# Fundamentals Of Particle And Fluid Solid Processing

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## Lecture - 10
## Fluid - particle mechanics (Contd.)

Hello everyone, welcome to another class of Fundamentals Of Particle And Fluid Solid Processing. Today, we will see the overview of whatever we have covered till now for the couple of last lectures, that this Fluid particle mechanics and specifically our interest was when the flow was around the immersed bodies.

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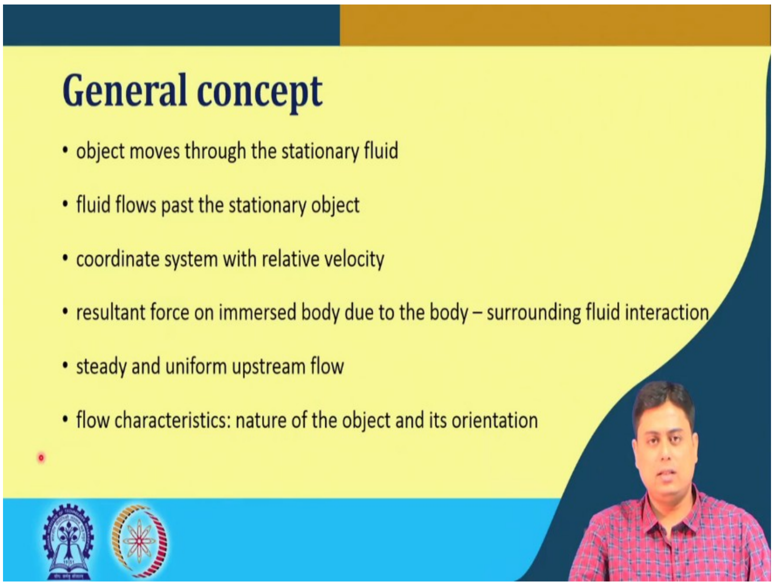


Now, we have seen several things, this lecture will serve kind of a overview to the all the things that we have covered till now, for this section. And it will summarize our understanding and will at the end I will pose some question, that you should think over it and I have already answered that during my this lecture.

So, the point is that the object when there is a flow around object, there can be 2 scenarios. The object moves through the stationary fluid or the fluid flows past the stationary object. So, both the scenarios the things can happen that we can fix a particular coordinate system with the relative velocity, where eventually the systems becomes that there is object around which flow is happening.

So, again the two scenarios are there one let say stagnant or the stationary pool of liquid, where a particle is falling. So, that is the example of object moves through stationary fluid. And the other scenario can be that the fluid flows past the stationary object. So, let say there is a flat plate, we have seen this example and wind stream is flowing over that flat plate.

So, in both the cases the objective is to calculate or to understand the drag that acts on the plate or the object, how the fluid behaves around that object, how the flow behavior happens and specific interest is to calculate the drag force ok. So, basically we can fix we can determine a coordinate system, but defining relative velocity.

So, that all both this systems can be determined by the problem of flow past an object. Now, the point is that so, here there is a resultant force on a immersed body, due to body and surrounding fluid interaction or the object and the surrounding fluid interactions. Now, in all the cases that we have I mean seen till now or in fact, that all this understandings are basically based on the one of the vital assumption, that the flow upstream flow is steady and uniform ok.

So, if you remember the flat plate example, there was an upstream velocity of the fluid, where we have assumed that the flow is steady and coming on to the plate with an uniform velocity profile. So, this flow characteristics around the object we have seen, depends on the nature of the object that its shape size and other vital thing is its orientations.

So, depending on that several flow characteristics will be there and accordingly we have to find out that, what is the drag force or how the drag force behave on that when a fluid flows over that particular shape object.

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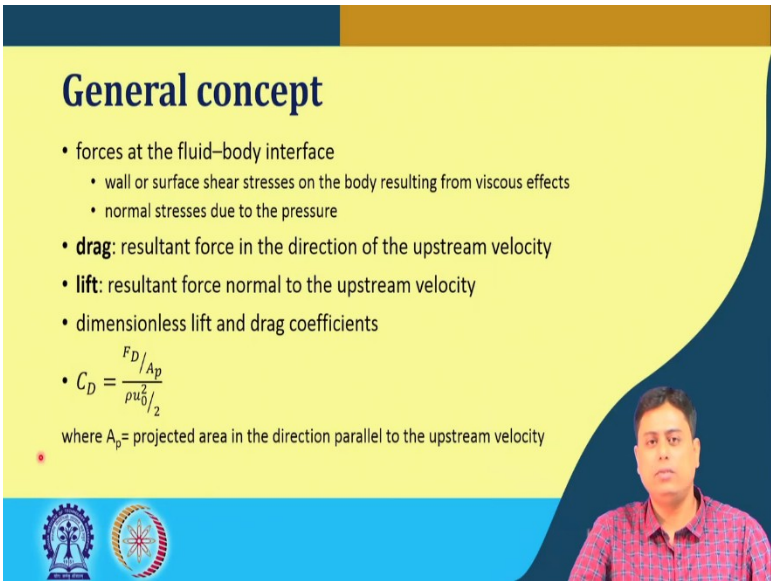


So, the forces that acts on the fluid body interface are principally two type of forces; one is the wall or surface shear stresses that on the body resulting from the viscous effect ok. This is mainly due to the fluid viscosity, that gives us the wall or the shear surface shear stresses and there is a normal stress due to the pressure. So, these two components actually contribute to the overall drag force. The drag force when we calculate has certain component of this shear stress drag and the normal stress drag that is comes from the pressure.

So, we say the drag which is a resultant force in the direction of the upstream velocity. And the other force is the lift force, which is the resultant force normal to the upstream velocity, by typical convention we understand that this drag force when we say it is the components of this shear stress drag and the normal stress drag, because remember the objects are not of a flat surface ok, it has its curvature. Therefore, this pressure and the shear stress have its component in the direction of the flow or the upstream flow upstream velocity ok.

So, these two resultant force or the components of this shear stress and the normal stress, this contribute to the force that we call the drag force. And the other force that acts that is normal to this. So, it is a kind of if the surfaces angle at a theta the cos theta I mean theta with the horizontal surface, then or the x plane conventional x plane if the object surface is oriented like that, then you can understand that the cos theta component contributions the drag force.

The shear stresses and the vertical component or the normal component contributes to the lift force ok. Now, to determine these or to have quantify these parameters, there is the concept of dimensionless lift and drag coefficients ok. Our interest here is the drag coefficients ok, lift and the drag coefficients so, here we mainly focus on the drag coefficients where the drag coefficients.

If you remember that we define as

$$C_D = \frac{\frac{F_D}{A_p}}{\frac{\rho u_0^2}{2}}$$

where $A_p$ is the projected area in the direction parallel to the upstream velocity. So, basically shear stress contributes mainly to the drag force ok, when the flow is in the surface is in parallel to the flow directions and it in fact, it is the dominant factor.

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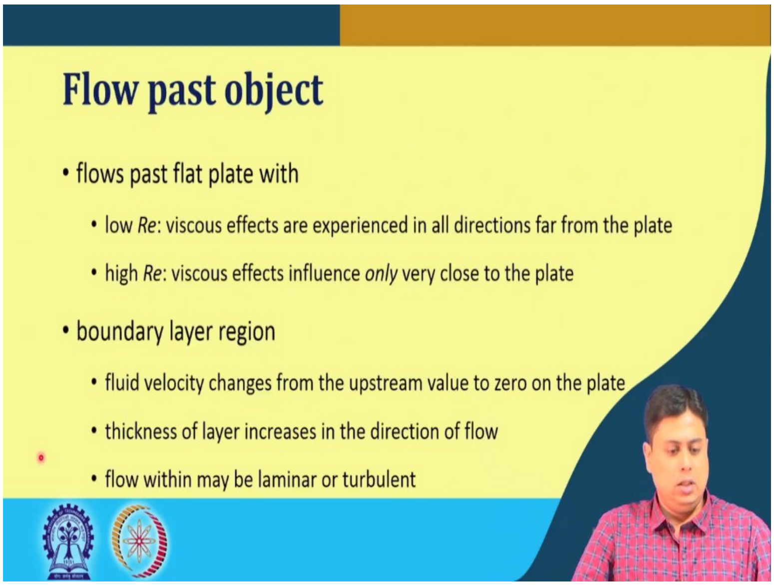


So, the thing that I mentioned when there is a flow past a flat plate with a low Reynolds number, the viscous effects are experienced in all directions far from the plate, for low Reynolds number cases. Now, here the Reynolds number is defined back based on the characteristic length scale ok.

So, if that is a flat plate, it is the length of the plate ok, if that is shear it is the diameter of the shear and similar to that. So, here for the low Reynolds number case now again remember the Reynolds number is the inertia force by the viscous force. So, the case of low Reynolds number; that means, we have very low inertia and the viscous force are dominant. And in this case it is actually experienced in all directions when there is a flow over a flat plate.

And, in fact, if you remember the flat for such scenario, the velocity the region of the boundary layer is basically much larger. And, it starts far from the upstream point also I mean from the leading edge in fact, ok. So, the thickness of the boundary layer is also high fine, but for the high Reynolds number cases the viscous effects influence only very close to the plate.

So, here high Reynolds number cases means that, there is a huge effect of the inertia and naturally the viscous effects are less experience over a broader region. It is mainly contained with a smaller region near the plate. These high Reynolds number cases can also be thought of like having very low viscosity flow ok.

Although for real fluid there is a substantial amount of viscosity is there, but there is a flow called the inviscid flow ok, when the viscosity is 0o the Reynolds number is infinite which practically does not happen, but in such cases, the boundary layer the thickness of the boundary layer or the effect of this viscous force only contains near the wall very thin layer ok, when the Reynolds number is very very high. Now, we have seen the concept of boundary layer also.

The boundary layer is the scenario where fluid velocity changes from its upstream value to 0 on to the plate ok. So, the boundary layer has a thickness, but it is of not that much sharp interface that is available, the thickness of this layer actually increases in the direction of flow.

The flow within this boundary layer may be laminar or turbulent. Basically, you can think of this boundary layer region as a region, where the viscous effects are dominant. Outside this the flow happens as if the flow is inviscid, which means there is no effect of viscosity, but that rarely happen, but this is the part that demarcates this effect, that inside that region to the near to the plate or the near to the surface. The effect of viscosity is there is very velocity gradient ok, but outside that region the velocity is nearly equals to the upstream velocity. So, there is no variation of the velocity gradient ok.

Now, based on this laminar or the turbulent flow inside that region this thickness of this boundary layer varies ok.

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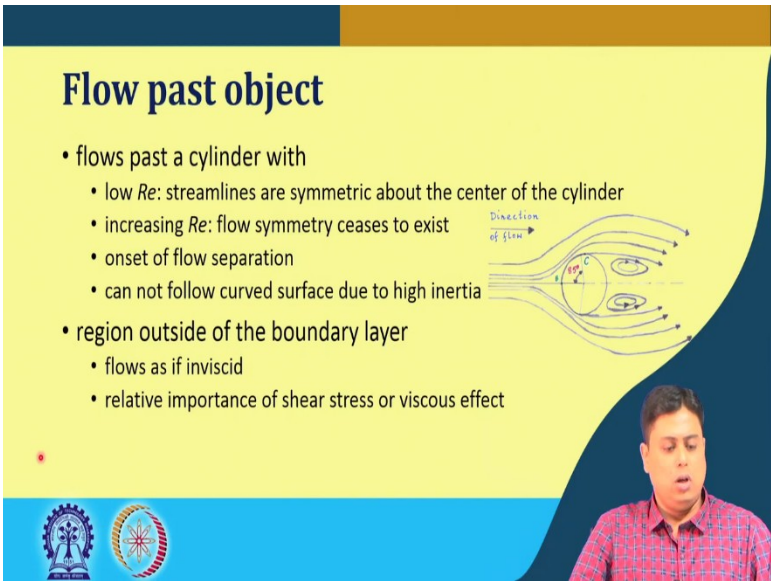


So, then there where is the flow past a cylinder similar to the flat plate. For the low Reynolds number the streamlines are symmetric about the center of the cylinder ok. So, the interesting feature is that if the flow profile at the front of the spherical object and the rear point of the spherical object is nearly symmetrical, when there is low Reynolds number flow or the fluid flow is highly viscous flow ok. Or you can say the velocity is very low ok. Because, this Reynolds number low Reynolds number can be achieved by adjusting several parameters.

So, in case of low Reynolds number the streamlines across this cylinder when there is a flow across the cylinder the streamlines are nearly symmetrical about the center of the cylinder. But, as you increase the Reynolds number this flow symmetry ceases to exist; that means, this the curvature surface curvature the streamlines cannot add up the surface curvature of this cylinder rear at the rear portions of the cylinder, when it passes through upon to the surface it is upper surface or lets say the lower surface. With increasing velocity or increasing Reynolds number such scenario happens and after a certain time flow separation occurs ok.

If, you remember this figure here this C was the point of flow separation, because it cannot follow this streamlines rather cannot follow the curve surface due to high inertia as the Reynolds number is very high ok or higher and higher as it goes higher and higher, this separation point the there is a onset of this separation point. And, as it happens exactly at the rear point of it is this object there is a wake formation happens ok. There are wakes that forms and in fact, here the flow in this region is opposite to the direction of the upstream flow ok. And that creates a huge pressure gradient.

So, outside this boundary layer flow behaves as if this is a inviscid flow; that means, the viscosity is zero, but that does not happen, but again the high Reynolds number can be achieved with the very high fluid velocity ok, very high characteristic length and similar to that parameters. So, basically the relative importance of shear stress or the viscous effects is that you have to gauge or you have to consider that, inside the boundary region that actually defines the boundary region the boundary layer region ok.

Because inside that region this shear stress or the viscous effects will be there and outside that there will be no such influence for them ok. Now, in this case as I said that as the Reynolds number increases ok. This flow separation points ok, it is pushed back ok. And this wake formation region ok, it gets larger and larger ok, we will see that also in the couple of slides later. So, the point is we have to understand this relative importance of shear stress or the viscous effect ok. And that actually gives us the measure of the boundary layer.

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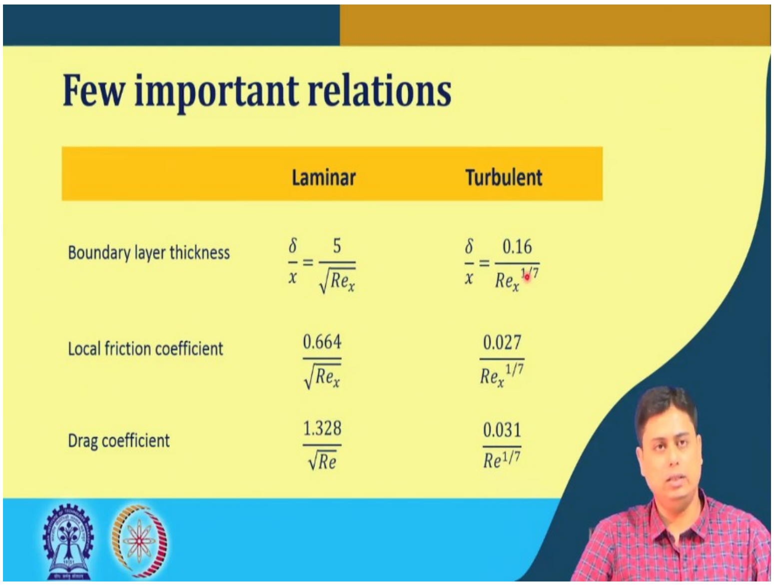


So, the boundary layer thickness in the laminar and the turbulent both the cases are listed here as well as the local friction coefficient and the drag coefficient value. So, these relations are what you have to keep in mind, because several problems in several questions these are typically asked and during some calculations you have to remember this relations.

So, the point is we can see the boundary layer thickness varies with the Reynolds number to the power half in case of laminar flow

$$\frac{\delta}{x} = \frac{5}{\sqrt{\Re_x}}$$

and to the power I mean at the denominator and here at the denominator it is one seventh ok.

$$\frac{\delta}{x} = \frac{0.16}{\Re_x^{1/7}}$$

The local friction coefficient has also varied similarly in the as so, as the drag coefficient ok. So, these expressions you have to keep in mind; keep in mind and remember to use it wisely.

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Now, coming to the concept of drag we have seen there are two types of drags; one is the friction drag which is a part of drag resulting from the shear stress this we have mentioned also, it is the its magnitude depends on the magnitude of the wall shear stress and the surface orientation ok. So, it is basically in the direction that you can think of in the direction of the upstream velocity or along the direction of the of its surface. So, flat surface parallel to upstream velocity, the entire shear stress is basically the friction drag ok.

There is no pressure drag, but on the other hand when there is a flat surface normal to the upstream velocity, there is no contribution of the shear stress and the overall resistance is contributed from the normal forces ok. Typically, this drag is independent of the plate the plate roughness for the laminar flow, but in other cases for the turbulent cases, it is actually in fact, drastically changes, drastically increases with the plate roughness. If you remember this Moody's diagram there you can possibly see that after a certain range of laminar Reynolds number value, there are the surface roughness effects are in are into play there ok.

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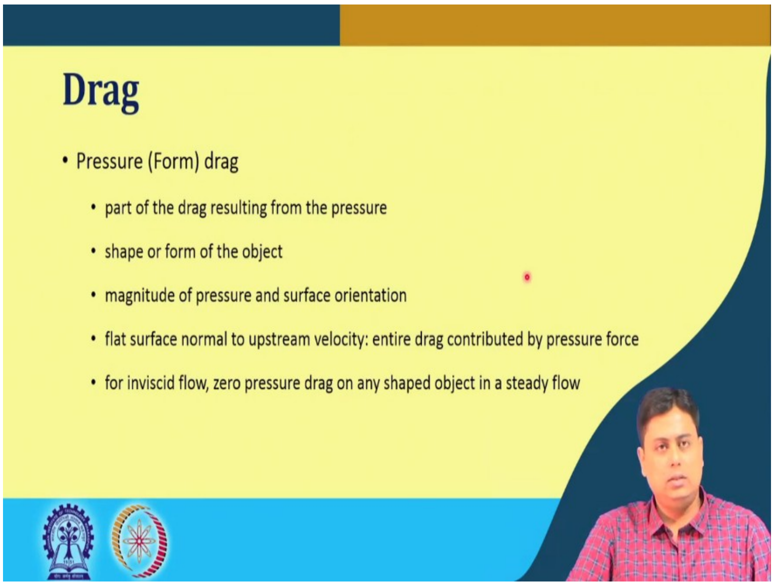


So, the other drag is the pressure or the form drag. The form drag, because it is actually comes or dictated by the shape or the form of the object, it is a part of the drag resulting from the pressure and the its magnitude is dictated by the magnitude of pressure and surface orientation similar to the this skin drag ok.

So, for example, in the last case that we have mentioned when there is a flat surface normal to the upstream velocity the entire drag force is contributed by the pressure force ok. And for inviscid flow there is zero drag, pressure drag on any shaped object in a steady flow. Because, this comes by its logical conclusion that for inviscid flow there is zero pressure drop, zero pressure drag on any kind of object when the flow is steady.

So, combination of this two drag contributes to the overall drag values ok. So, the overall drag coefficient also is basically the skin friction coefficient, the skin drag coefficient and the pressure drag coefficient fine.

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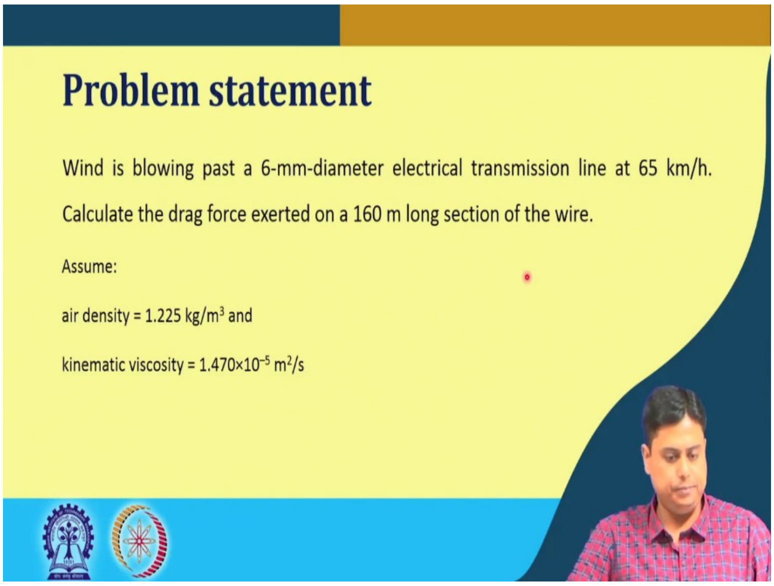


So, of we now again come back to the problem one problem just to summarize the whole thing or how the things we have described is that, the wind is blowing past a 6 mm, diameter electrical transmission line at 65 km/hr. We have to calculate the drag force exerted on a 160 m long section of this wire. So, this is a kind of wire you have seen for the electrical transmission, it is of 6 let say it is of 6 mm diameter the wind is blowing at a rate of 65 km/hr at a constant value.

So, what is the drag force that is exerted on a 160 m long section of this wire? So, let say the distance between two poles of this electrical transmission line. So, here you can assume that the air density at that particular temperature of that condition is 1.22 kg/m$^3$ and the kinematic viscosity has such value, $1.470\times10^{-5}$ m$^2$/s.

So, the things immediately that should come into your mind that ok. This we have to calculate basically the overall drag force, that is the $F_D$. For the calculation of $F_D$we need the drag coefficient value. Drag coefficient value depends on the Reynolds number. So, first of all we have to find out the Reynolds number.

Based on the Reynolds number is it either in laminar or in turbulent or in mixed region, there are correlations or plots are available ok. For different shape of the object, different orientation of the flow, there are several charts there are several tables are available ok. So, first object or the first task is to calculate the Reynolds number for this flow or the for this problem ok. And then we decide we take the value of $C_D$ accordingly and then we calculate the simple drag force.

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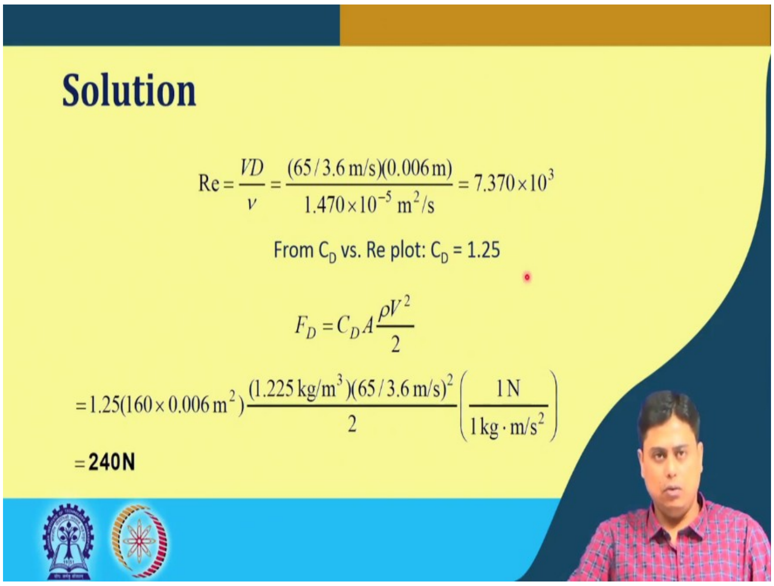


So, here the Reynolds number is calculated like this, which is velocity multiplied by the diameter divided by the kinematic viscosity, we converted this kilometer per hour to meter per second to be consistent with the units, the diameter is given kinematic viscosity is given. So, we can see the Reynolds number comes in the range of 10 to the power 3 or 7.3 multiplied by 10 to the power 3.

Now, the $C_D$ versus Re plot for this kind of let say this is basically a cylindrical object. So, flow across a cylindrical object if we consult the $C_D$ versus Re plot or $C_D$ versus Re drag line for this we find that $C_D$D for this particular Reynolds number is 1.25 and then the rest of the problem is very easy because we have seen several such examples.

So,

$$F_D = C_D A \frac{\rho V^2}{2}$$

where A again is the projected area to this flow or the area that is exposed to this flow basically the projected area. So, here this is basically $L \times D$. This is the projected area when the flow is happening across this wire ok, where these values are also given. So, we replace those numerics and we find out that this is the force that is acting on this 160 m long 160 m long section of the wire ok. So, this 240 N is nearly a 25 kg of weight that is hanging on the that section of the wire.

So, this is the kind of force that is the wind or wind velocity is 65 km/hr and happens over a 160 m length of the wire having a diameter of 6 mm ok. So, this is the overall summary of the things that is required for this course.

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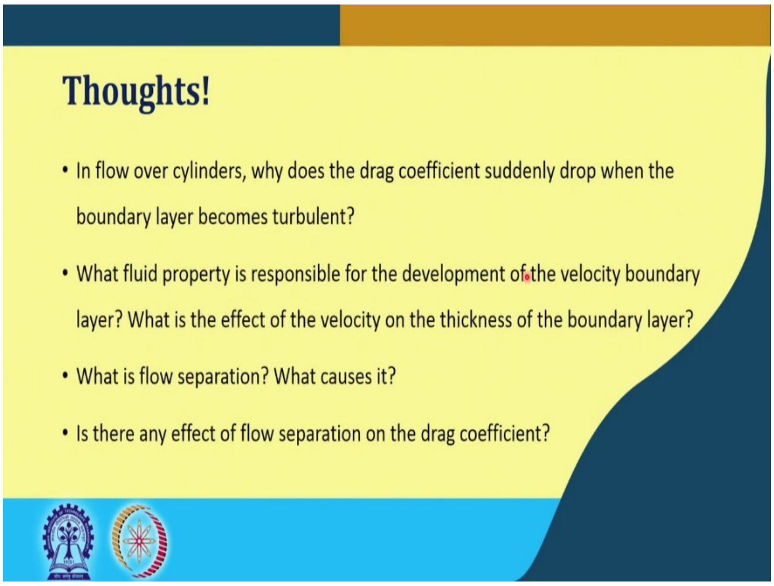


And then I put these questions this you have I have already answered this if you have listened to this to the lectures previous lectures, you will be able to understand and you should think about this.

That in flow over cylinders, why does the drag coefficient suddenly drop, when the boundary layer becomes turbulent ok. Is not it the contradictory that is not it should happen the other way round, but in reality what happens, that when there is a flow over cylinders the drag coefficient suddenly drop ok. As the boundary layer becomes turbulent why this happens, let me give you a hint it has to do with the flow separation point ok.

Why the fluid property which fluid property is responsible for the development of velocity boundary layer ok. If, you think of the concept of boundary layer and it is importance you can easily answer that. What is the effect of the velocity on the thickness of the boundary layer? Effect of velocity you can translate that into the effect of Reynolds number and then easily you can answer such question.

What is flow separation and why it happens? And is there any effect of flow separation on the drag coefficient. You should be able to answer these questions because in the previous lectures as well as in this lectures this answers are already given ok. So, with this food for thought I conclude this class here and will see you with the next section in the next lecture.

Thank you for your attention.