Fluid Mechanics
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Lec 37: Drag and Lift

Good morning, let us have a today class on drag and lift which is the last class of this course okay. This is lecture number 36 and drag and lift. I think discussion of the drag and lift I started from the lecture number 2 where we illustrated how we can estimate it what will be the drag and lift forces of the towers, the And also we talk about this how the bars drag and lift forces in linear momentum equations. So if you look at that we have really remarkably progressed in experimental fluid mechanics or we talk about wind tunnel testings or water flow testings as well as we also remarkably improved in numerical experiments using computational fluid dynamic software as we demonstrated many cases. So if you look at that to really design a fuel efficient car or you talk about design wind turbine all he needs a information knowledge on this drag and the lift which actually help us to generate wind powers from wind tunnel. So if you look it that way I am not going more details I again I am to encourage you just look it the very good illustrations are there and in the book of Sinzel-Cembala which gives you a lot of interest on the fluid mechanics if you look at the illustrations what is provided in Sinzel-Cembala book.

But today I will be very briefly I will talk about the slip drag and lift and frictions and pressure drags, drag coefficients of common geometry and will be have a parallel flow over the flat plates which already we discussed in boundary layers concept that is the same concept we will talk about. Now if you look at that take a simple examples okay when you have a cyclist okay driving a bicycles okay if you can look at recent Olympics and all if you see these persons lean seat okay as to reduce the drag forces it just leans it as going with so the basically minimizing the drag force so it leans up depending upon the speeds and you can see that the bicycles what is designed for the low velocity and the racing bikes are the different and more often if you look at the the cyclist how it changes to reduce the drag forces which is acting in the directions of flow. So in direction the flow because of air distance because of the flow structures all it is created as equivalent to a drag force. So most often we define the drag force is a functions of half rho v square is a dynamic pressures as we discussed earlier.

multiplied with a Cd this is called coefficients of drag into A is the frontal area. So the basically this coefficient drags we can get it from experiment basically conducting wind tunnel test. or we can do numerical experiment. We can do the numerical experiments to estimate what will be the CD value okay or we can do a wind tunnel physical experiments to estimate the CD because CD is is a functions of velocity, functions of rho density of the fluid. It depends upon the velocity which we can say that is a free stream velocities and it also depends upon the frontal area, the shape, size and orientations.

So the basically a cyclist who participates like very competitive racings like Olympics and all he tried to reduce this a value he will try to reduce this a value or will be try to reduce the cd value that is 2 things he can reduce it so that drag force will be that minimum and he can increase the velocity. that is the availability for any cyclist or the racers in any competitive racing things he can practice so well that he can reduce this frontal areas that is what he will have a the clothes fitting dress and such a way that so the frontal area he can reduce it, he can lean such a way that it will reduce the frontal area as well as it has to look at what is the shape and size the orientations. based on that cd varies. So if you look it any cyclist which is a really participating like national or international camps he try to do level best to reduce the frontal area and reduce this coefficients drag. So that he can increase the velocity with the same force he can increase the velocity.

So if you have a very simple examples that if I do not have the cd variations okay if you have a upright positions okay just driving like this okay the cd value will be about 1.1 and if you have this cd value can goes if you just bend it the cd goes to almost 20% slower that is what it happens it. almost the 20% slowest we get it the Cd just you bend it. So that is the basic idea how the research does it. Same way if I give a very simple examples like there is a half Dix and if this flow is coming like this if this velocity v or Dix having the diameter d if I have the half digs as close to a umbrella okay.

So if you have the velocity v and half digs as you can understand how the flow turbulence structures will happen, how the boundary layer formations are there. We are not going to detail about that. We are just looking at how the flow separation is happening. All details we are not going it because this type of shape with a velocity v we can conduct wind tunnel test or the numerical experiment using computational fluid dynamic software. So if you do it you will get a Cd value is equal to 0.

4. 0.4 that is what the Cd value if I have the velocity like these in you have a high semi circles and not going details which okay it is considered the Reynolds numbers greater than 10 to the power 4 in the turbulent regions. So we have the Cd value is equal to 0.4. But same things if I can just reverse it like you do it sometimes your umbrella okay. The wind directions and your umbrella directions will be different.

In that case the Cd will go to almost 3 times of this value 1.2. That means the drag force is exerted when you have parallel your umbrella with the velocity that is what will be 0.4 times of half rho v square N2a okay, dynamic pressures N a but same umbrella if I just hold it differently. So the force because of these orientations these force will be if I put the dash it is a 3 times of the FD force that is what you can experience it when you try to do a normal case when you have a raining, how to handle the umbrellas okay.

That is the way you change the drag forces which is almost three times higher okay with a CD is 0.4 to 1.2. There are number of examples okay. You can really see in the real life conditions how the drag and lift is playing the rules for us when any external bodies flow past over a bodies or flow past over a bodies you can see that how the drag force and lift force are working it and how we can change the drag force and lift force which very simple way it is defined as a CD.

the coefficients of drags will more details will come which will be the is nothing else force of drag divided by dynamic pressures rho v square is rho is a density into the frontal area okay as equivalent to the force due to the dynamic pressures that ratios is equal to the coefficients. drag coefficient that is what you can have. So simple way the examples what you have given it here as you know it nowadays we have been implementing series of wind turbines. So wind turbine to harvest the wind energy. So if you look it if you have this velocity v is coming it how to design this belt okay such a way that will be high powers will get it okay.

So if you look it very smaller area it just like a wing the aircraft wings you have a drag and lift because of these drag and lift forces this is what going to rotating it. okay. So more details you can understand it in higher classes but if you look at the wind turbines you can talk about the cyclist, we talk about swimmers or you talk about any gymnastics okay. If you just look at the beautiful part of the gymnastics that he here trains himself with a lift and drag force such a way that he knows that how to change the body shapes, and also the wind speed such a way that he can really perform these gymnastics very well. Same way if you look at the in crickets when you somebody is spinners or the bouncers they are throwing the balls and all these interactions you can understand it within these left hand tracks.

So it is a very interesting subject. But as we have very limited time of finishing this course in this class. So let us talk about drag and lift friction and pressure drags okay which is definitions wise how the drag coefficients are common geometry as I just given some examples of and parallel flow over the flat plate which is the boundary layers. And then you will solve a very few examples on how to solve this real life problems using this lift and drag concept. Now if you look at the drag okay which is a it is a very simple definitions as you can understand it that is a force flowing fluid exerted on a body in the flow direction is called the drag okay.

Just normal to that components we can say that is that lift okay. So if in a flow directions okay this is the flow directions in these directions If there will be a force acting this because of the boundary layer formations because of the pressure difference all details we are not going it which we already discussed in boundary layer concept. If I have a small air of foils so where we can compute the drag forces okay which will be the force. of flowing fluid exerted on a body in the flow direction is called drag force just perpendicular of that force is the lift force that is what the lift force. So you have a lift force you have a drag force.

So as you know it, how the boundary layer formations happens, how the flow separation happens, all we discuss in the class in boundary layers. The component of the pressures and the wall strips in the direction normal to the flow tend to move the body in that directions. Their sum is called the lift. Now if you look at these cases okay, if I consider a airfoils consider a aerofoils and I have the free stream velocities coming like this. If I you know it there will be boundary layer formations and there will be the pressure difference will be generated.

So if I take a small area dA and for that area I have a wall shear stress tau w into dA will be the force components and I have the pressure which is acting on P into dA is a pressure force okay. And I have the normal components and that is what I can look at that it is making a theta degree angles okay. It is making a theta degree angles. okay at this normal component with the components of the horizontal directions the flow directions is making a theta degree angles. So if you can see that as you discuss in the boundary layers there will be a generations of boundary layers the flow separations and boundary layer thickness okay which generate the wall stresses variations okay and we are not going details we are just looking it and this also have the pressures.

So if I have the pressure field if I know this wall shear stress with a very simple force component resolutions okay just compounding the component in these directions as well as the perpendicular this. So this direction is a drag force direction this is the force direction is a lift force direction. So two dimensional flow the resultant of the pressures and shear force can be split in two components one in the direction of the flow which is the drag force another in the directions of normal flow which is the lift that is what I repeatedly saying these things. But if you generally we have three dimensional structures where is a side force component also comes normal to the base normal to this blackboard to move in that direction. So anyway we are not discussing how three dimensional flow happens in these course curriculums.

So if I look at the drag force and lift force it is a simple things now for us because we take a small area dA we estimate the force because of wall shear stress and the pressures and if I result it these components in terms of the drag force for a element of dA small element of the dA I will get it the force component P dA cos theta negative signs because it is opposite of this flow velocity light and you have a the force components due to the walls shear stress that is what you will get it for the and the drags. This is coming that if I know it from any experimental studies if I can measure the pressure as well as can measure the shear stress I can also compute it what is the drag force of each small elements of this surface. for each element of the surface I can estimate it is not a big issue okay if I have a conducting this experiment in the wind tunnel or if I conduct in a numerical experiments like computational fluid dynamics I can get the pressure field I can get the velocity field from that velocity and pressure field I can estimate it what will be the wall shear stress okay. also some of the CFD softwares also gives the wall shear stress. So as you know this wall shear stress you can just integrated this part to understand is total force integrating these equations entire surface okay you will get the drag force and the lift force okay.

That means the drag and lift force is varying with a smaller dA of the surface area we are just integrating it which is very simple things. But most often as I said that for engineering applications or designing experiment conditions, we simplify the things. We do not go for very complexity because we conduct the wind tunnels, we conduct the numerical experiment. End of the day, we give a chart of the coefficient of drag, and or the drag coefficients or we talk about the lift coefficients. So because that is will be easier for engineers to implement it to understand it how the better design should be there.

The for examples like you have a tall buildings okay. you have a tall buildings okay you want to design the wind speed maybe as we have given the example of the same things in very beginning of the classes of if there is a cyclones having around 200 kilometers per hours okay and we can have a two type of platforms we can have one is the plan form of these tall buildings could be around more than let be 50 meters high. And you consider the wind speed of 200 kilometer per hour as close to a cyclone whether the building footprint or the plan of the building should be square or the circular to reduce the drag force. That means basically reduce the Cd value. So we can look at this elementary geometry and you can understand it that which one will give a minimum Cd values.

That is what you can understand it. It is not from just graphically you can say. So that is the reasons we conduct a series of experiments and we finally we provide the Cd values which is the guideline for a engineer to decide it when you constructing a high rise building. He has to look it whether he has to go for this shape, rectangular shapes or a circular shape. that is a very simple Cd values and if you can interpret it that how the Cd values variations are there and which one will be the more just think about that.

So that means we can define it a very simple way the coefficient of lift and the drag coefficients is a functions of because if you know the Cd value you can estimate the drag force half by rho v square into a okay a is the frontal area. That means for this case my frontal area is b and it is this the length l so the frontal area is a frontal area is b into h that is what is my frontal area. AE will be there. But in this case I have the diameter d and length the frontal areas will be d times of L that means you will looking this what is the projections in the just looking from the velocity sides flow velocity directions what is the projections that the projections is the frontal area. So if you look it for the circular case you have a frontal area d into L but in case of a rectangular case in the B so you know the frontal area.

So you know the frontal area you know this Cd value you know the design velocity you can always compute it what will be the drag force is very simple thing. Same way we also make it the lift force is a very simple way C L F L is a lift force divided by same functions rho v square into a okay. So this drag and lift coefficients are primarily functions of shape of the body as I said it it also depends upon the Reynolds numbers and the surface roughness okay that is also matters it okay. What type of buildings we have okay if I have a new constructions building versus old buildings. So definitely the city will be the different.

The roughness will be the different. That is the difference. So if you look at that how Is it a new buildings or any type of roughness we are creating because that what is matters us and also the flow Reynolds numbers. That is what we will be discussing that the CD also have a functions of velocity, rho, frontal area also the Reynolds numbers and roughness as similar to we discuss about the roughness for pipe flow the similar concepts we have the roughness I am not going more detailed here. So now if you look it that this is two concepts if you look it it is a very very tiny dust particles when you falling down in a very standstill air conditions air conditions that how much of force is acting on that. So if dust particles very very tiny dust particles it is falling down there will be the force weight the buoyancy force and the drag force.

And when it attains this maximum velocity which we call the terminal velocity after that it does not change it. So in that is the conditions when you have a velocity increases the drag force until the all the force balance each others that means net force acting on the body is 0. Then after this velocity attains the maximum velocity which is the terminal velocity. So that means a smaller dust particles it will fall on a terminal velocity okay terminal velocity. That is the conditions when you have the a balance between the buoyancy force weight and the drag force.

So that means if it is moving with v terminals the drag force is equal to weight minus buoyancy force okay. That is what you can easily compute it what will be the weight what will be the buoyancy force depending on the fluid density and the density of the dust particles. So we can always compute it what will the weight what will be the buoyancy force you can compute the drag force. there could be a flow separations and all it also depends on the Reynolds numbers and the roughness. The same way if you look at that when you flow past in aerofoils.

So you will have a positive will be negative pressure difference and there will be friction drags as well as the form drag or drag due to the pressure difference that is what is happens it the top of baton there will be pressure which generate the upward force that tends to lift the wings and the aeroplanes to which connected okay. That is what if you look at that how the aeroplanes are taking off how they are operating this the van during the lifting and also the landing conditions or all the lift and drag force concept we generally correlated to look at all the operations what is done by the So that is what you can understand it a similar way. Now let me have a very simple way the frictions and pressure drags. As I said it that part of drag directly from the wall shear stress which is called is a skin frictions drag since it is a caused by the Fichtner effect because of the boundary layer formations. There is a part which is a directly depend upon the pressure difference which is the drag force because of pressures.

So sometimes because it depends upon the shape or form of the body as I said it a tall building high-rise buildings having a rectangular shapes plant forms or a circular plant forms it different it. So that means all it difference between the form drag which is depends upon that what type of shape and form of the body. So we again define it the same way. frictions and C D pressures. So the frictions and the C D pressures we it is a different between the lift that we are talking about a dominancy force component is one is a frictional part another is a form drag.

But the lift and drag force all components we are considering in the flow directions and another is perpendicular to that. But in this case we divide it depending upon why it is happening because of the pressures and because of friction separately that is the difference between the coefficient of drag coefficients and the coefficient of frictions. Coefficient of frictions talk about because of the frictional effects what is coming it okay and this is due to the pressure drags because of form drags as it depends upon the state. So that is what we define it to. So as I say that the drag coefficient FD it has is two component okay.

FD will have a two component one will be FD as a frictions and FD for the pressure or the firm drag that is what. Now if you look at one of the very simple examples that how the drag coefficients Cd varies okay friction drags and the pressure drags varies it as we change the d by L ratio okay. So d by L ratio if we are changing it of a flow systems how this CD of friction drag and pressure drag and this is what is total drags. So if you look at that the total drags comes like this which gives a there is a minimum points the ratio between D Al where we will have a total drag is the minimum. So this type of design we consider it when you try to design a object.

Now come back to very common geometries okay which is very easy to we have from experiments but if you look at a smooth spheres okay and the difference is a smooth because there is not much roughness is there okay that is the reason is a smooth it is a Reynolds numbers as the cd So if you can look at the first part is a linear then its behaviors like comes like this okay. So beyond this it is a turbulence and there will be the laminar regions. So if you look at that the coefficient of drag or drag coefficients which is really varies between the laminar flow, the creeping flow, the laminar flow, transitions and turbulence and it has a smooth. So these are the reasons if you look it then again decreases okay.

This is a linear part follows by these parts okay. So this linear part when the flow is laminar okay or very creeping less than the Reynolds number 1, less than very very less than 1 values okay that is called the creeping flow. So if you can see that for that we can define for a simple a functions with a Reynolds numbers okay that is because it is a linear functions okay. So that is what is defined it for a spherical space the Cd is 24 by Reynolds numbers. So you can ask how did you get this ones okay. This is all the experimental study was conducted almost 100 years back to with a simple experiments to find out the drag forces with different Reynolds numbers and you can find out the series.

For other cases we see this functional relationship how the Reynolds numbers is varies similar with the smooth cylinders okay. For the smooth cylinders you can have so as I was talking about the Cd for a hemispheres circular case all no doubt inversely relations with a Reynolds numbers the higher the Reynolds number Cd value usually less but the coefficients that is what is different okay. As you expected it in case of this type of case we will have the drag force is less because that is what we do it okay. So if you look at that basically what I am to say that you please commonly related to your day to day activities with a drag and lift force then really you can enjoy these chapters which is it is a give a knowledge to us that how we can really make it interesting of the fluid mechanics or how can you use the fluid mechanics for day to day lives or any engineering subjects when you try to do it we can just think it that how lift drag force are happening it or you can cross reference to look at the standard tables are given in lift and drags in many of test book like Sinzel Cimbala or F.

M. White you can understand it how the drag force are changing it just observe looking this value of Cd. So as coming back to the gripping flow it is a very simple things okay. When you have a Reynolds region number there that is what is Cd is equal to 24 by Reynolds numbers okay. So that means when you have the dust particles there is no much wind flow that what will be the flow will have a Reynolds numbers much much lesser than the one or close to the 1. So in that case you will have a same formula CD rho v square by 2 into area.

So that is what you dynamic pressures multiplied by the frontal area into the CD. So as this is a 24 by Reynolds numbers that is what is got it from experiment into the rho v square So you know very well that frontal area so you can find out what will be the frontal area that is what is you can for a d surface okay. So as a spheres so we can get a frontal area phi d square by 4 okay. Substituting all these Reynolds numbers and all finally with a simple equations you will get it v and d that means the drag force is a directly proportional to velocity, diameters and the dynamic viscosity of the mediums okay in which the dust particles are falling down okay. So you know it the dynamic viscosity of air also changes with the temperatures that also you know it.

So that way if you can try to understand it the dropping of the dust particles it has the functions of velocity at what velocity is coming it and it also defines that the diameters and the mu value. So that is what is called Stokes law, it is valid for the dust particles not only that any suspended solid particles in the water also follow the Stokes law. It is very simple law because it has considered the force components as we know it and also is considered with the experimentals the what is the Cd value that is the relationship between the Cd and the Reynolds numbers. more details of the parallel flow as we discuss in the classes okay in boundary layers. I am not going more details but as the object surface okay as just a simple way I will just talk about.

Already we have discussed it that so we can have a laminar regions, laminar boundary layers, and the turbulent boundary layer. So that way you can get it a coefficient of frictions variations for laminar and turbulence is a different which is a functions of the Reynolds number which is the functions of the Reynolds numbers. It has given this threshold Reynolds numbers and if you just want to do it total average friction coefficient then you can have a Cf will be 1 by L just integrate it Cfx ds. So you are just integrating the Cf dx values 0 to L that is what will give you average friction coefficient. So that way you can always do the integrations for the laminar regions, you can do for the turbulent regions and you can estimate if a plate is too long partly turbulent and all you can do a integration between that if you find it okay only the laminar flows happens it what will be the average flow or you just assume it okay it is the laminar flow is not significantly contributing the average friction coefficient only the turbulence reasons you can consider it which will give it in a function of Reynolds number.

Same way if I are considering there are two laminar as well as the turbulence happening it. So you can do the integrations to estimate what will be the average friction coefficient. So for more details if you look it for entire plate you can have these components as that integrations part and here is showing it for a smooth and rough flats that is what you can have put the Reynolds numbers the CF values okay and here is fully rough and all. This figure is very close to resembles to Modi chart same way the concept is the same. as we discussed in Modi charts and the same way the roughness, Reynolds numbers and the CF values okay is the average friction coefficients okay.

Similar way the lift forces you will get it as we discussed earlier. This we can have lift and drag forces and you can contribute to look at the directions as I thoroughly discussed earlier and when you look at the lift and drag forces very short way I can say it you have to look it where the flow separations happens. Most of the times in engineering we try to avoid the flow separations because if there is a flow separations then will be the force due to the pressure difference that formed that will be much more higher. So that is the reasons we try to avoid two formations of the flow separations. But this is what so that means the stagnations points and you can look it how the symmetric, non-symmetrical two-dimensional flow around an air of foils.

So you can understand it. I think these are the things we discuss more details but let us come back to a two examples which after this we will be finishing this class is a very simple examples of wind tunnel test. The car is moving with a 60 miles per hours okay and the force frontal area known is so A is known the frontal area is known to us and the velocity is known to us okay. and the drag force with a simple pulley arrangement we can estimate it what is the drag force we are getting it and so you have to compute it what will be the drag coefficients. So it is a very simple things okay. Fd is equal to half rho v square dynamic pressures multiplied the frontal area which is given to us I think it is quite easy for us.

Only you have to know it what is the density, velocity is given to us, area is also given to us, the drag force is given to us. So just to substitute these formulas and get it what will be the drag force okay. Just you look at the solutions part. It is simple. First is you have to compute, estimate the density of air for pressure and the temperatures.

So we can get it this as I have said it the drag force is this part as so you just substitute it and rearrange it you will get it drag Cd value which will be 0.34. okay the simple substitution of equations of draft force equation. Second example is quite interesting it looks like a tennis balls as I said it if you talk about cricket ball or tennis balls all these aerodynamic things we try to understand with a drag force and lift force okay.

This is this very simple examples of how A tennis ball with a mass of 0.0567 kg, it has the diameter 0.064 and it has speed is about 20.

1446. It is spinning it okay, so this is a 4800 rpm. rotations per minute. Determine if ball will fall or rise under the combined effect of the gravity the lift during the spinning shortly after being hit at a air at one atmospheric pressures and 80 degree Fahrenheit okay. And C L is given to us okay. The coefficients of lift is given to us that means we can find out lift force okay. We also know it the weight. So if a lift force is more than the weight then you can easily find out ball will be rise it if a lift force is greater than the weight.

Reversely if the lift force is lesser than the weight so ball will fall. So this is very simple cases but description is written it in terms of tennis balls. It has the mass, it has the diameters which needs for to estimate the frontal area. We have the velocity and you have a spinning speed which is not necessary here because it is already given it what is the lift coefficient for the spinning conditions okay. So that is it is given to us. So that is the reasons you can compute the density, you can compute estimate the kinematic viscosity.

So ball is hit horizontally thus it could normally fall under the effect of the gravity without a spin because if you look the density and the density of mass is given. So we can compare the density in normal case anyway ball will fall into the gravity okay without spin. Spin generates a lift but ball will raise if the lift is greater than the weight of the ball that is what I told okay. So you can just look at this. So we need to compute the lift forces okay as lift forces again I have to read it same things okay half rho b square into the a.

So that means you know this area and lift force which is coming about 0.161 Newtons but the weight of the balls is coming around 0.556 okay. So that way the weight is greater than the lift force.

So ball will fall down. So no doubt about that. So ball will fall down. So that is the reason the spinners try to change the speed of the spinning. So that ball can remains at the risings or the balancing levels. That is what it if you look at the spinners how they work hard, practice hard to make it throw the ball such a way that it remains the spinning conditions or the lift conditions okay. More details of the fluid mechanics and the how biological systems works, how the any sports activities if really it is a interesting subjects and all because it is introductory levels I am not going to that levels but I tried my level best to give a lot of illustrations as well as I try to give it a one of the best books in which Apart from giving a mathematical treatment to the fluid mechanics also there is series of illustrations the figures are there which really give you impressions that we can really learn many things about the fluid mechanics okay which day to day lives we can use that or you can be a best engineers to adopt some of the fluid mechanics knowledge okay. With this I am not repeating this coefficient of drag and lift coefficients part as a summary of these lectures and the thickness and coefficient of frictions okay.

You with this let me I conclude today lectures with giving really heartfelt thanks to all my students who really helped. Thank you a lot. So,