Experimental Methods in Fluid Mechanics
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Lecture 22
Measure of velocity components by 3 holes and 4 holes probes

Good afternoon, I welcome you to this session of Experimental Methods in Fluid Mechanics. And today, we will discuss about another module of the Flow Measurements, you know Flow Measurement technique that is, the Measurement of Velocity Components by Using Probes.

In fact, in one of my previous lecture we have discussed about, you know, measurement techniques where the measurement principle of velocity and other flow parameters, static pressure, stagnation pressure using probes and where we discuss about the 3 hole and 4 hole probes. If we try to recall, that we have discussed 3 holes probes are not suitable in places where flow is 3 dimensional and for that the concept or the new designer of 4 hole probe, you know came and the addition of another hole that is probe, that is why it is called 4 hole.

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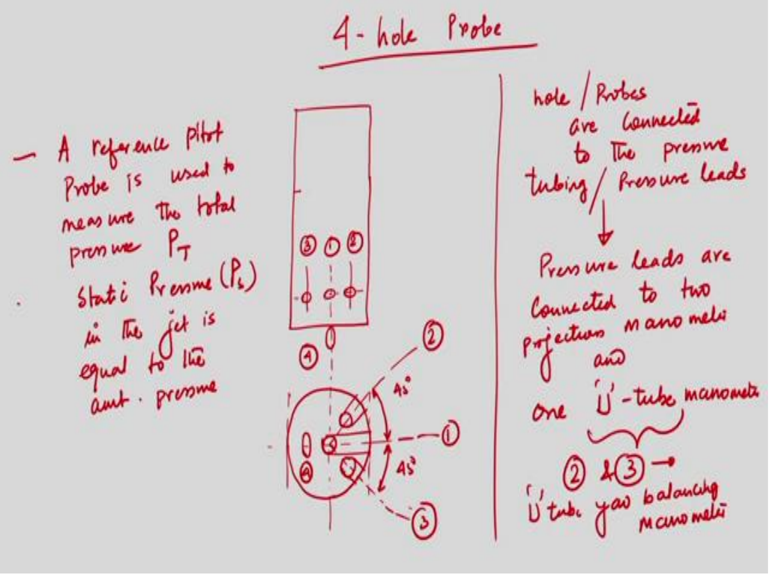

So, the 4 hole probe, 4 hole probe, so this 4 hole probe, 4 hole probe is used to measure flow parameters that is a static pressure, stagnation pressure and also, we can measure the velocity components. So, today we will see that using this 4 hole probe, how we can measure the velocity components. That is very important in, you know in different areas of fluid mechanics research, in particular where I would like to measure, you know excel flow machines or in different other turbo medicines.

So, now, but before I go to discuss about the measurement, rather I can say, you know calculation of velocity components, I would like to you know redraw the schematic of a 4 hole probe. And from there we will try to understand how we can, you know calculate velocity components using this probe, to be precise by measuring the pressure using this probe.

Now, so the schematic of a 4 hole probe that is very straightforward that I, have drawn it in the, in one of my last lectures. So, this is you know simple type and so, this is, that is, you know this is still tube which is having 3 different holes. Say, this is the central, so this is number 1, this is 2 and this is 3 and another hole is there that is the 4 hole and this 4 hole, so this is fourth number of orifice or hole. Now, we have discussed that these are readily drilled hole and these holes are connected through pressure tubing, now connected to the pressure tubing.

So, this probe is used to, in fact we can place this probe. This is a special type of probe where we can place even, I mean we can place this probe in spaces which is, rather which are close to the solid wall and solid boundary. So, again I need to draw another view of this flow. So, if I try to draw, say this is, in fact I can draw the here only, so this is the central hole. And so this is, so this is angle is 45 degree, this angle is also 45 degree and this is number 2, this is number 3, this is number 1 and this is number 4.

Now, if you try to recall, this hole is suitable for measurement of flow parameter that is static pressure stagnation pressure as well as, the velocity components and this is suitable in places where flow field is highly, flow field is highly 3 dimensional. And also, this probe can be placed very, in a region which is close to the solid wall or solid boundary.

Now what is done essentially, that is we will discuss today. See this probe this, you know, as I said that the you know there are 3 different, you know 4 different holes, number where there is center hole 1, then hole 2 and 3 these are connected. Now, we need to know that these probes that is holes, multi holes or probes, these are connected to the pressure tubing. Now, that means, using this probe, we can measure the pressure and once we calculate pressure, then from there we can calculate the velocity components and, that is what we will discuss today.

Now, how can you calculate, how can you measure pressure using the probe that is now we will discuss. We have seen, we have, rather we have discussed that this, you know this probes

2 and 3, this probe 2 and 3, these are connected with, rather I can say that the pressure tubings or I can write pressure leads, pressure leads. Now, the person leads, you know are these pressure leads, these pressure leads are, you know connected to 2 projection manometer and 1 U tube manometer. Now, this point probes 2 and probes 3, these 2 probes are connected to U tube manometer, U tube yaw balancing manometer to precisely. So, there are 4 different probes.

The probes 2 and 3, these 2 are connected to U tube, yaw balancing manometer and other 2 probes are connected to the projection manometer. So, that is what we have understood. So, which probes, I mean which probe is used to measure static pressure or stagnation pressure, that we need to know. That means, which probe is used to measure which pressure that is we should know. But now, I can see that we will get pressure P1 using the probe 1, we will get pressure p 4, using probe 4, 2 and 3, these 2 probes are connected with U tube yaw balancing manometer. So, I mean, we, these 2 probes are responsible.

We will discuss, why these 2 probes are connected with yaw balancing manometer. So, I can say that our reference pitot probe is used to measure the total pressure that is PT and static pressure Ps in the jet is equal to the atmospheric pressure. So, I am placing this probe in a jet, where the jet static pressure is equal to the atmospheric pressure Ps, our reference pitot probe which is used to measure the total pressure. Now, the probe is yawed, now why it is done, I have discuss this aspect while we have discussed about the working pressure of the probe. Now, probe is yawed until pressure at point 2 and 3 become equal.

So, pressure at orifices 2 and 3 must be same, for that the probe needs to be yawed and this process is done until the pressure at point, at orifices 2 and 3 becomes equal. And if the pressure becomes equal the, you know the balancing manometer will show the 0 differential head.

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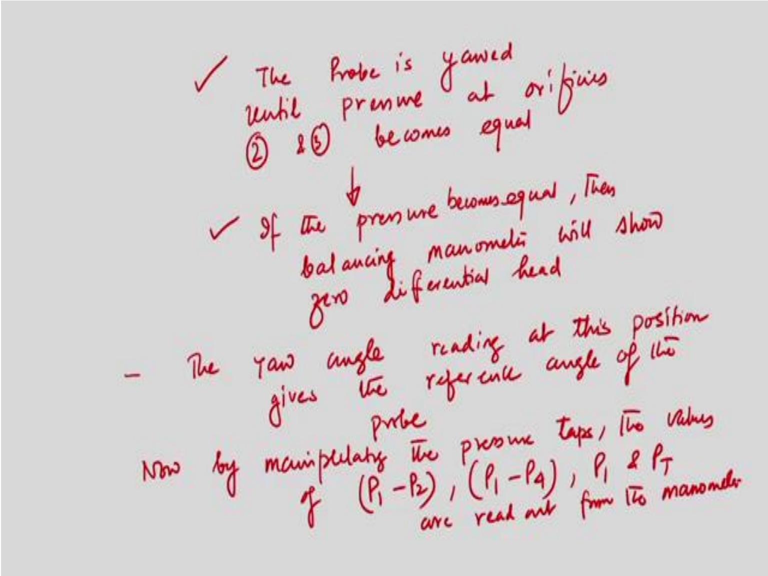

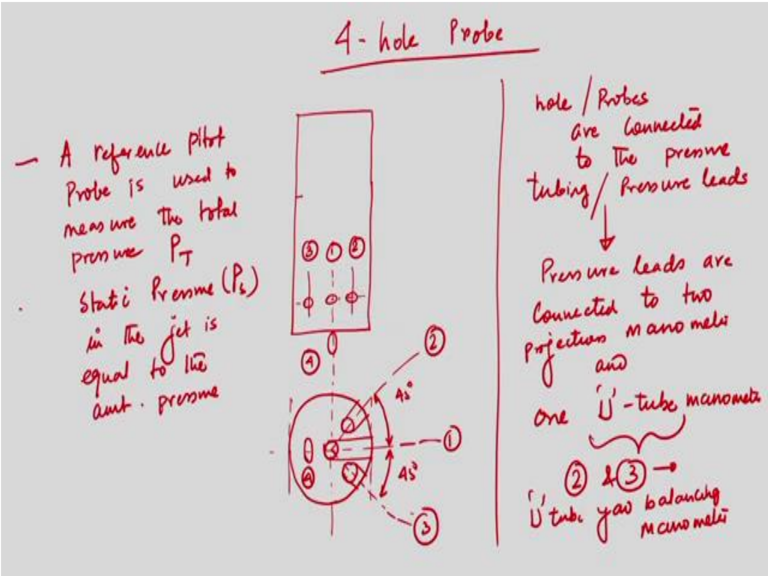

So, that means I can write now, that the probe is yawed until pressure at orifices 2 and 3 becomes equal. And how do I know that the pressure is equal, if the pressure is equal, then balancing manometer, rather pressure if the pressure becomes equal, the balancing manometer will show 0 differential head, balancing manometer will show 0 differential head. So, knowing the reading from the differential manometer, we can say now, the pressure at point 2 and 3 is equal. So, that is done until by yawing the probe, and until it is done until they become equal.

The yaw angle, at which the pressure or the yaw angle for which the pressure at orifices 2 and 3 becomes equal that yaw angle is known as the reference angle of the probe. So, the yaw angle, you know for which, or I can say the yaw angle reading at this position, you know gives the reference angle of the probe. So, what I said, the probe is yawed until the pressure at orifices 2 and 3 becomes equal.

And when they become equal, we will come to know from the reading of the balancing manometer, the balance balancing manometer will show 0 differential head and at that position, the yaw angle, if we know and that is the reference angle of the probe. So, that is a case.

Now, what is done, manipulating the pressure taps, the value of P1 minus P2. So, now what we will do. If I go back to the previous slide, so 2 and 3 are connected to the balancing, yaw balancing manometer (())(16:01) will be probe is placed, in a jet and we can calculate the total pressure using reference pitot probe. 2 and 3 since they are connected to the yaw balancing manometer, the probe will be yawed until the, you know the differential head on, of the yaw balancing manometer is 0. And at that position, we will read the yaw angle and that is the reference angle of the probe.

Now, what I can calculate now, I can calculate the P1 minus P2 that manipulating the pressure taps and of course, P1 minus P4. So, and P1 and PT, so what I can do. Now, by manipulating the pressure taps, the values of P1 minus P2. Since, P2 and P3 are equal that is what, so P1 minus P2 is as good as P1 minus P3, P1 minus P2, P1 minus P4, P1 and PT, PT that is the total pressure that is, you know obtained using a reference pitot tube. So, these are read out from the manometer. So, this is and what this process, I mean, so what we are doing, we are placing the probe in a jet.

We are using a reference pitot probe to calculate to the total pressure, the atmospheric pressure of the jet, jet static pressure is equal to the atmospheric pressure. The probe will be yawed until the pressure at orifices 2 and 3 becomes equal, that will come to know from the differential, from the 0 differential head of the yaw balancing manometer. Once the presser at orifices 2 and 3 becomes equal, then we will read the yaw angle and that is reference angle of the probe. And at that position, by manipulating the pressure tap, we will calculate the P1 minus P2 that is what to have written P1 minus P2, P1 minus P4.

Since, P2 and P3 equals so P1 minus P2 is as good as P1 minus P3 and P1 and P2. So, we will read this reading, we will read this from the manometer. Now, the procedure is repeated for different each angle with a, in step of 5 degree and in the range of plus minus 45 degree. So, each time pressures were read only when; pressure again I am telling, so we will calculate

P1 minus P2, P1 minus P 4, P1 and P2. So, the procedure is repeated in steps of 5 degree and it is, and in the range of plus minus 45 degree. And each time, we will read, rather we will take readings when pressure at orifices 2 and 3 becomes equal.

So, now question is after knowing P1, PT, P1 minus P2 and P1 minus P 4 from the manometers. As I said, P1 and P2, this I mean 1 and 4, these 2 orifices are connected to the projection manometer, 2 and 3, these 2 orifices are connected to with U tube manometer that is balancing a manometer. Now, taking reading from this, reading of the pressure from this manometer, now we can calculate a few coefficient, that is the pitch coefficient and the total pressure coefficient. So, now what I will do, you know that this calibration and that is known as calibration. So, the calibration results are presented in terms of the probe coefficient.

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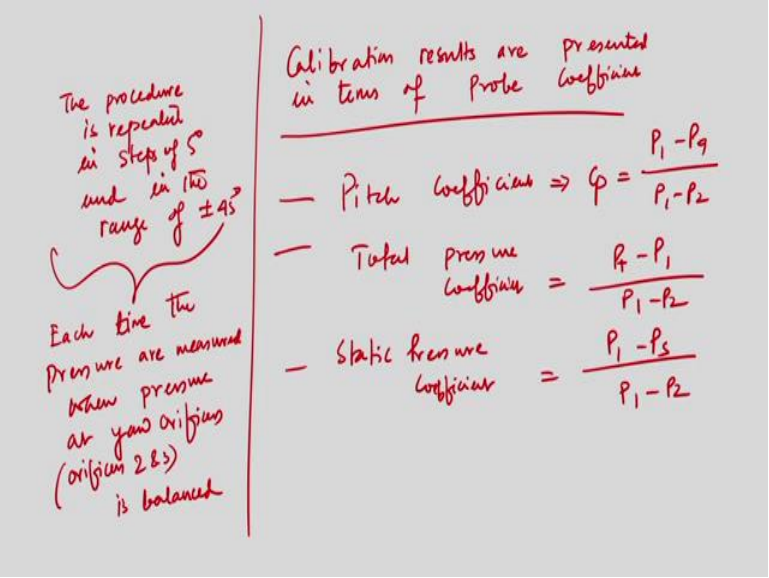

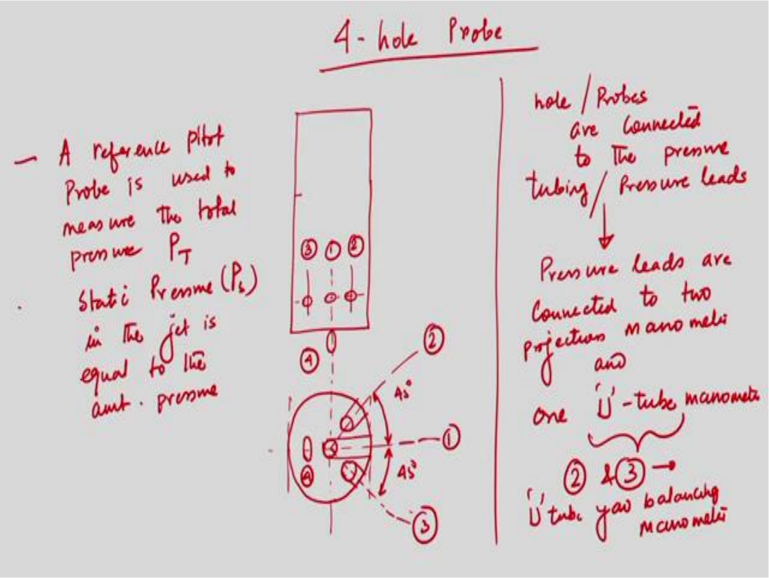

So, the calibration results are presented in terms of probe coefficient. And so, what I said, the, you know as I said that process or procedure is repeated in steps of 5 degree and in the range of plus minus 45 degree. So, and that is very important that each time the pressure are measured when pressure at yaw orifices, that is orifices 2 and 3, is balanced. So, that means this is the procedure. I do repeat again, so what are the steps, we need to place the probe in a jet, orifices pitot tube is, a reference probe is used to measure the total pressure.

Now, that is what I have written that a reference pitot probe is used to measure the total pressure, static pressure of the jet is equal to the atmospheric pressure. Now, the 1, 2, 3 and 4, they are 4 different probes, 1 and 4 these 2 probes are connected to the projection manometer. Probes 2 and 3 are connected to 1 U tube, yaw balancing manometer and these orifices are known as U orifices. What is done, after placing the probe in a jet, the probe is yawed until the pressure at orifices 2 and 3 become equal.

When the pressure at orifices 2 and 3 is equal, we just take the reading of the yaw angle and that is the, you know reference probe angle, or reference angle of the probe. And when the differential head is 0, of the differential head of the you know, yaw balancing manometer is 0, then we will come to know that the pressure at orifices 2 and 3 is equal. And that the time, we will calculate by manipulating the pressure taps that is P1 minus P2, P1 minus P4, P1 and PT. Now, this procedure is repeated in steps of 5 degree and within the range of plus minus 45 degree.

One thing we need to note that each time of the, you know calibration, we need to measure pressure from the manometer when only the pressure at orifices 2 and 3 that is at yaw orifices is balanced. So, now, this calibration results can be presented in terms of the probe coefficient. So, that means we can define a few probe coefficient and which we are, which we will write now. So, that is the pitch coefficient that is Cp and this is P1 minus P4 divide by P1 minus P2, total pressure coefficient equal to PT minus P1 divide by P1 minus P2 and static pressure coefficient, static pressure coefficient that is P1 minus Ps divide by P1 minus P2.

So, these 3 coefficients, these 3 different coefficients are calculated, rather calibration results are presented in terms of this pitch coefficient. Now, we should know, rather we need to know, knowing this pressure coefficient, how can we calculate the velocity component that is another important thing and we should know. Because using probe, we can measure the pressure and we can represent those pressure in terms of the different coefficient.

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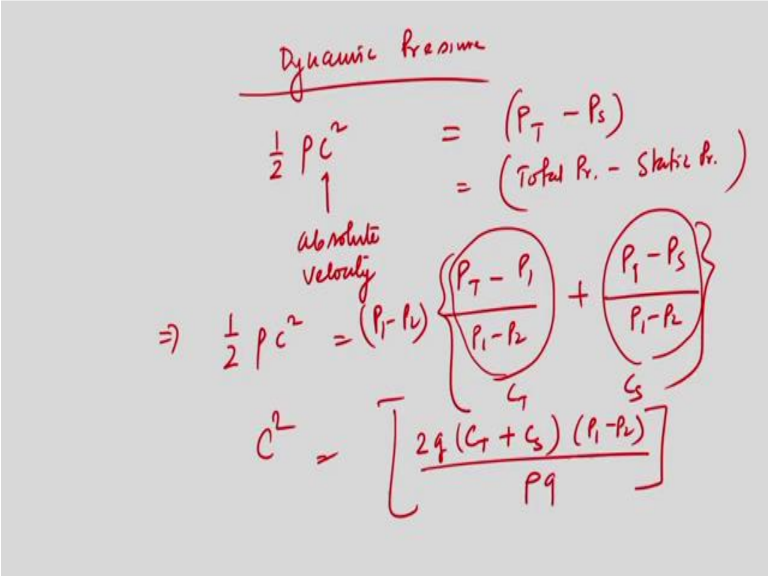

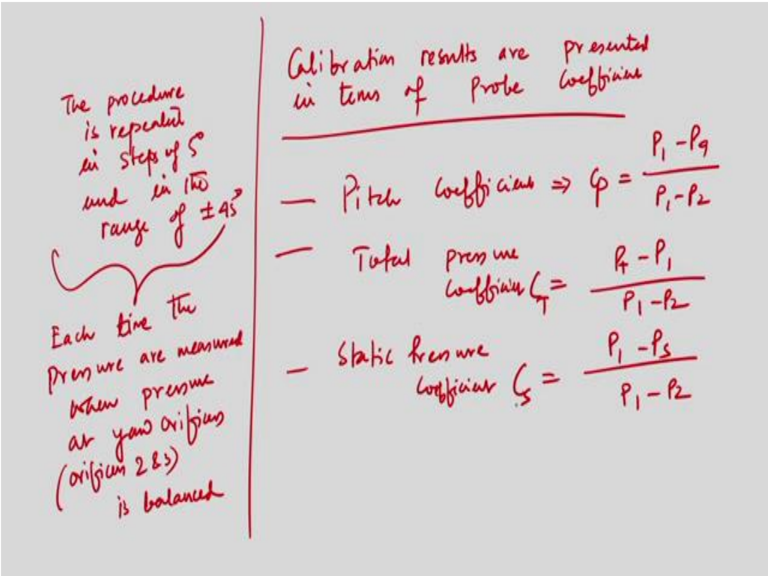

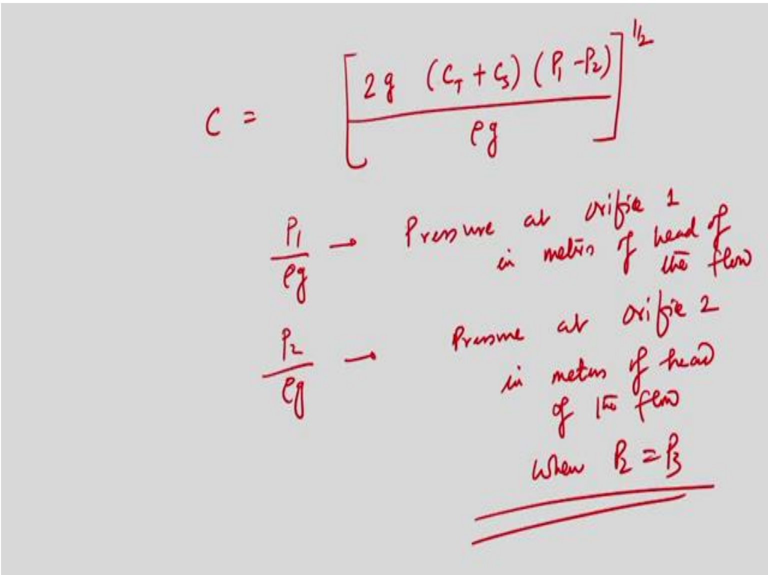

And so, now, I will try to explain how I can measure the velocity components. See, we know that the if we place the probe in the jet, so say the dynamic pressure, dynamic pressure just I am doing this, you know mathematical calculation. So, dynamic pressure, you know half rho into c squared, if c is the absolute velocity of the jet. So, c is the absolute velocity. Now, this is nothing but PT minus PS. So, this is total Pressure minus static pressure, and so we can write this half rho c squared is equal to PT minus P1 divide by P1 minus P2 plus P1 minus PS divide by P1 minus P2 into P1 minus P2.

So, this algebraic manipulation, we are doing essentially to express this, you know dynamic pressure in terms of the, in terms of different pressure coefficient that we have defined in the previous slide. So, what I can write therefore, this c, half rho c square or I can write c square will be equal to, so this is, this is, this is we have defined. PT minus P1 if I go to the previous slide, PT minus P1 divide by P1 minus, you know P2 that is, what is defined by total pressure coefficient CT and this is static pressure coefficient CS.

So, now, I can write this is CT and this is CS, so I can write 2 CT plus CS into P1 minus P2 divide by rho. So, that is we can write C square is equal to of course, so 2g I can write rho g. Now, I can write one step further that is C is equal to 2g into CT plus CS into P1 minus P2 divide by rho into g or half So, this P1 by rho g and P2 by rho g. So, these 2 terms are there I can rather we can see from this expression. So, this P1 by rho g that is pressure at orifice 1 in meters of head and P2 by g that is pressure at orifice 2 in meters of head of the flow. When P2 is equal to P3, that is very important, head in meters of head of the flow.

So, that is, this P1 by rho g that can be written the expression c, that absolute velocity can be written in terms of P1 by rho g or P2 by rho g. So, P1 by rho g that is a pressure at orifice 1 in meters of head of the flow, when pressure P2 and P3 are equal that is PT is equal P3. So, now, so what we can do that means, we can, we have calculate the total pressure, I mean absolute velocity. So, if I now draw the schematic then from there from that schematic it will be clear, knowing C, how I can calculate the component of velocity.

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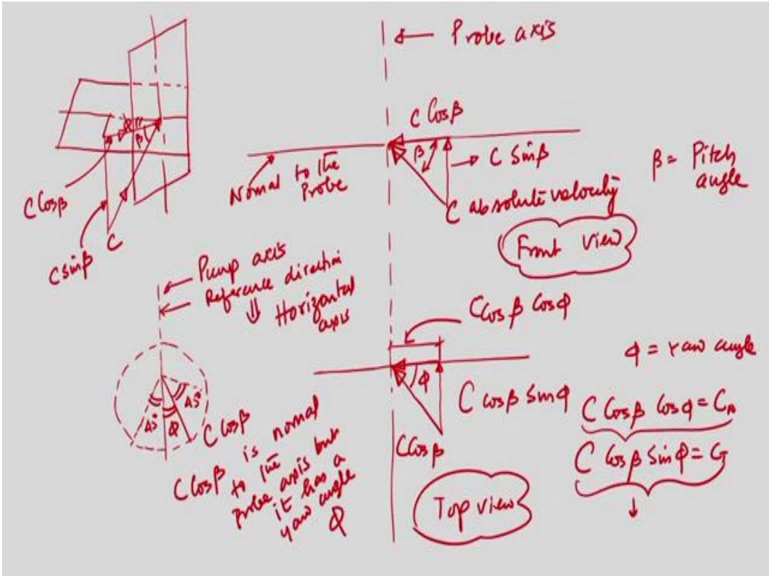

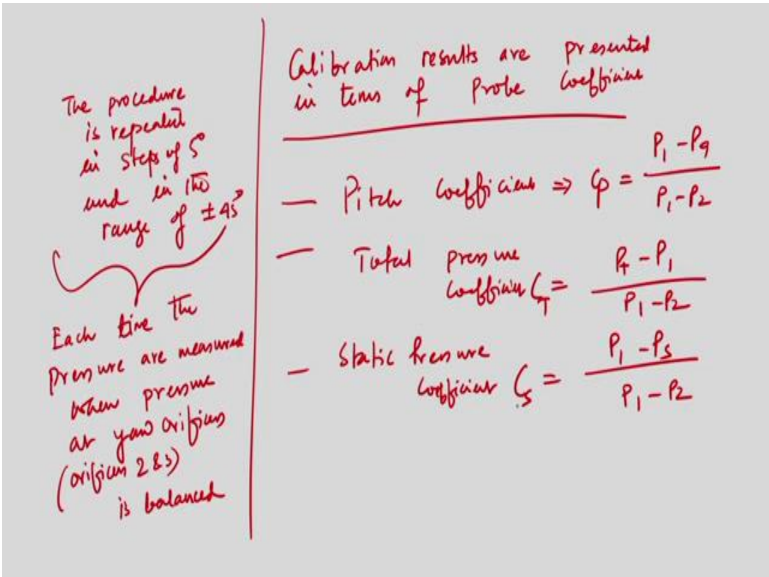

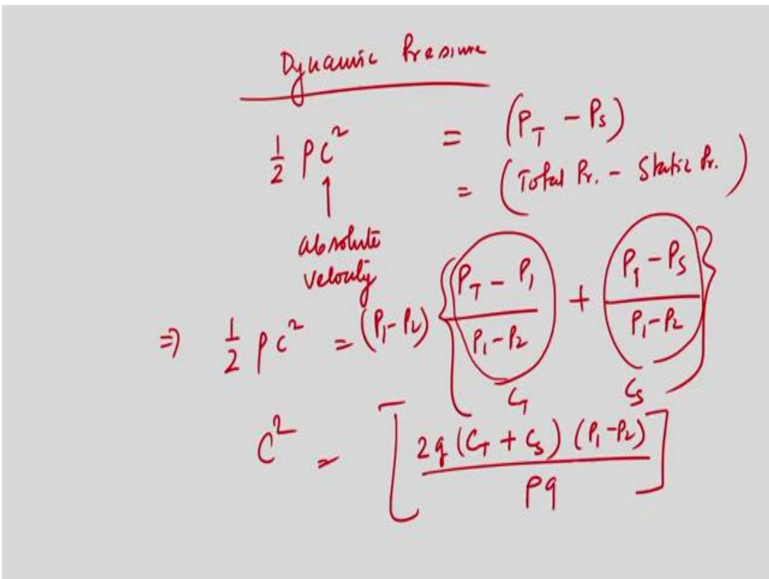

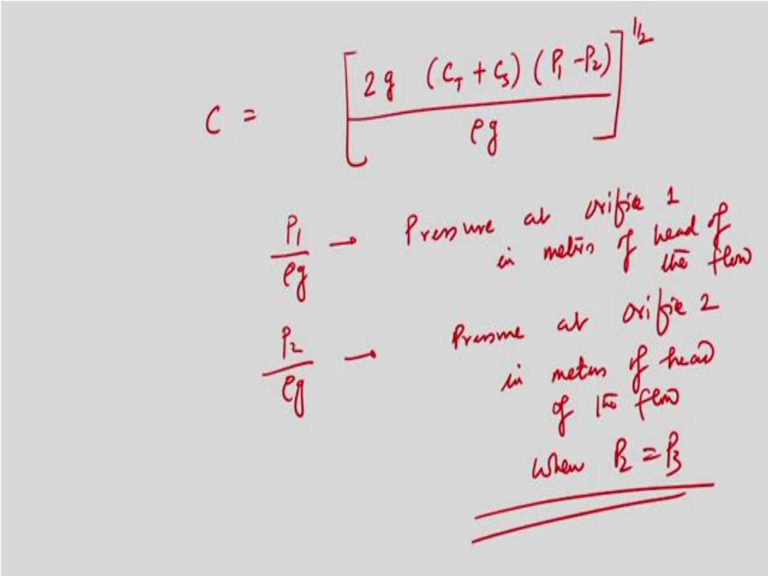

Say, this is the probe axis, so this is, so this the probe axis. Say this is, probe axis, and this is normal to the probe, normal to the probe and say the component of velocity that is C, this is C. So, this is C absolute velocity, so this is C and this makes an angle beta and this beta, this beta is known as the pitch angle. So, beta is the pitch angle. So, that is if I try to recall, that if we try to recall that the pitch characteristics of the flow, to know up to measure the pitch characteristic of the flow, we have modification of the 3 hole probe that means, the concept of 4 hole probe came into the picture.

So, the pitch characteristic of the flow cannot be measured using a 3 hole flow. So, to measure the pitch characteristics, additional hole is there and that responsibility of additional hole is to obtain the pitch characteristics. So, this is absolute velocity C, beta. Now, this component, so this is beta. Now, this component is C sin beta and this component is C cos beta. So, this is the front view. Now, if we take the top view, the top view will be like this. So, this is C cos beta. So, therefore, this will be, and this angle is phi and phi is yaw angle. So, this will be C cos beta sine phi and this component will be C cos beta cos phi.

So, this C cos beta cos phi is Cn and C cos beta sine phi is equal to CT. So, this is the tangential component absolute velocity and this is the normal component of the absolute velocity, Cn and CT. So, that means, this is the top view, so now say I can tell that, say this is pump axis, this probe is use to measure the static pressure, stagnation pressure, as well as the velocity component for a centrifugal pump.

So, I mean you are placing the probe to measure the static, static pressure, stagnation pressure and the velocity components. The static and stagnation pressure that is we have seen that is, obtained using the probe coefficient, total pressure coefficient, stagnation pressure coefficient and the static pressure coefficient. Now, say, so this is, you know pump axis or reference direction or this is reference direction. I can say this is horizontal axis and if I try to recall that, say velocity component that is C, that is C cos beta and this angle is 5 and so, this angle and this angle is 45 degree, 45 degree and I can draw like this.

So, this is the, so C cos beta, C cos beta is normal to the probe axis but it has a yaw angle phi. So, this is, I mean it would be much more clear that means, if I, so C cos beta which is normal to the probe axis but it has a yaw angle phi. So, that means, I mean I can draw the, I can draw one, another one schematic from there it will be much more clear. So, say this is, this C and this is C cos beta, this angle is beta and this is C sin beta and this C cos beta which makes an angle phi. So, this angle is phi, so this angle is phi.

So, the C cos beta which is normal to the probe axis, C cos beta which is normal to the probe axis, but it has a yaw angle phi and that yaw angle, as I said you that the, it is yawed until the pressure at the orifices 2 and 3 becomes equal. So, now, so, today what we have discuss from this chaotic, it is clear that if we can, if we place a probe in a flow field in a jet and if the absolute velocity of the jet is C.

So, using this probe, as I said that using this probe we can measure following the steps that we have discussed today, we can measure pressures that is total pressure, stagnation pressure. Also, the measured results are presented in terms of the calibration coefficient, so pressure at orifices 2 and 3 they are equal. Pressure, the orifices 1 and 4, these 2 orifices are connected to the projection manometer.

So, we can calculate P1 and P4, if we know P 2 and P 3 because that is the procedure, we need to follow, from where we can calculate P1 minus P4 and P1 minus P 2 and the static pressure of the jet is equal to the atmospheric pressure and the total pressure is measured using a reference pitot probe.

So, knowing all these pressures, we can represent result in terms of the pressure coefficient. Now, if the dynamic absolute velocity is C, then the dynamic pressure half rho C square can be represented, that is total pressure minus static pressure. And doing this, through this mathematical analysis, we have seen that the C square, the velocity component, the velocity can be represented by this form, where P1 by rho g and P2 by rho g these 2 are the pressure at orifices in meters of the head of the flow and P2 and P3 will be equal.

Now, if the C is the, you know absolute velocity and this, you know, 2 different, you know that is front view and top view, we have shown the velocity components, from there it is clear that if the C is the velocity of the jet and it has a component C cos beat, which is normal to the probe, but this is also has the C cos beta has another component that is, but with an, the C cos beta makes an, you know C cos beta has a yaw angle phi.

So, C cos beta can be decomposed further 2 components, that is C cos beta sine phi and C cos beta cos phi. This C cos beta cos phi, that is the normal component and C cos beta sine phi is the tangential component of velocity. So, knowing the jet which is you know, within the turbo basis in the centrifugal pump by placing the probe, we can calculate the velocity components. So, if you know the velocity components from there you also can calculate the, what will be the flow rate.

And if we calculate the flow rate and by knowing the velocity components and if you theoretically whether the fluid from the pump, we can check whether the calibration results are correct or not. That means, by knowing the measurements of different pressure, we can calculate the different velocity components following the state which we have discussed today, and knowing the velocity components we can calculate flow rate.

Now, the mathematical calculation of the flow rate, once we know the velocity components will be compared with the fluid delivered by the pump and if we find a closer match, then we can say the calibration results are correct. So, this probe are important instruments, rather I can say the multiple probes are important instrument to measure the static pressure, stagnation pressure as well as the velocity components in places where velocity fluid is highly 3 dimensional. And I mean, which is also very close to the solid boundary.

So, to summarize today's discussion, we have discuss about the operational principle of the multiple probes in one of my previous lectures. But today we have discuss about the procedure by how we can calculate the velocity components by measuring the pressure using multiple probes. And knowing the velocity component, we can check whether the velocity component, measured velocity components using this probe is correct or not. And for that, we can calculate the flow rate and that flow rate will be compared with the actual flow rate that is delivered by the pump.

So, with this I stop my discussion today and we will continue our discussion in the next class. Thank you.