Transport Phenomena
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Lecture Number 29
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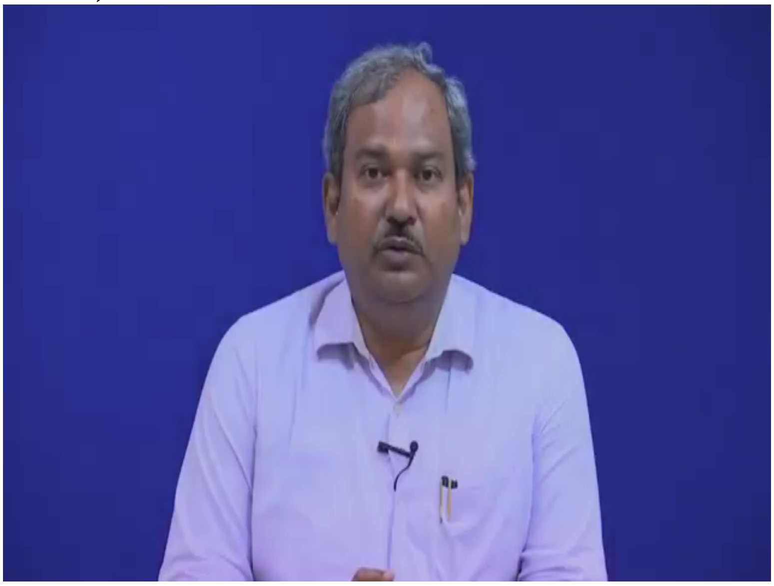

So we were discussing cricket, the cricket ball. What is the speed at which I need to bowl in order to create swing, out-swing or in-swing; the seam directed towards the slip or the seam directed towards the leg side? In one case when it is directed towards the first slip, as it comes towards the batsman he is committed to play it along the line that he perceives when the ball leaves the hand of the bowler. But what to his dismay he would discover is that the ball is not straight, it is moving away from him and he is uh, he is, in a subconscious way he is going to follow, try to follow the length, line of the ball and he will commit a mistake.

He won't be able to hit the ball the way he was supposed to if the ball was coming straight at him. Similarly if something is coming from outside, then it is very difficult to stop that ball hitting your stumps. So to decide about the line of the ball is extremely important and swing in air can totally disrupt the balance of the batsman in thinking, in deciding which line to play. So we are, we are, I am going to give you an example and to decide how to bowl, how to, how to bowl a swing ball to a batsman. So some of you, some of you among uh, may be cricket bowler so next time when you try to swing ball try to think of boundary layers. So the problem that we have in hand is

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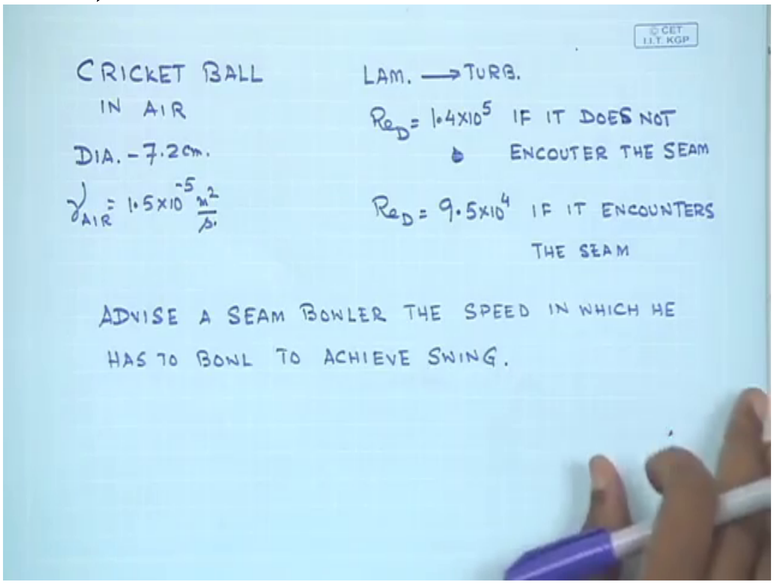

a cricket ball which is moving in air Its diameter is about 7 point 2 centimeters. The kinetic viscosity of air is 1 point 5 into 10 to the power minus 5 and through experiments it has been established that the trip, laminar to turbulent transition takes place on a cricket ball if Reynold's number based on the diameter of the ball is about 1 point 4 into 10 to the power 5 if the ball does not if the air does not encounter the seam. And Reynold's number, transition from laminar to turbulent would take place at a lower Reynold's number of 9 point 5 into 10 to the power 4 if it encounters the seam.

So if the air over the ball encounters the seam, the transition takes place at this value of Reynold's number. If it does not encounter the seam, this is the Reynold's number at which the transition would take place. That's all the information which we have and based on this you have to advice a seam bowler the speed in which he has to bowl to achieve swing that means movement of the ball while it is in air, Ok. So that's essentially the problem.

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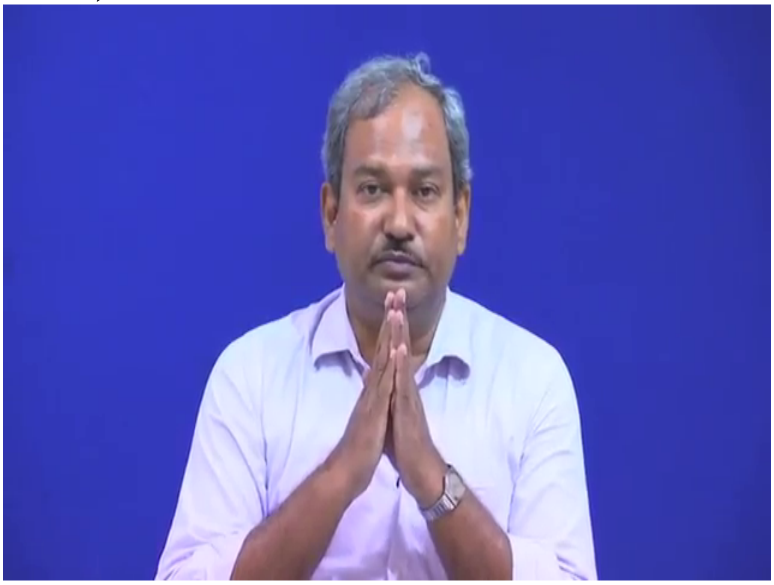

What is the velocity with which I am going to release the ball and make it move in air, either away from the batsman or towards the batsman? Keep in mind that the problem itself is very simple. The experiments have already established when are you going to have transition from laminar to turbulent flow. Is it the point when, have you seen, I mean you all have seen very fast bowlers. The fast bowlers, very fast bowlers could depend on the speed only to beat the batsman, they do not swing. In fact they cannot swing. If you move the ball, if you throw the ball, if you throw the ball at a very high speed it will never move while in air. If your velocity is too small, if you are a spin bowler, it will also not change its direction while it's coming towards you while in air but it’s the medium fast bowlers, it's truly the swing bowlers who can make the ball move in the air.

So not very fast bowlers, not slow bowlers, someone in between who is a medium fast, who is a swing bowler, Ok. So we would like to see why that happens and how do we, how do we advice what is the velocity with which he has to bowl. Why would anything change its direction when coming towards you? It can only happen when there is a force either moving it away or towards the batsman. So there has to be a force, a disbalance of force between two sides of the ball when it is coming towards the batsman and the disbalance of force, pressure force in this case, it has to be pressure force, a disbalance of pressure may be created on two sides of the ball if the flow regime on two sides of the ball are different.

That is the crux of the problem. If we have laminar flow on one side and turbulent flow on the other side, then the pressure generated at the left and at the right end are going to be different. And as a result of this pressure difference, the ball would start to move. What happens if it is a very fast ball? If it is a very fast ball, then most likely you are going to have turbulent flow on both sides of it and if you have turbulent flow on both sides of it, then more or less the forces due to pressure will neutralize, will neutralize each other and it will move in a straight path. If the ball is slow ball, is a slow ball then you are going to have laminar flow on both sides of it.

And therefore the ball will move in the straight path. So you have to bowl in such a way that you create laminar flow on one side and turbulent flow on the other side and the way to initiate turbulent flow at a lower velocity is, if you can use a turbulence promoter which would create, which would disturb the growth of the boundary layer and therefore will create a condition of turbulence at a value lesser than the prescribed threshold of laminar to turbulent transition and the turbulence promoter that you have in a cricket ball are these seams. These seams would create an obstruction, a perturbation in the flow path if it's like this.

So when the, when the air comes towards the ball it would start to move in, on this side and it would move, it would start to move on the other side. While it is moving to this side it encounters the seam, on this side it does not encounter the seam. So you have created laminar flow on one side and turbulent flow on the other side and therefore a pressure imbalance on two sides of the ball and it would start to move in the specific direction. So that's the science of swing. Let's see if we can convert that and the experimental observations into the range of velocities in which the bowler has to bowl using the seam and achieve swing. So what are the information that we have? What we have is

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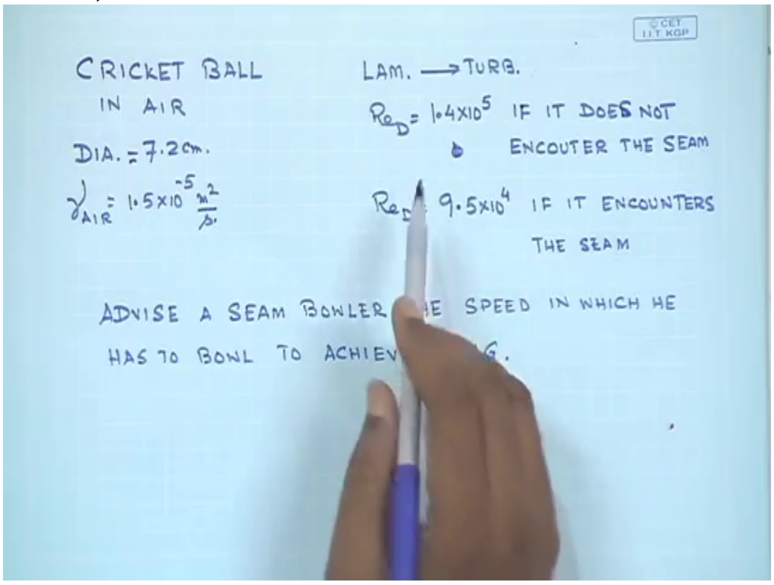

Reynold's number to be 1 point 4 into 10 to the power 5 if it does not encounter the seam and Reynold's number 9 point 5 into 10 to the power 4, if it encounters the seam. So obviously the velocity, the upper bound of the velocity would be the corresponding Reynold's number multiplied by mu times d, this mu is the kinematic viscosity which is and we know that the upper bound would be 1 point 4 into 10 to power 5, the kinematic viscosity is 1 point 5 into 10 to power minus 5 and the diameter of it is 7 point 2 into 10 to power minus 2 meter per second so it would be equals 29 point 1 6 meter per second which is roughly

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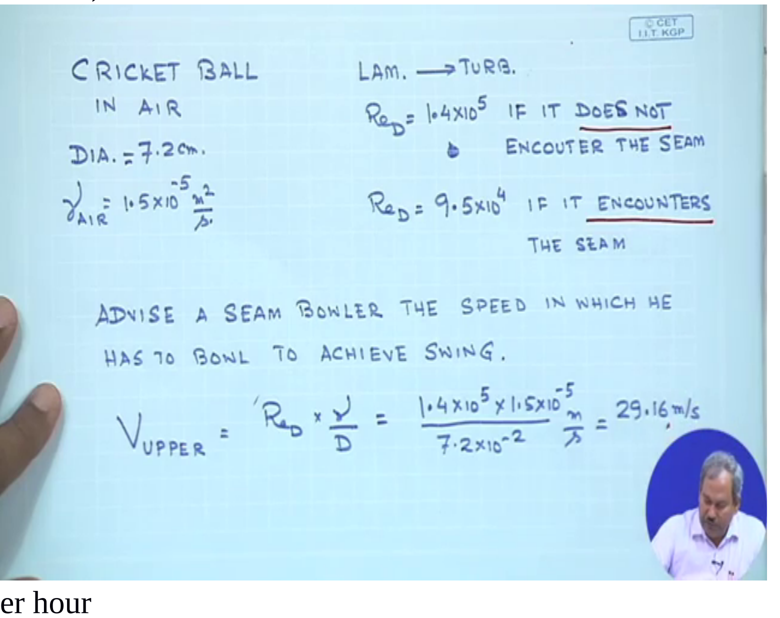

1 0 5 kilometer per hour

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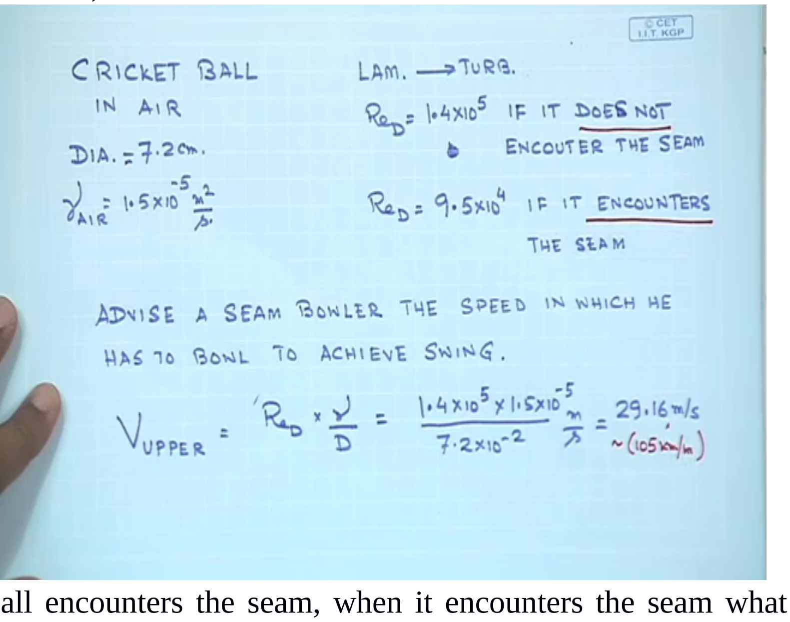

The, when the ball encounters the seam, when it encounters the seam what you have is v lower in that case would be r a d times mu by d but in this case the value of r a d would simply be 9 point 5 into 10 to the power 4 from this into the same thing, kinematic viscosity by the diameter of the cricket ball, this much of meter per second which would translate in 19 point 7 9 meter per second and this is equivalent to 71 point 2 5 kilometer per hour.

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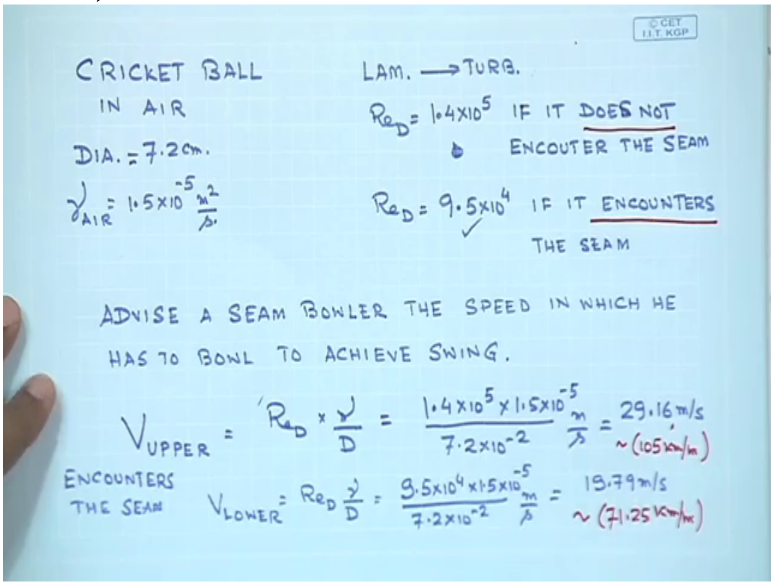

So these two essentially give you the range of the

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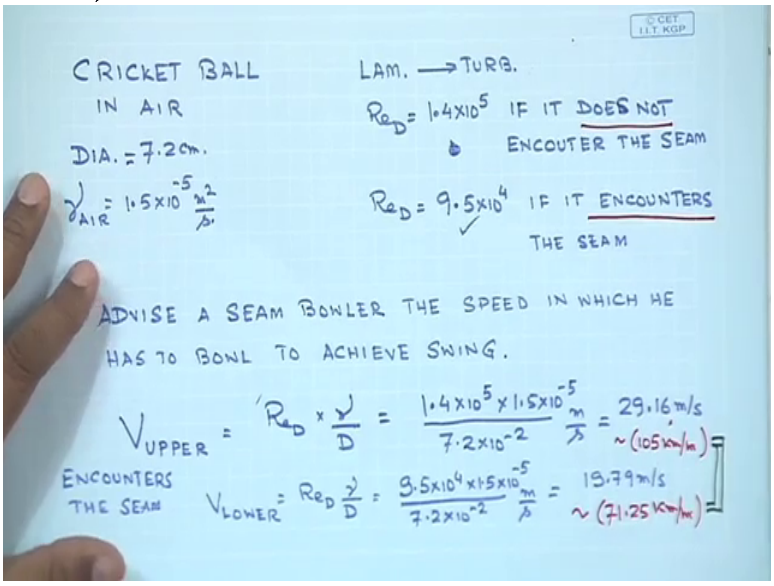

speed of the ball. So in order to achieve swing a bowler has to bowl with a

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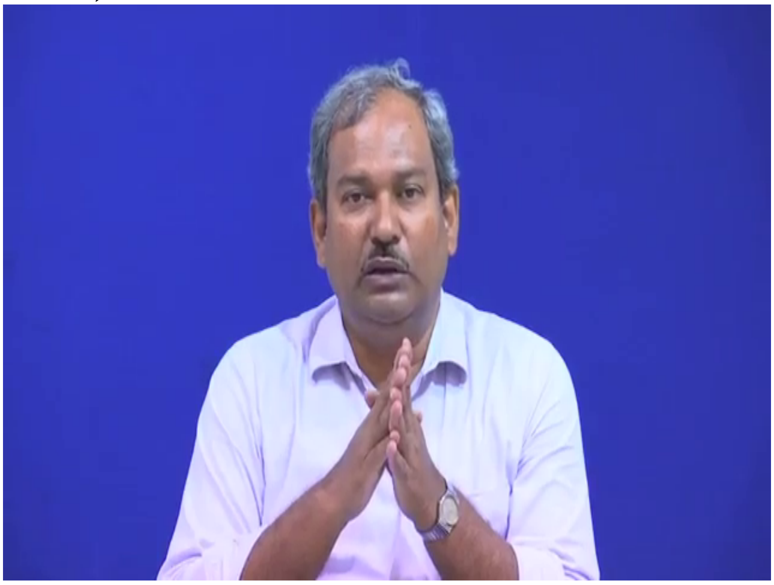

speed in between 100 0 5 and 71,

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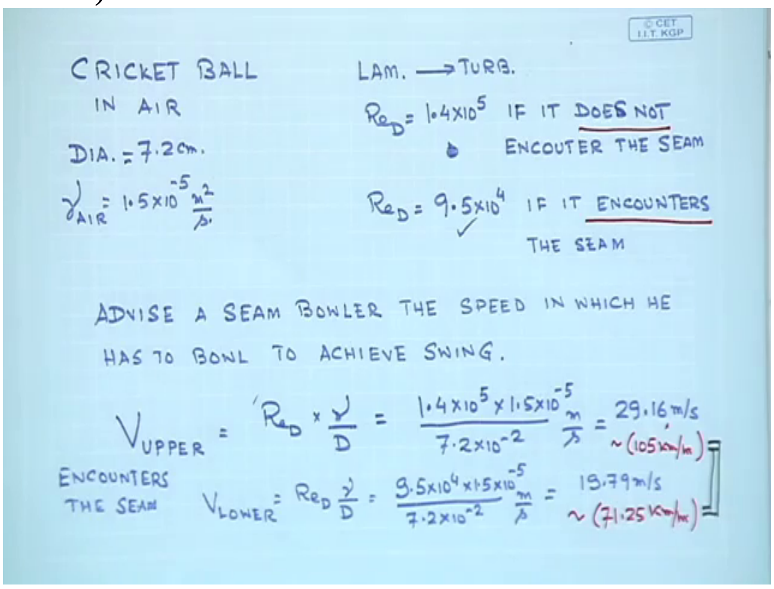

so 105 and 71, if you can bowl in that

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range, then you are going to create turbulent flow through the use of your seam, turbulent flow on one side and the laminar flow on the other side. So if you, if you bowl within this range with the, through the use of seam, you can move the ball in air out-swing or in-swing. So this is, what happens if it is more than 1 0 5, if the velocity is 115 kilometer per hour then what you are going to get is irrespective of whether you use the seam or not you are going to have turbulent flow on both sides of the ball and therefore the pressures will cancel each other and it will not swing if your velocity is less than 71 km per hour then even if we use the seam it will still be laminar.

So you have laminar flow on the plain side and laminar flow on the side facing the seam as a result of which it will move in a straight path. Therefore next time when you try to, try to deliver a swing ball, make sure your velocity is less than 1 0 5 but more than 70 kilometer per hour. There is a second, so that's why when a bowler tries to bowl; the batsman will intently look at the seam position of the ball in the hand of the bowler. So he will look at the seam position and decide that the ball that he is going to face. Is it going to be an out-swing or is it going to be an in-swing?

So the moment the ball is released from the hand of the bowler, based on the last seam position the batsman will decide or batsman will know what he may expect as the behavior of the ball while in air. So it is important that the batsman is able to see the location, the seam location of the bowler when he delivers the ball, specially for fast bowlers, fast and seam bowlers. There is a second; the second part of the problem is even more interesting. There is another class of bowl which are even more unplayable, it is almost unplayable than a swing ball. It is something which is called late swing.

What is late swing? You see the seam position. You know that its, its coming to you but the moment when you, when the bowler releases the ball it comes straight towards you. So you are committed to play, as a batsman you are committed to play assuming since the ball, it is coming towards you in a straight path, it is going to reach you at a specific line but inexplicably at the middle when you are completely, physically and mentally committed to play in a specific way it starts to move and this is very difficult to adjust to. Your body and eyes cannot adjust to a fast ball which is coming towards you at a, at a straight line and suddenly when it has crossed may be half of the (()), it starts to move in a specific direction. That is what is called late swings. So late swings are probably one of the most difficult balls a batsman may face. So the next part of the problem deals with late swing. So what we have then is the fact that we are provided the mass of the ball is 0 point 1 5 6 k g the dia remains same as in the previous part 7 point 2 centimeter and it's

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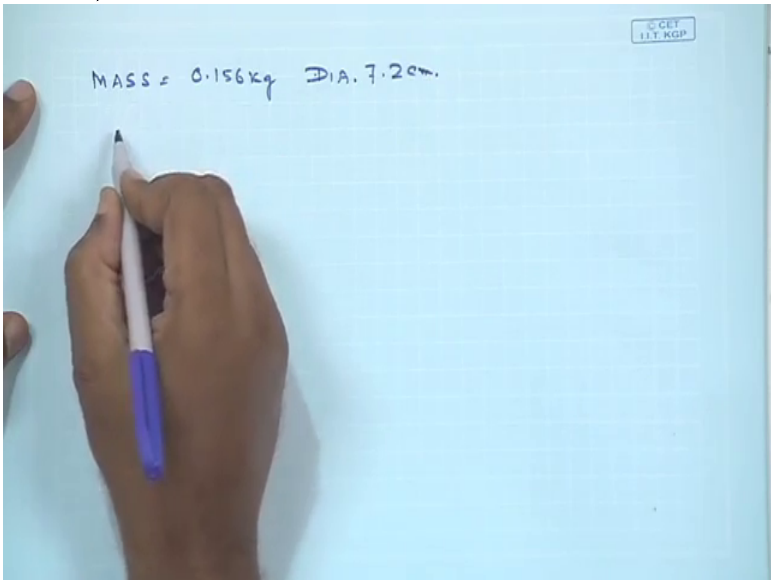

being bowled with a velocity v naught which is greater than the upper limit which we have seen to be equal to be equal to 105 kilometer per hour so since the release velocity is greater than the upper limit you have turbulent flow on both sides of the ball. And therefore it cannot swing. The drag coefficient in this case is 0 point 1 5 which is, which is provided and you need to

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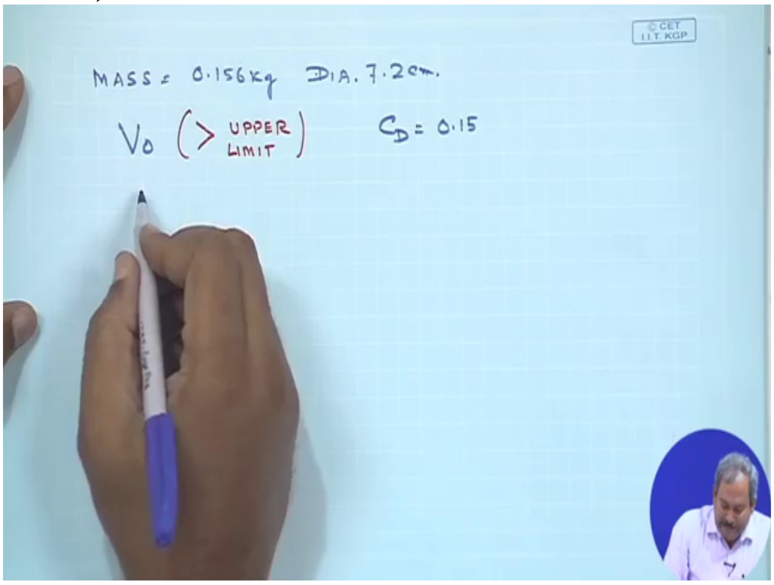

find out the velocity, find v naught such that it starts to swing at a distance of 15 meters from the bowling end and we already know

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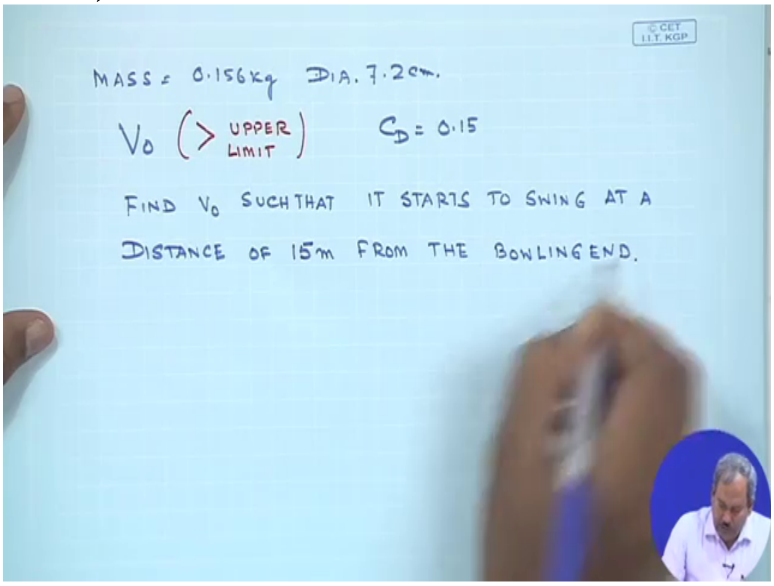

we already know that this v, from our previous, from the previous, from the previous part that v upper is 29 point 1 6 7 meter per second which is equivalent to 105 kilometer per hour this is when it does not

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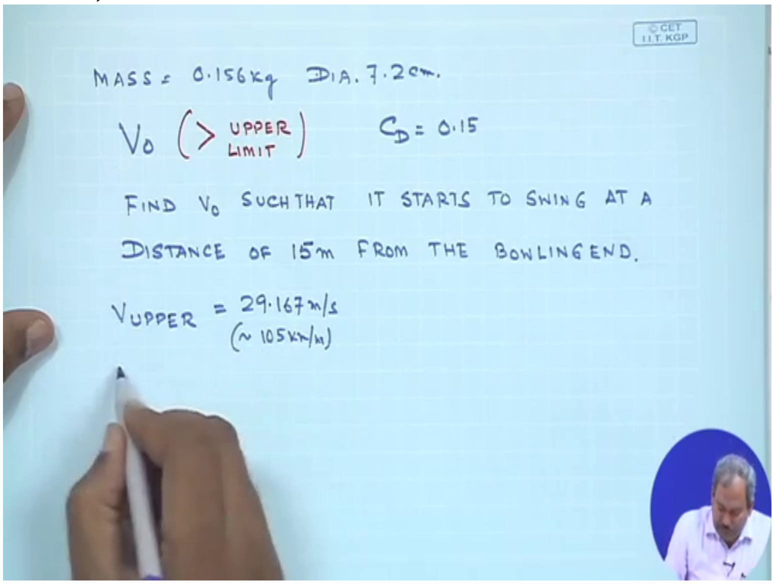

encounter the seam and v lower is equal to 19 point 7 9 meter per second or 71 kilometer per hour

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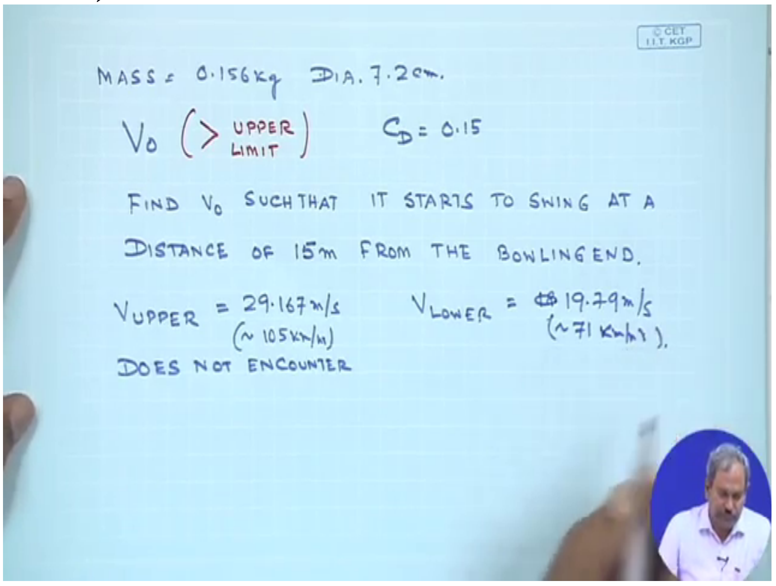

How do you, first think how do you solve the problem what happens when you throw the ball

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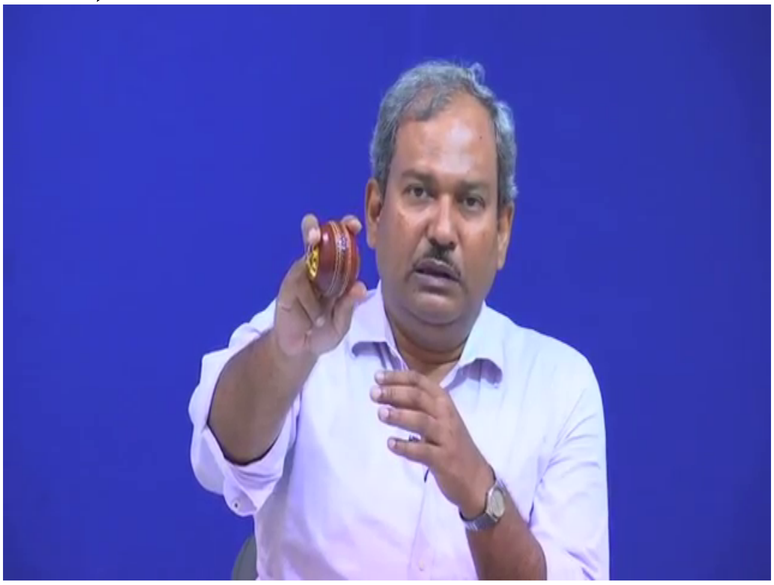

at a speed higher than the speed upper limit of the speed you have turbulent flow on both sides? If you have turbulent flow it does not swing but as it moves in air, the drag, the drag due to air acts on the ball and slows it down. So as it is slowing it down, there is a possibility that even though you have thrown, you have thrown the ball at 110, let's say 110 kilometer per hour, while crossing, while coming towards the batsman the drag of air has reduced the velocity within the range at which the ball is going to swing.

So you start with 110, 110 kilometer per hour, the drag acting on the ball will, will keep on reducing the speed of it and before it reaches the batsman the velocity is less than the upper range of the velocity, upper limit of the velocity it is 105 kilometer per hour if that happens from that point onwards, when it has reached 105 kilometers per hour it will start to move in a specific direction because your seam starts to, the position of the seam will come into play when the velocity is less than 105 kilometer per hour. So you throw the ball at more than 105 kilometer per hour you understand that there is a drag in air which will slow it down but you try to ensure, try to throw it with such a velocity that the drag of air would it down within the range of velocity at which the ball can swing.

So the batsman who sees the ball coming straight at him and slowing down, imperceptible slowing down of the ball, at some point it will start to move away. That is what is (()). So we need to make the force balance. Of the forces acting on the moving ball and the velocity, the starting velocity and the end velocity keeping in mind the length of the pitch which is available to me within that 15 meter the velocity has to reach 1 0 5 meter, 1 0 5 kilometer per hour so that it can swing.

So I throw the ball at a velocity higher than the upper limit but the drag force will slow it down over a distance of 15 meter to 1 0 5 kilometer per hour or lower such that from 15 meters it will start to move in this direction. So that is essentially the problem. The drag coefficient is provided to you. You know what is the force acting in it and mass times, mass of the cricket ball times acceleration which is the force must be equal to the drag force. So if you think in that way, that it's an easy problem so to say. So let's quickly work out the numbers and see what one has to do in order to bowl a late swing.

So we start with,

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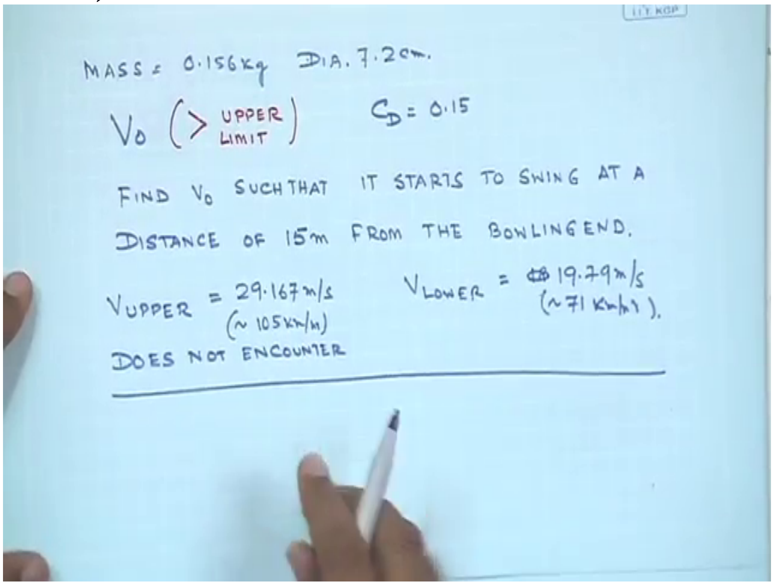

conceptually we start with, that is a drag force acting on the ball must be equal to minus m d v d t where m is the mass of the ball and d v d t is simply the acceleration

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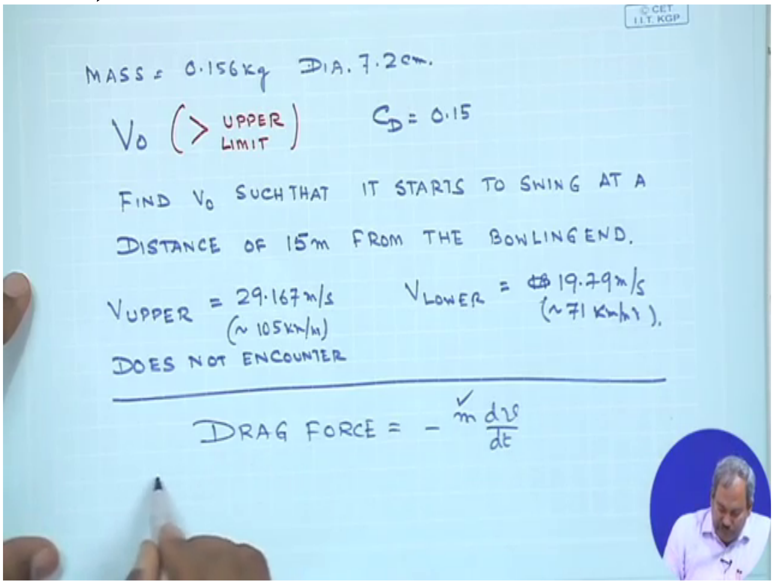

and by definition the drag force is c d times half rho v square and the area which is pi d square by four so this is essentially the frontal

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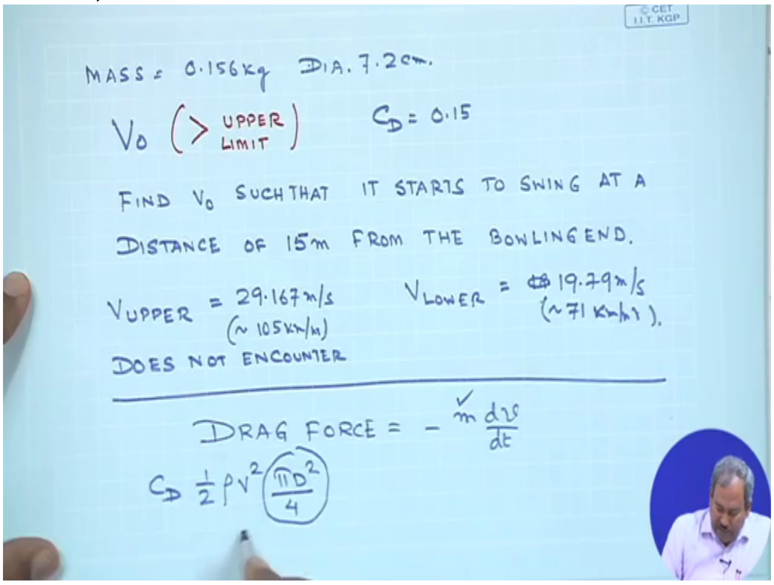

area of the ball That's how c d is defined based on the frontal area which would be pi d square by 4.

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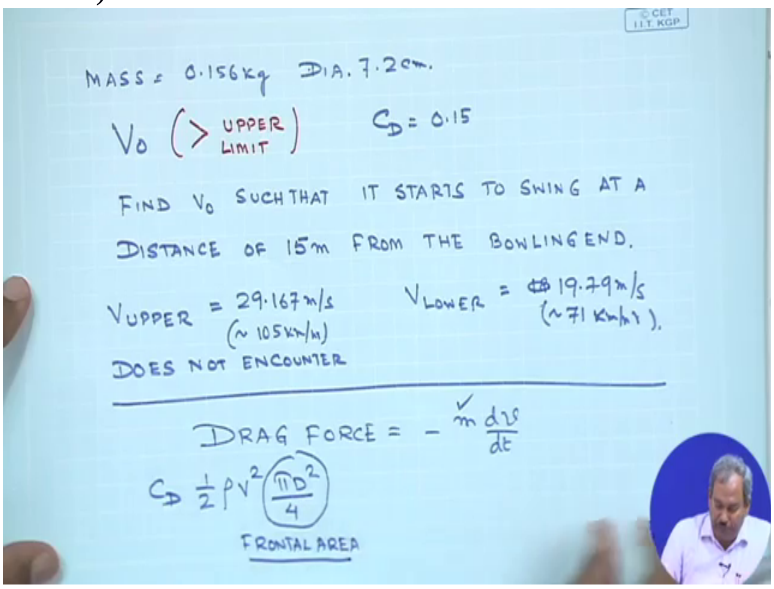

So if this c d,

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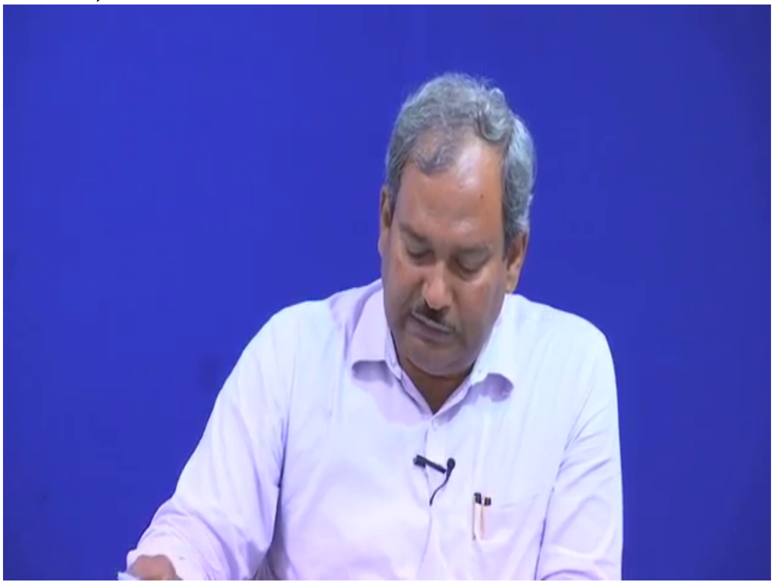

if this expression is now used, c d times half rho v square pi d square by 4 which is equal to minus m d v d t then you put in the numbers

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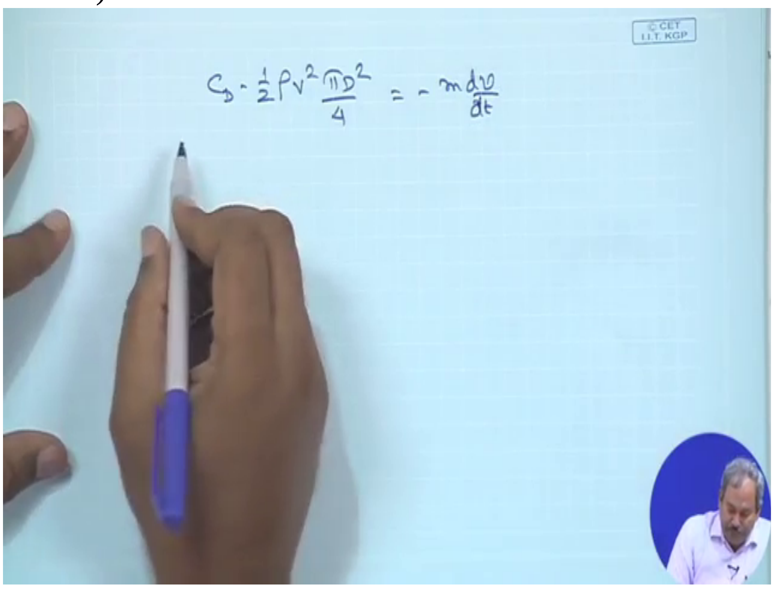

and integrate so it is from zero to t, the value of c d is point 1 5, the density of air is 1 point 2 2 kg per meter cube times pi diameter is provided as 7 point 2 into 10 to power minus 2 by 4 times bring the m to this side so the m is point 1 5 6 k g d t would be equals minus v initial this is the velocity at which the ball has left the hand of the bowler and it is going to bring it down to v critical and by v critical we know that this v critical is the upper limit of the swing ball d v by v square so when you perform the integration

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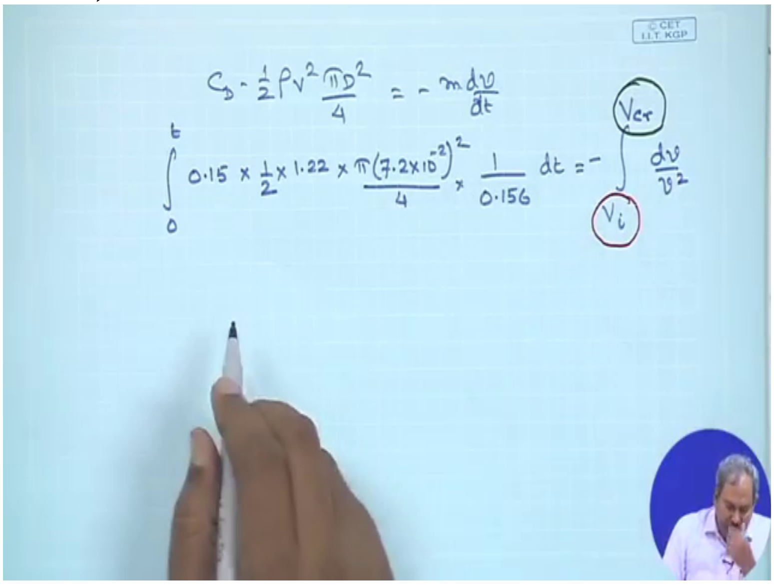

and calculate the numbers what you get is minus 1 by v initial minus 1 by v critical is equal to 2 point 3 9 into 10 to power minus 3 times t. So this is a relation which connects the time,

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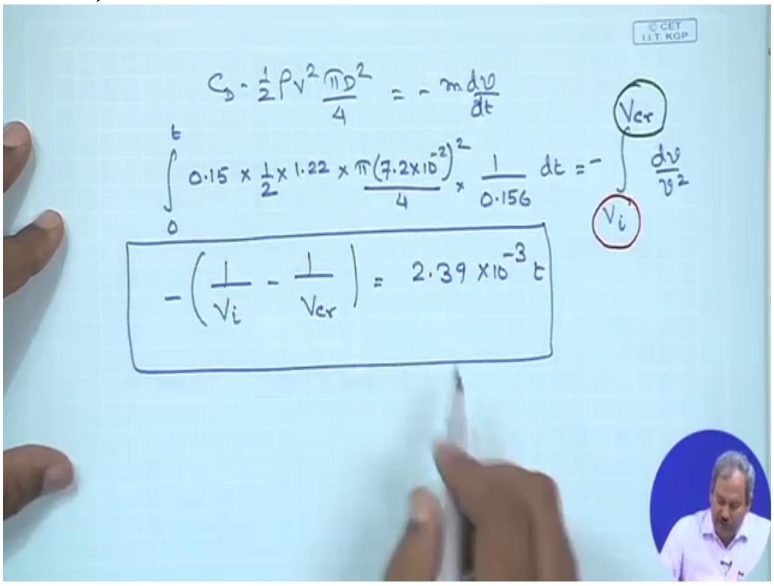

the value, the critical value of the velocity which we know is equal to be 105 kilometer per hour and this v initial is the velocity with which the ball has left the hand of the bowler.

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So we can approximate t to be equal to l by d i and this l is 15 meter as specified divided by v i so this is roughly this is an approximation which would give

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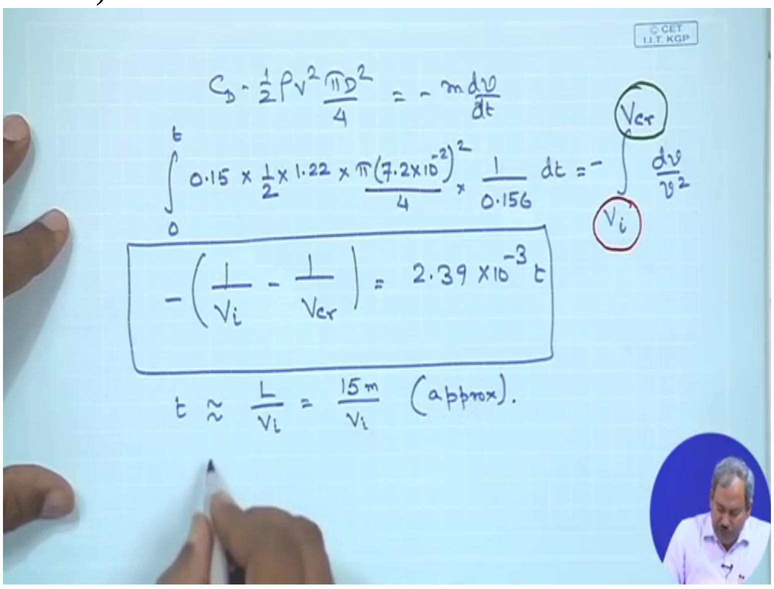

you one by v c r minus 1 by v i to be equals 0 point 0 3 5 8 by v i

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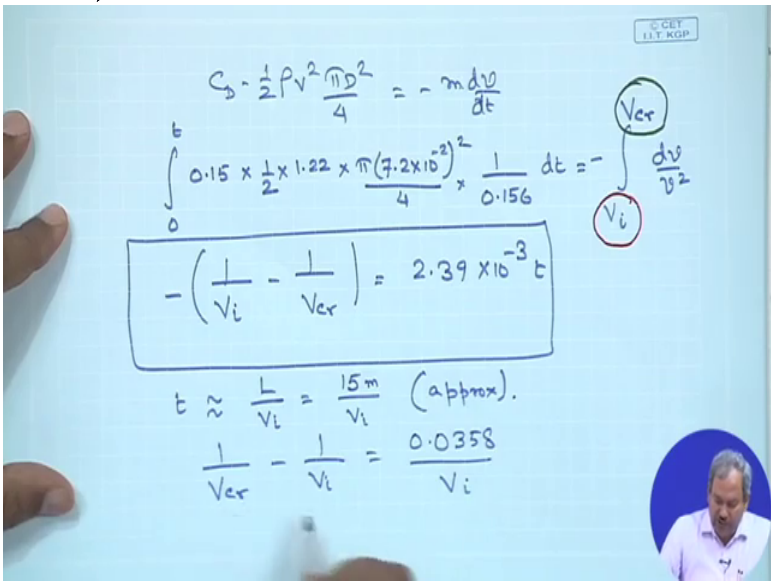

so this is the relation, this is the desired relation between the critical velocity with which at which the speed has to be

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reduced in order for it to start swing v i is the velocity with which the ball has left the bowler's hand. So it and the numbers essentially suggest contribution from c d the length after which it should start swing so this is a nice example of the drag force reducing the value of the velocity of the cricket ball to a point where the location of the seam, the position of the seam will start to, start to play so if your velocity is higher than, is very high then you will not be able to come down to the critical velocity by the time it reaches the batsman therefore the velocity therefore the, the ball will move in a straight path and the batsman will probably be able to play the ball without much of a difficulty. So you have to be very careful, you have to be very precise to decide what is the velocity of the ball. So let's just work out the numbers and it would be interesting to see what is going to be the velocity of the delivery of the ball. So if you put in the numbers, the velocity of the ball should be equal to 1 point 0 3 6 v critical and this v critical is essentially the v upper that we have obtained in the

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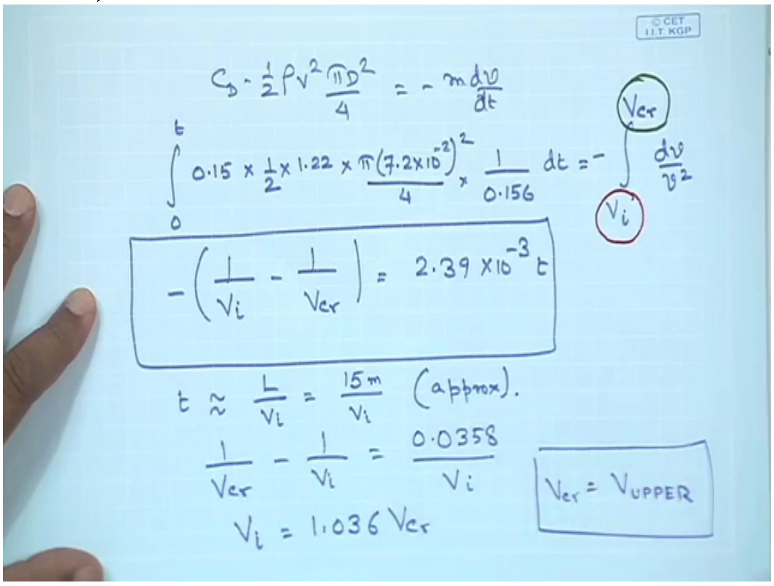

previous case So the final result is this.

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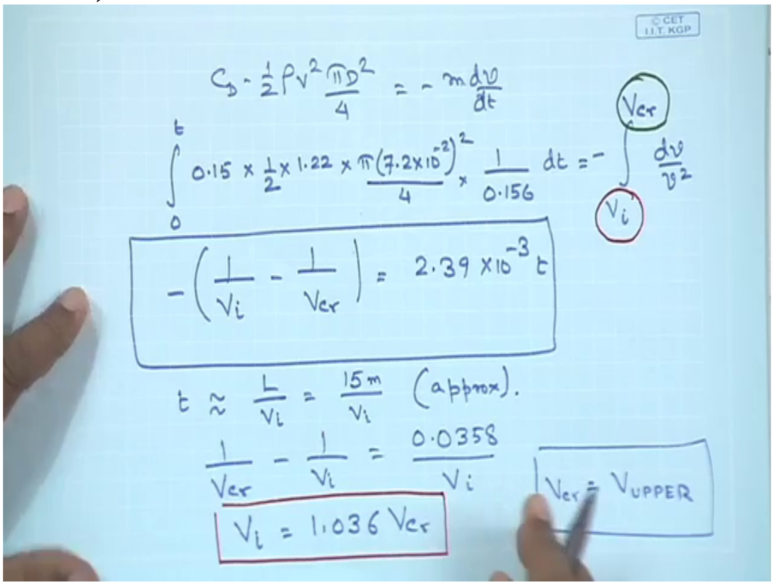

Now when you put in the value of v critical, this should be about 1 0 9 kilometer per hour so as

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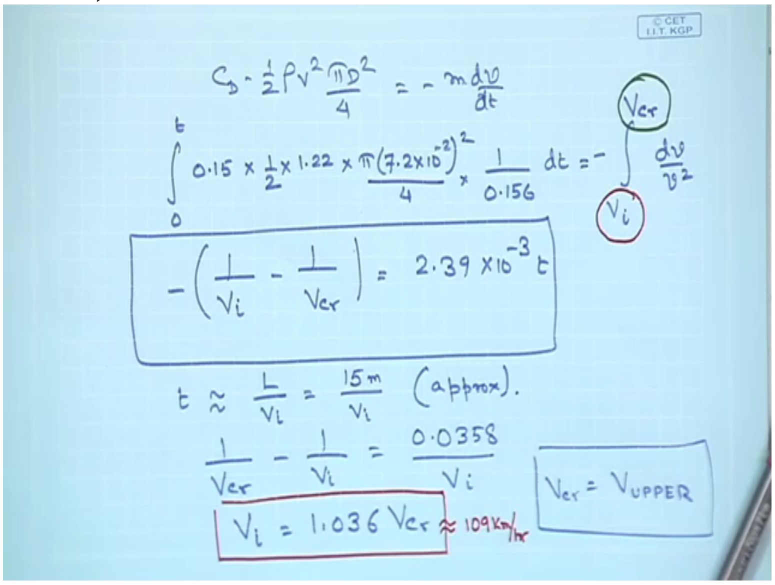

a bowler, you can,

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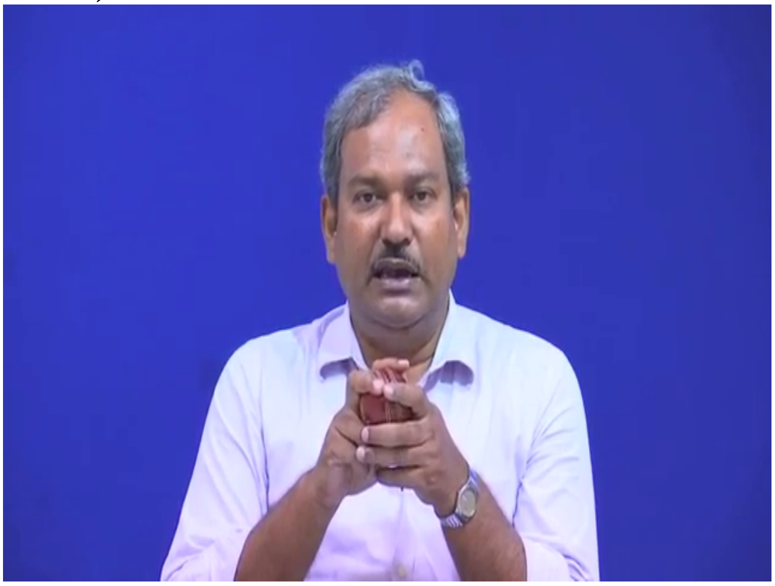

you see what you are up against. You have to bowl very, very close to the upper velocity, upper bound of the velocity but not right at the upper bound of the velocity because if you bowl at the upper bound of the velocity then it would start to swing the moment it leaves, it has left your hand and looking at the seam position at the time you deliver the bowl the batsman will have an idea how to play it, which way it's going to swing.

But if you bowl just slightly above the critical velocity then looking at the position of the seam in your hand at the time of delivery, the batsman would think either swing either out-swing or will be an in-swing delivery but he will be perplexed to see that instead of moving in the direction that it would seem it would move based on the location of the seam it is coming directly at him in a straight path. But as it is coming towards him at the straight path, the drag force acting on the moving ball is slowing it down. The velocity which was more than the critical velocity is slowly coming down and coming down to the point where it would hit the upper bound of the velocity and the moment it does it would start to swing.

So important thing, there are two important things, is fool the batsman into thinking it is going to be a straight ball and, but he would realize his mistake quite late. It would start swinging late and that's why it is called a swing ball. But as a bowler, the challenge is to bowl only at 1 point 0 3 6 times v c r so if your upper bound is 105, you are allowed to bowl at a velocity of 108 kilometer per hour only. If your velocity is higher than that it is going to, it will swing so late that it would reach the batsman before it starts to swing. If your velocity is just slightly above 105 point 5 then it would start to swing almost the moment it leaves your hand and therefore the batsman would be prepared.

So it is often said that late swing or to bowl a late swing is more a matter of chance than that of design. So mostly late swings are extremely difficult to play and extremely difficult to bowl because of the small threshold in velocity that you have 108 and 105 that if you can bowl perfectly within that velocity only then it would let swing. So it's more like a matter of chance but this demonstrate the role boundary layers interaction between a moving object and the surrounding fluid. The type of the boundary layer, the growth of the boundary layer, the laminar boundary layer and the turbulent boundary layer, the forces experienced by a moving object in a fluid, the drag, all this would contribute to something which we often see but do not think about. So next time when you watch cricket, think about transport phenomena.