Experimental Methods in Fluid Mechanics
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Lecture 30
Constant Temperature hot-wire anemometer, LDA

Good morning, I welcome you to this session of Experimental Methods in Fluid Mechanics and today we will try to discuss about the measurement techniques which are used to, which are used for the chaotic flows that means, the techniques which are used to measure flow parameters for the chaotic flows and while we are, you know trying to, you know, know the measurement techniques typically used to measure the flow parameters in a chaotic flow environment.

We will be focusing our discussion on the constant temperature hot wire anemometer and the LDA and in fact, if we try to recall that these two measurement techniques that is the you know, constant, hot wire anemometer, that is thermal anemometry as well as you know the laser doppler anemometry we have discussed in the context of flow parameter measurement in the previous classes.

And today, we will try to recapitulate those and rather we will try to focus our attention that I mean, on a particular, we will focus our attention on a particular you know, aspect. That these techniques can be used to measure the, you know, flow parameter which are associated with the, which are used to, which are, you know, important for the chaotic flow environment?

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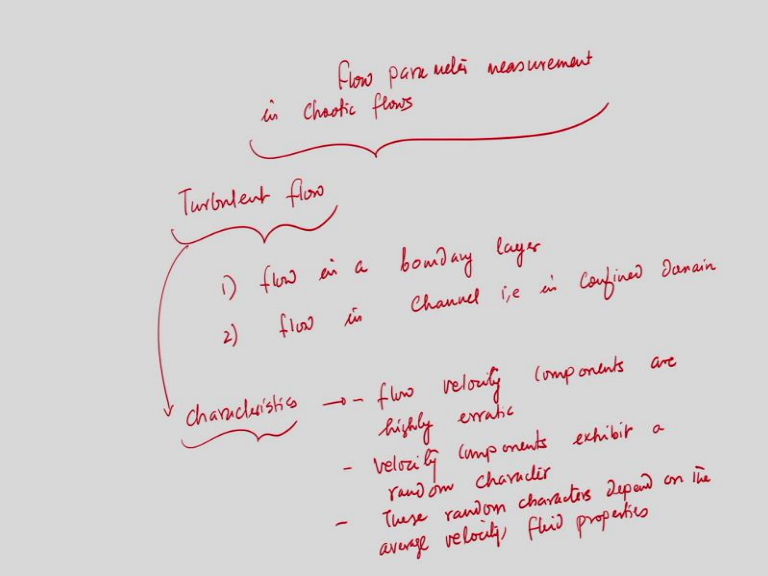

So, we will start our discussion with the, you know, flow parameters measurement in chaotic flows. In particular, we will try to you know, discuss that if we are interested in measuring the flow velocity in a turbulent flow. Then what are the techniques available? We have discussed that for the measurement of velocity, measurement of other flow parameters and also the flow streamlines, we can use different instruments and those aspects have been discussed in a greater detail in the previous classes.

But today we will try to focus our attention on the turbulent flow. Turbulent flow that means if the flow is turbulent, then I mean, if the flow is turbulent then, how can we measure the turbulence characteristics? That means, we know that the turbulent flow which is, which is maybe the flow, in a boundary layer or the flow in a channel that is in confined domain.

That means if the flow in a boundary layer or if the flow in a channel that is in a confined domain. Then if you would like to measure, if we are you know interested in measuring the turbulent flow characteristics. Then what are the techniques available and specifically we have mentioned that the hot wire anemometer and the laser doppler anemometry can be used.

So, in these, in these two cases that is flow in a boundary layer or flow in a channel that is in a confined domain, the flow characteristics, I mean typically the flow velocity, you know components are highly erratic not, you know. The flow velocity is not I mean I can say uniform in the domain, they are highly erratic and the velocity components. Since the flow velocity is highly erratic, velocity components exhibit, you know, I can say random character.

So, this and this random, this random characters depend, depend, the random characters depend on the, you know velocity. I can say average velocity, average velocity and other fluid properties. That means, the turbulent flow which is characterized by its randomness. It is highly chaotic, highly erratic velocity components exhibit a random character and this random characters depends upon the average velocity, fluid properties like fluid density viscosity, that we have studied in our undergraduate fluid mechanics course.

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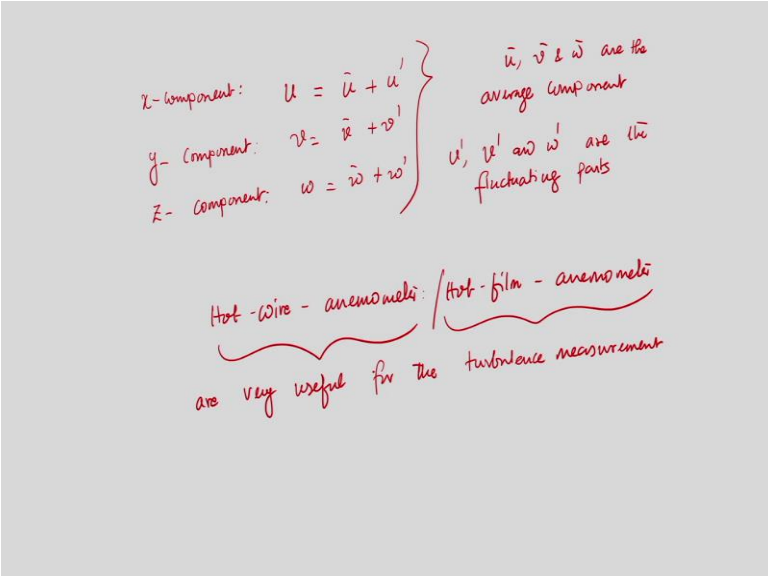

So, if we try to recall that, that the velocity component in the turbulent flow environment can be represented that is u bar plus u prime that is of course, the x component of velocity. So, this is x component velocity. Similarly, y component velocity v equal to v bar plus v prime and z component velocity that is w bar plus w prime.

So, the velocity components in a turbulent flow can be characterized by two different parts. One is the average components, one is the average component that is the, you know u bar, v bar and w bar are the average. While u prime, v prime and w prime are the fluctuating part.

So, what we can see from this, we have studied this in a greater detail in our undergraduate fluid mechanics text, fluid mechanics course. So, the turbulent flow can be characterized by two different words, one is the average component other is the fluctuating component. So, the measurement of turbulent flow parameter, I can say the velocity components and other parameters is not so easy.

So, it involves the measurement of turbulent flow properties involves complicated, you know measurement techniques methods and but we will see that if we are really interested in measuring these average as well as the fluctuating parts then how we can measure. So, that is the important part.

Now, if we try to recall that the hot wire anemometers. That is I have discussed in the context of flow parameter, flow measurements that is, there are, you know that, in the context of thermal anemometry. We have seen that the thermal anemometry is again the measurement technique essentially to measure flow velocity by measuring the heat transfer that you have discussed and the thermal anemometry that is there are two different methods that is the hot wire or the thermal anemometry uses hot wire and hot field method to measure the flow velocity.

So, the hot wire anemometer is used to measure the fluctuating components, components of velocity. So, I am not going to discuss in detail about the averaging and other important aspect of the turbulent flow. But at least we this is good enough to understand that when you are looking for the turbulent flow properties, components of velocity in a turbulent flow environment, we need to measure the average as well as the fluctuating part.

So, time average and the you know space average, this are discussed in detail in the context of turbulent flow course, also in the I mean briefly discussed in our, in the undergraduate fluid mechanics course. But what is essential to know in this context is that, in a turbulent flow environment, we need to measure the fluctuating parts and different components. So, it is not a case that we will have only the unidirectional flow and we need to measure the flow components as well as the fluctuating parts.

So, this hot wire anemometer that we have discussed in the context of thermal anemometry either hot wire or hot field anemometer, these two methods are very useful in, very useful for the turbulent, for the turbulence measurements. So, if the flow is turbulent, then these two defined methods are used.

I cannot say these, only these two methods are used. There are many other methods, sophisticated methods are available, you know in todays experimental paradigm, experimental (())(13:03), you know fluid mechanics paradigm. So, these two methods are very useful for the turbulence measurement. That is what we have discussed in the context of flow measurement and just today we will try to see how we can really measure this turbulence using the, this technique.

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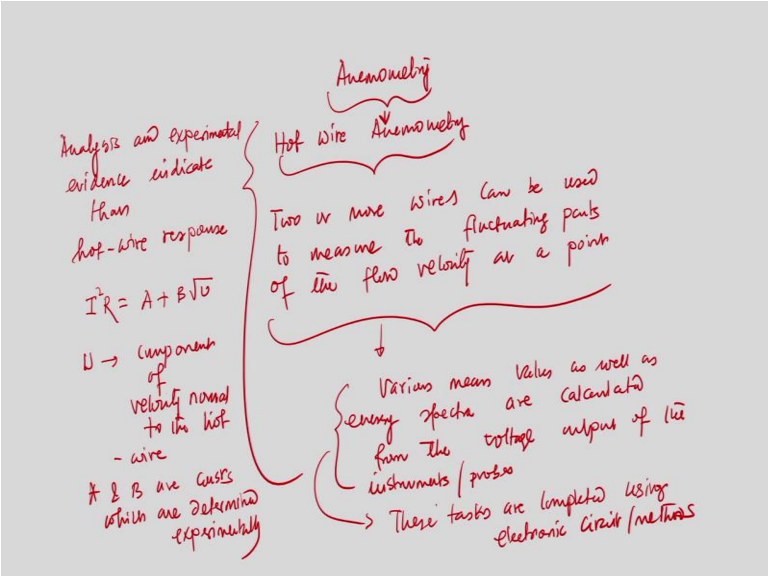

So, if we go to the next slide and if we try to recall that anemometry. In particular, hot wire anemometry. So, this hot wire anemometry, these, this, you know instrument can be placed in a flow field to measure components of fluid velocity. That is what we have, you know, discussed in a context of our flow measurement module. Now, if we try to recall that this hot wire anemometry what we need to do? Two or more wires can be used to measure the, you know, fluctuatings parts of the flow velocity at a point.

So, this is what we have seen and just to you know, you know briefly recall that hot wire anemometry, you know the, this instrument relies on the measurement of heat transfer to correlate the velocity. So, if we can recall that analysis and experiments that is what we have written that analysis and experiments you know.

I can say experimental evidence indicate that the hot wire response is given by that I square R heating that is nothing but A plus B route U. So, this is the component of velocity, where this U is the component of velocity normal to the wire, hot wire I can say that is the hot wire and A and B are constant, constants which are determined experimentally.

So, that is what we have discussed. So, the component of velocity normal to the hot wire that is U that will be measured by measuring the heat, you know heat transfer that is I square R heating. Now, question is if you use this hot wire anemometry, then of course, the various mean values as well as energy spectra are calculated from the voltage output of the instrument probes. That means, I square R that is essentially to need measure the current and resistance. So, these that means, we can you know, what will be the voltage?

So, the voltage output, voltage output of the probes are used to calculate the various mean velocities as well as the energy spectra that is, what is the, you know basics of this measurement technique and of course, this performance and this task, this, this is, this task I can write, completed using electronic, using electronic circuit methods. So, these perform I mean these task are completed.

So, what we have understood that now question is. So, we have also discussed that hot wire if we put in a flow field, this is a probe it will definite lead in a placing of a probe will try to disrupt the flow field that you are, that you also have discussed.

Now, by measuring the, you know, I square R heating we can directly correlate the velocity that, that is the velocity which is normal to the hot wire. Now, if we can place two or more wires at a, you know, at a particular point. So, by measuring the normal component of velocity by two, three wires, we can measure the components of velocity at that particular point.

So, that is nothing but the measurement of fluctuating parts or their components of velocity at a particular point if the and of course, if it is the turbulent flow. Then there will be you know chaotic, erratic. So, it is not expected that the streamlines will be perfectly parallel, rather we will have a fluctuating component.

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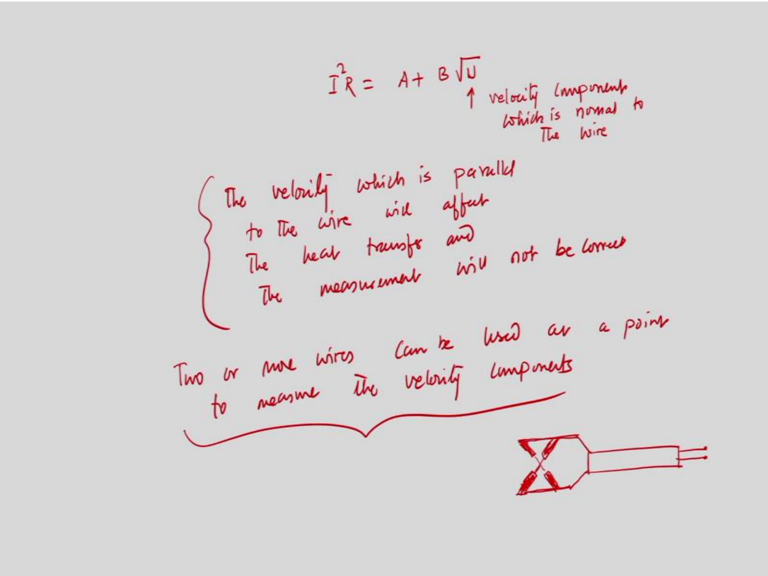

So, if we try to recall that, this I square R that is nothing but A plus B route U. Where U is the velocity component that is again, I am writing, velocity component which is normal to the wire. So, if we can place not only, I mean we can keep two, three wires and not only the case if we place this particular probe, if the probe is having only one wire. Now, if we place the probe in the flow field and the flow field is really you know, you know I can say turbulent then what will happen.

So, if we, if we place the probe, where the probe is having only one wire, then the flow field is highly chaotic. So, it is highly you know, unexpected that the measurement using this flow will give only the flow velocity. So, that means what I would like to say that if we, if we place this probe, then the velocity component. The probe will measure only the velocity which is normal to the wire. But it is not expected, it is highly unexpected rather that the velocity, the component will have only one normal component.

So, there will be velocity which is parallel to the wire. That means, it is highly chaotic, erratic. There will be different, three different components of velocity. So, velocity which is parallel to the wire will, you know affect the heat transfer and the measurement will not be correct.

That means, I would like to say that in a turbulent flow environment. There will be three different components, fluctuating components. So, instead of using one wire, we can use two or more than wire. So, that means two or more wires can be, you know, used at a point, you know to measure the velocity components and that is what in fact we have discussed that.

Typical example I can, show you that we have you know. So, these two wires are kept right angle to each other. Now, this two wires arrangement can be used to measure two different components. Similarly, by suitably arranging three different wires, this probe can be placed in a flow field and if the flow field is highly chaotic the velocity components can be measured simultaneously at a particular point and we can use this probe for the measurement of the turbulent flow.

So, this is what is the basic principle, basic technique of using hot wire to measure the flow velocity components in a turbulent, turbulent flow environment. I am not going to discuss in detail about the, you know hot wire and hot field measurement techniques that we have discussed in the context of flow parameter, flow measurement.

So, next would like to see that, we can use this you know hot wire anemometry to calculate the flow velocity in the context of turbulent flow, in the area of turbulent flow. But, you know, I would like to say that, in fact we have discussed many times. That when we are placing any object in a flow field, then the placing of that particular object maybe it is a probe.

That is hot wire or hot (())(52:55) anemometer or any pitot tube, pitot static tube. So, any object even if it is thermometer that we have discussed in the context of temperature, pressure as well as the velocity measurement. So, if we place any object in the flow field, placing of that object into the flow field or in the flow field will leads to the disturbance, will create a disturbance in the flow field.

That means, we are inserting a probe to measure a particular flow parameter. But we need to be careful that, that placing of that particular instrument in the flow field will definitely alter the flow dynamics and as a result of which the measured quantity, I mean using the particular flow may not be the correct one. So, that means the, you know experimentalist user of that particular instrument should be careful using the tool in a particular, in a flow field.

So, it is seen that any mechanical object as I said maybe it is a probe or a thermometer or sometimes, we are placing pitot static tube or pitot tube. So, whatever will be the instrument and measurement methods the placing of a particular probe in the flow field will disturb and as a result of which, our I mean our objective of measuring a particular quantity, I mean will be I can say erroneous.

So, to circumvent this problem, in particular I can say in the context of turbulent flow that is very important. Instead of putting a particular probe, it is, nowadays, sophisticated methods are available. Wherein, the flow visualization techniques are used by you know, you know, by I can say, allowing light to pass into the flow field by, you know, using any source to you know, using optics and other you know, sophisticated methods.

So, the object is that instead of putting the probe into the flow field, if we try to visualize the flow field using, nowadays, you know sophisticated optical tools are available. So, using light to be precise. So, using light, if we can illuminate a particular joining the flow field and from there if we try to obtain, if we try to quantify the flow parameters, flow field either quantitatively or qualitatively that will be, you know, very correct information as compared to the conventional method of using in any particular flow.

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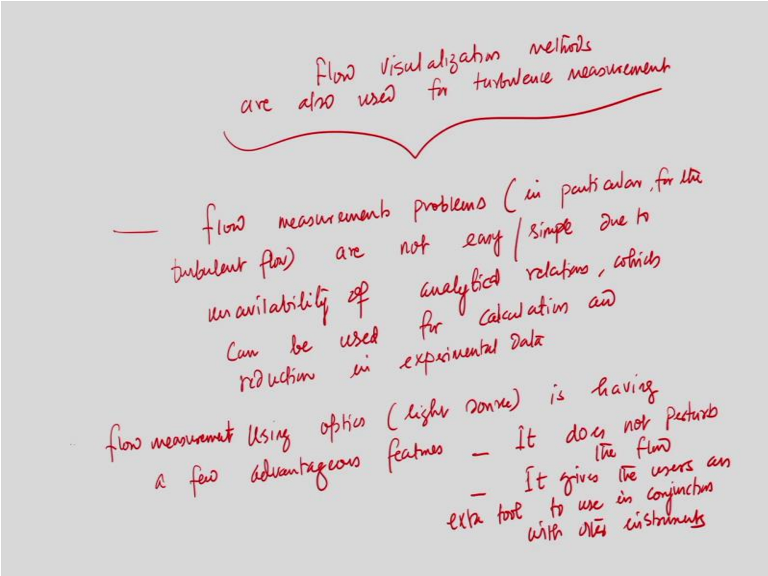

So, this flow visualization methods, this flow visualization methods are also used for turbulence measurement. So, that means, instead of putting the probe into the flow field we can illuminate the flow field using light source, using sophisticated optical instruments, optical platform. We can visualize the flow domain and from there we will try to correlate the flow parameters, even if the flow field is, you know turbulence. So, this is very important.

Now question is that fluid flow, if we try to recall in our fluid mechanics knowledge that we have studied from our fluid mechanics course, undergraduate, postgraduate that, it is very difficult to have, you know I can say analytical solution of a three dimensional flow field and because of this unavailability of unique solution of the three dimensional flow field flow structure, it is very difficult to you know correlate to measure the flow parameters in the turbulence measurement.

Because in a turbulent flow, since the flow parameters flow velocities, you know flow other fluid properties are highly you know, chaotic I mean, I mean velocities are you know I, it is unexpected that we will have only unidirectional flow. So, velocities are always three, I mean, flow field is always three dimensional.

So, in the context of turbulence flow measurement, it is highly unexpected that we will have a unique solution and we can compare our flow visualisation, you know result with the unique solution. So, what I would like to say and because of this complicated problem, that the analytical solution is not available in the context of turbulent flow, where flow field is highly three dimensional.

Since no analytical techniques, I mean is you know present even todays scenario. So, we cannot compare the results which you are getting from the flow visualisation techniques and we can certify that the flow which you are visualizing using sophisticated optical tools is correct or wrong.

So, this is very important that means, flow, I am writing flow measurements problem. In particular, for the, in particular in a turbulent environment, flow measurement problem in particular for the turbulent flow are not, I can say easy, simple due to unavailability of analytical relation, which can be used for calculation and reduction in experimental data. So, this is, although the flow visualization techniques can be used, which can be used I can say to avoid, to circumvent the problem associated with the, you know placing of a probe in the flow field.

But, again using this technique since analytical solutions are not available in particularly for the turbulent flow, you know cases and because of this unavailability of analytical relations, which can be further used to correlate the result and reduction, the experimental data, the flow measurement techniques, even for the turbulence measurement, I mean are not very simple and very easy.

But I can say if we compare the, this particular technique with the other available techniques, using optics that is light source, light source is having that means flow measurement. I can say the flow measurement using optics is having a few advantages features. What are those? Number one, it, you know I can say that does not part of the flow.

Number two is it gives the users an extra tool, extra tool to use in conjunction with other instruments. So, although the measured data, experimentally measured data using optics light source cannot be, you know I can say compared to the three. I mean, you know, analytically calculated results.

Because for the three-dimensional solution and you know turbulent, you know turbulent flow environment. Since the flow field is highly chaotic. But even then, the optics that means the use of light to visualize the flow field, to measure the flow parameters is having a few, you know advantages features that is, it does not disturb the flow field. So, it is you know, advantages from that perspective and it gives the user an extra tool at least to use in conjunction with the other instruments.

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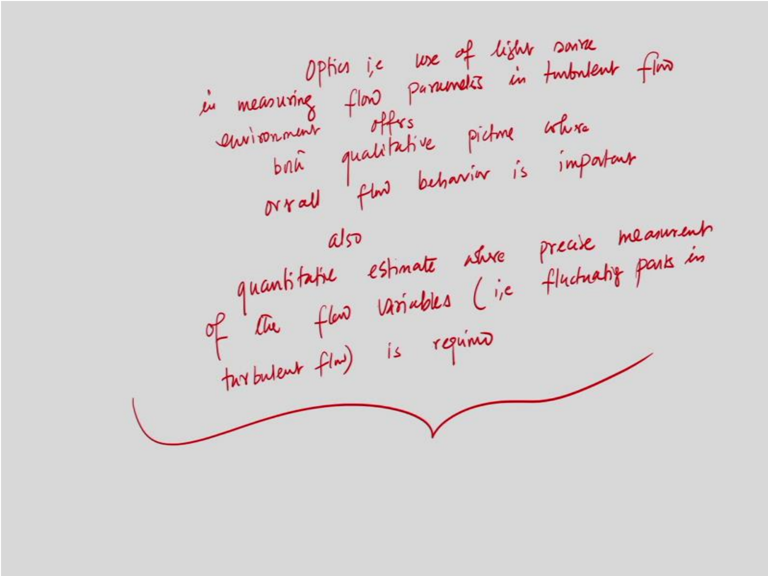

So, now, if we write that this optics, optics that is, that is use of light source, light source in measuring flow parameters in turbulent flow environment, offers both qualitative picture, this is very important, both quality picture, where overall, you know, flow behavior is important. Number one, also quantitative estimate where I can write you know precise measurement of the flow variables. That is for the turbulent flow, that is the fluctuating parts in is required.

So, these two are important that means, maybe we can use optics. Although the you know analytical solution is not possible. But What at least we can, we can use analytical solution are not there for the three-dimensional flow field turbulent flow environment. Still we can use this optics as you know and it is having a few advantages feature as compared to the other methods and it can provide both qualitative as well as quantitative picture in two different scenarios.

That means quality picture, where overall flow behavior is important. As well as the quantitative picture or estimate, where the precise measurement that is the fluctuating components are important and that is important in the context of turbulence measurement. Now, using light, one method is which is available and we have discussed in the context of our, you know, flow measurement module.

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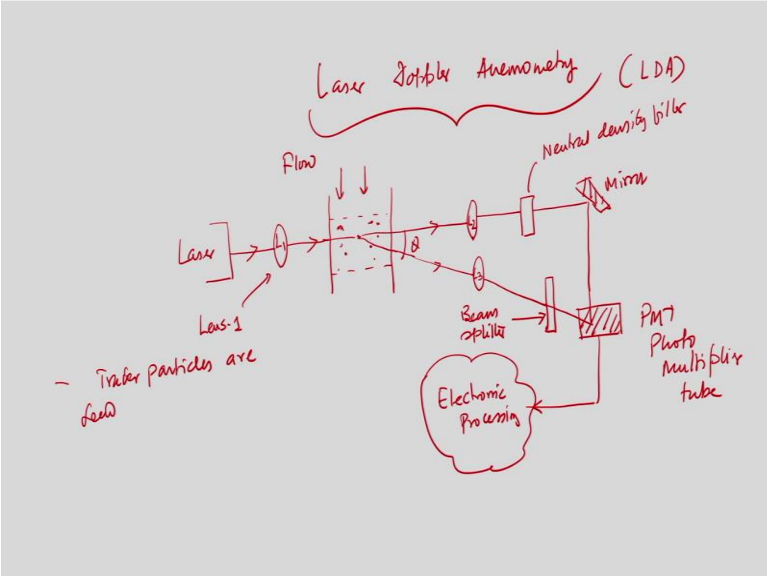

That is laser doppler anemometry. So, this is LDA in short. So, just I will try to recapitulate briefly. In fact, we have discussed in detail about this laser doppler anemometry. What we have seen that a laser source, I mean a light source, which is used, laser is used to sub provide monochromatic light and the flow field, a part of the flow field is illuminated by the laser source.

And we have discussed in detail about that, the flow field is now seeded with you know tracer particles and the particles which are seeded in the flow field will have a few properties. We have discussed those aspects in details and just we will try to do you know briefly recapitulate what we have learned.

Now, laser doppler anemometry is that again, we have discussed that it uses light source to illuminate a particular portion of the flow field, where the flow is having a few tracer particles I mean that those are seeded. Now, the tracer particles also will try to move and the tracer particles properties are such that they will try to follow the bulk flow and when the tracer particles are flowing that means the particles will try to, largely try to you know follow the, you know, fluid velocity.

Now, when the light is falling on the fluid, on a particular flow field, on a particular portion of the flow field. Then the tracer particles will get illuminated and that is what we have discussed in the context that we can scatter the light and also some portion of the light will be transmitted directly. From there we have tried to you know understand what is known as doppler shift and using this method we have obtained the flow velocity components.

So, we will try to briefly recapitulation what we have learned from you know there. That maybe we have a flow field. Now, if we provide one laser source and you know light is you know, taken through a lens L1. So, this is lens, lens 1 and light you know is now. So, this is the zone of our interest. So, light is coming over here and light is, the fluid is having. So, the fluid is flowing maybe from top to the bottom. So, this is flow direction, the fluid flow field has some tracer particle.

Now, there will be, the since the light is now falling on the tracer particle the light will be scattered but some portion will be transmitted. So, light is coming, portion will be transmitted directly. But as some portion of the light will be scattered at an angle theta, at an angle theta and it is again taken to the lens and finally taken to the beam splitter. While the light which is getting transmitted that is again taken through another lens.

So, this is L2, this is L3 and it is taken through the, you know filter, which is known as neutral density filter and light is you know the mirror is there and these two, which is you know coming from these you know, transmitted light and this is taken through the beam splitter, splitter and these two lights are taken into the photomultiplier tube.

So, this is PMT. So, this is photomultiplier tube that is what we have discussed in the context of our flow module and this photomultiplier tube from there, we take for the, you know in the domain that is for the electronic signal processing, processing. So, this is, you know beam splitter.

So, this is what is the circuit? We have discussed. I am not going to discuss. So, laser is used to illuminate a particular portion of the flow field that is a zone of interest and light is taken through a lens essentially to focus a particle. So, this lens L1 which is used to focus a particular portion of the flow field and the flow field is having a few tracer particles and the tracer particles. So, these are the tracer, flow you know, you know flow I mean tracer particles are seeded, tracer particles are seeded, tracer particles are seeded in the flow field.

Now the particles when the, you know, when the fluid is flowing from top to the bottom, we are illuminating a particular portion that is our zone of interest. So, the tracer particle will try to scatter the light and the scattered light is coming at an angle theta, at an angle theta and it is again taken to the lens through beam splitter into the photomultiplier tube. While the transmitted light that will directly go through another lens L2 and ultimately a neutral density filter and it is taken through mirror into the, you know photomultiplier tube. Two important things are they are here.

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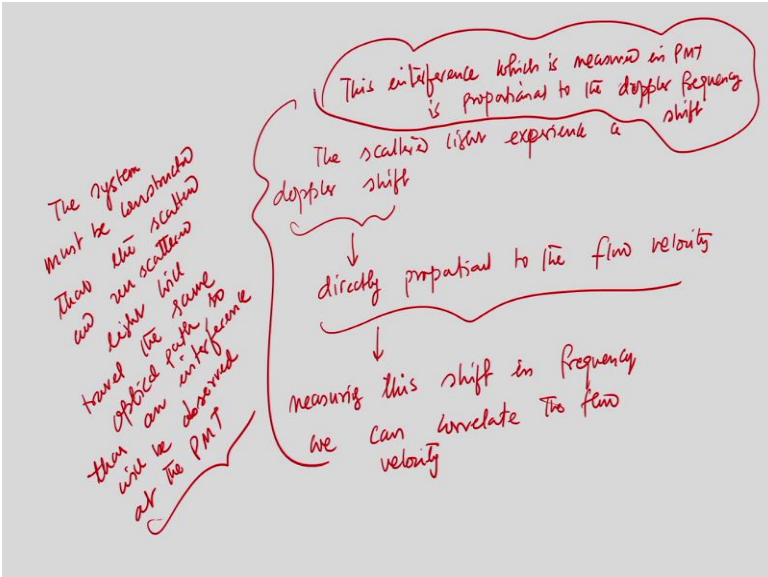

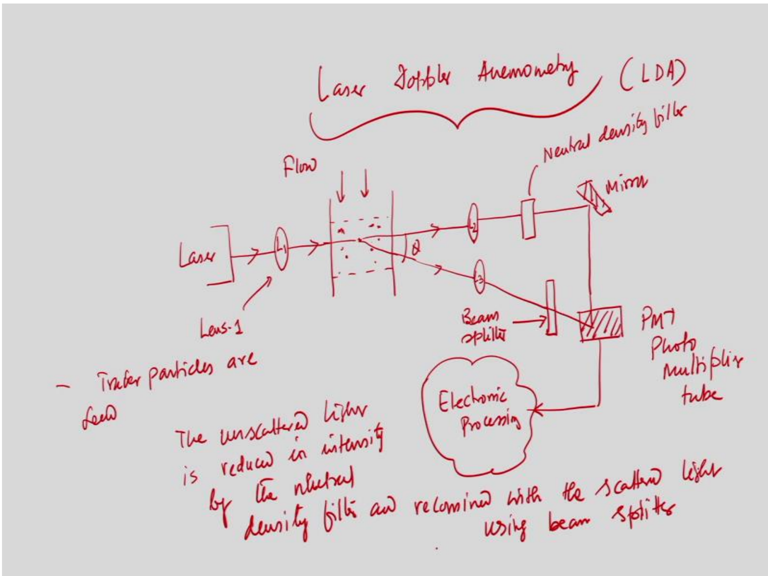

So, I like to say that. So, the scattered light, the scattered light now experience a doppler shift and this doppler shift is directly, you know proportional to the flow velocity. So, if we go to the previous slide, the unscattered light, unscattered I can say, unscattered light is reduced in intensity by the neutral density filter, by the neutral density filter and recombined with the scattered light, scattered light using these beams filter, using you know, using under the combined with the scattered beam to the beam splitter, to the beams splitter. So, this is what is done.

Now, so that is very important. So, this shift is directly proportional to the flow velocity. That means, by measuring this shift in frequency to be precise that is what we have discussed. I am not going to discuss in detail again by measuring the shift in frequency that is doppler shift. We can correlate frequency, we can correlate the. So, the scattered light experiences doppler shift which is directly proportional to the flow velocity and measuring the shift we can correlate frequency, we can correlate the flow velocity.

One important point that should be you know important that dopplers shift. So, the system, the system must be constructed that this scattered and unscattered, light will travel the same optical path. So that, so that the, you know, an interference will be observed at the PMT and this interference and this which is measured in PMT is you know which is measured in PMT is proportional to the you know, doppler frequency shift. So, this is very important.

So, the system should be in construct in such that the scattered, unscattered highlight will travel the same optical path. So, that the PMT will have an interference that will be measured in the at the PMT and the interface that is measured with the PMT is proportional to the doppler frequency shift and the shift can be correlated to the flow velocity.

Because the particle which are seeded are neutral (())(52:53) that will largely follow the bulk flow, not only that, the particles are very small. So, you know, that is very important to mention in this context that the particles are very small. So, that the slip of liquid and the solid, which is very small and negligible and we can ignore.

So, this is very important to mention over here that the, you know, the particles are so small that the slip of velocity between the, you know, I mean slip velocity. That is that you know I can say fluid slip between the solid and fluid is very small and we can ignore. So, we can say that the, you know adequate information about the fluid velocity can be obtained by knowing these frequencies shift.

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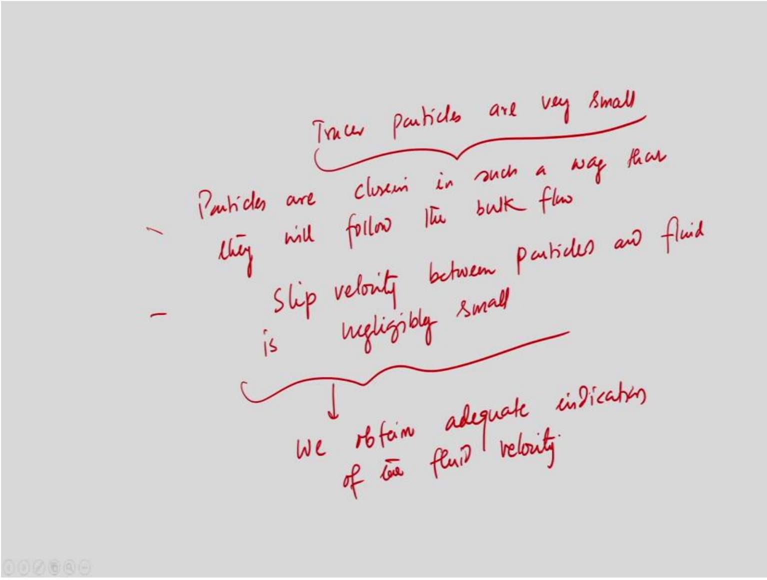

So, I am writing this is the last important point that the tracer particle are very small. The particles are chosen in such a way that, they will follow the bulk flow and the is important is that, the slip velocity, the fluid slip between the particle, between particles and fluid is very small or I can say is negligibly small. Thus, since this is true, thus and we obtain adequate indication of the fluid velocity.

So, that means the by shifting, by measuring the doppler shift and of course, we need to analyze using sophisticated electronic circuit. We can calculate, we can correlate the fluid velocity that is obtained using this method. Sophisticated, using sophisticated optical tools, it is highly possible to measure three different components in the turbulent environment using this technique.

So, this LDA that is a laser doppler anemometry which largely relies on the, you know doppler frequency, which is measured at the photomultiplier tube. The photomultiplier tube is now responsible to correlate the shift in frequency to the flow velocity and we can you know obtain the flow velocity components, even in the three dimensional, even in the turbulent flow environment, where flow field is highly three dimensional.

So, to summarize todays discussion we have discussed about the flow measurement techniques which are largely used in the context of, you know, turbulent flow environment and we have tried to recapitulate that whatever, hot wire anemometer which is used to measure the components of flow, you know flow velocities, which are there in the turbulent flow environment and also we have tried to recapitulate what we have learned from our LDA module.

That laser doppler anemometry which is used, which can replace the you know, conventional methods. That means the problem associated with the conventional method that is, if we would like to place a probe in the flow field. Then we will have problem, but that problem can be rectified using these, you know, optical techniques and this LDA which is can, which can be used both qualitatively and quantitatively to measure the velocity components even in the turbulent flow environment. So, with this I stop my discussion today and we will continue our discussion in the next class, thank you.