower, it handles more amount of air. When less amount of air is handled and is circulated or being sent through a duct, we employ fans for which the frictional resistance is less. So therefore a relatively less static pressure is required at the delivery end of the machine.

Whereas in case of blowers which handles more air and at a high velocity it may have to be conveyed or transported through along the, the frictional resistance is much more.

That means it has to overcome more frictional resistance so that the pressure drop is more. As a consequence, the static pressure at the outlet of the machine has to be higher. This is the reason for which blower, for blower static pressure is higher because it handles more amount of air. So this is the difference between blower and fan. The fan and blowers are basically the compressors but in this case the static pressure at the end of the machine is much lower as compared to its velocity. Okay. Thank you.