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Convective Heat over flat plate

Lec-10
Tutorial: Convection over flat plate

Dr. Arup Kumar Das
Department of Mechanical and Industrial Engineering
Indian Institute of Technology Roorkee

Hello welcome in the tenth lecture of my course convective heat transfer in this lecture we will be doing some numerical sums based on flow over flat plate whatever we have learned in the last nine lectures okay. So first let me give you the problems statement, so as first problem we will be doing this estimate the heat loss from a vertical wall exposed to nitrogen.

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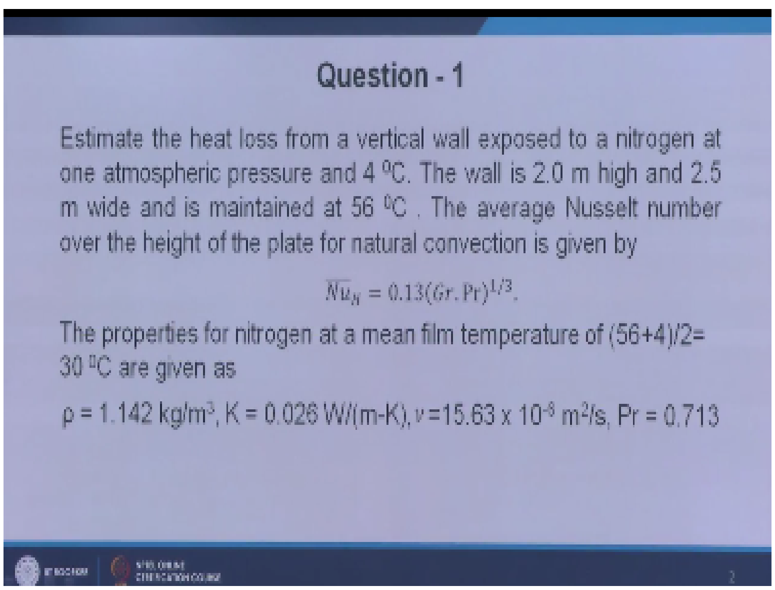

At one atmosphere pressure so 180 pressures and 4^0c okay the wall is 2m high and it 2.5m side and it is maintain that 56^0 c, the average Nusselt number wall the height of the plate for natural convection is given by so this is the natural convection case, so by this formulation so we have to use this. The properties of nitrogen at a mean film temperature so you can see the film temperature mean film temperature will be 56 + 4/2 and that is actually 30^0, so the properties are given ρ k µ and Pr number these are given okay.

So you have find out what is the heat loss from the vertical plate okay, so this problem is related to natural convection over a flat plate so let us try to do this problems first okay. So let me tell you how to solve this problem, as first as we are trying to do natural convection problem, so important thing what we need to evaluate is the value of β.

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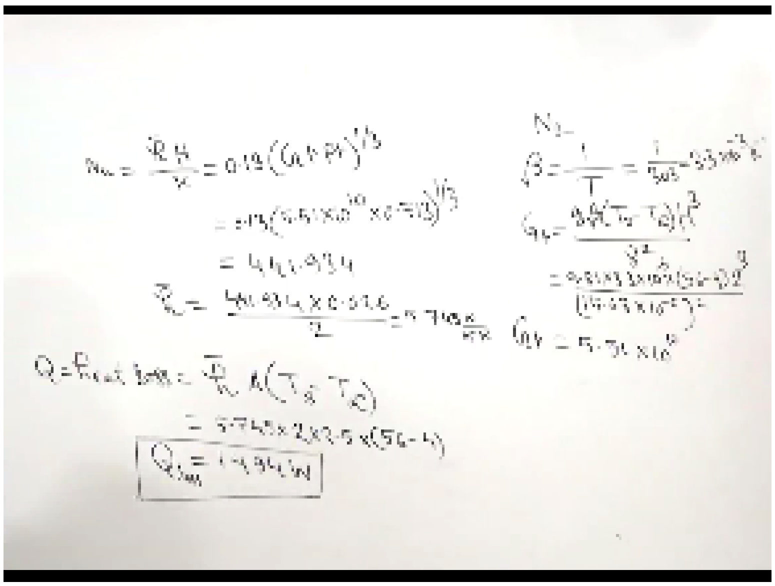

Because β is there in gas of number okay, so β is nothing but volumetric coefficient of x function so that for a natural gas ideal gas like nitrogen we can write down is equal to 1/t okay, so here that temperature we can take as you know 30^0 c. so average temperature is 30^0 c which means 303 Kelvin, so this is 1/303 so which is actually equivalent to 3.3 x 10^{-3} and unit will be Kelvin to the power -1 okay.

So first evaluation of β for nitrogen okay so for nitrogen we can do in this fashion okay. Next as we have found out β let us try to give the value of grass of number so grass of number will be nothing but g β then you are having surface temperature - fix time temperature okay then we are having h^3 height of the plate, and divide d by δ^2 okay, so new for the nitrogen at mean temperature is given in the problem okay.

So let me put the values so this becomes 9.81 x 3.3 x 10^{-3} the value of β and then we are having ts as 56 and t_{∞} is 4 x h is nothing but 2m heights, so we are having actually 2^3 / $\eta^{2,}$ η is also given in the problem you can see new is given over here as 15.6 x10^{-6} so that will be putting over here $(15.63 \times 10^{-6})^2$ okay. So if we find out grass of number like this grass of number comes out to be 5.51 x 10^{10} okay so this is value of my grass of number.

Now already for this type case in the problem the Nusselt number co relation is given as Nusselt number is equals to 0.13 grass of in to $Pr^{1/3}$, where Pr number is known as 0.713 at mean temperature 30^0c, so this we can use and we can find out the Nusselt number is actually hH/k so mean heat transfer coefficient in to height okay of the plate in to divided by k this is nothing but equals to as for the correlation 0.13 then grass of x $Pr^{1/3}$ okay, so if you use this values of grass of and pr it comes out to be 0.13 x you know grass of number we have got 5.51 x 10^{10} x Pr is given in the problem $0.713^{1/3}$ okay.

So ultimately you get the Nusselt number 441.934 okay, now if you try to evaluate the value of heat transfer coefficient so h bar will be Nusselt number 441.934 x k, so k is also given in the sum as at mean temperature 0.026 / h which is 2m. So if you do so h comes out to be 5.745 watt for m^2 Kelvin okay, so this is the heat transfer average heat transfer coefficient we have found out okay.

Now if you try to find out what is the heat loss okay so heat loss let say q, q is the heat loss my answer what I need to find out so heat loss will be actually h average so average heat transfer coefficient in to area in to surface temperature – fresh stream temperature okay, so let me put the value of h first so this is nothing but 5.745 x area, area is nothing but your height and wide width so height is 2 so it is 2 x with this 2.5 okay, so 2.5 mm 5 m wide plate.
So this in to ts – t_{∞} is 56 - 4 okay, so if you calculate this one so over heat loss becomes 1494 watt okay so this is my heat loss q okay, so heat loss q the final answer comes out to be 1494 watt okay so let me show me the final answer over here, so final answer is actually this one 1494 W, so in this way you can actually do sums for natural convection. Let me show you the next problem. So next problem goes like this water flow.

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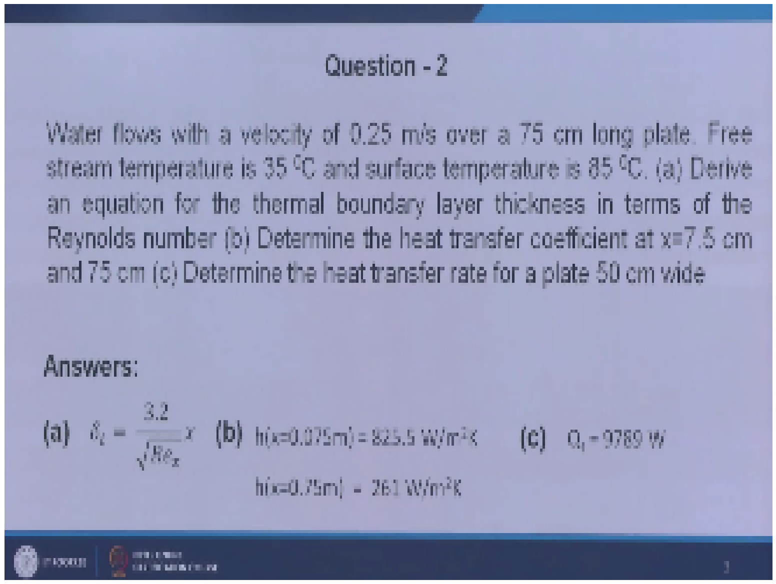

Water flow with the velocity of 0.25m/s over a 75cm long plate okay water flows with the velocity of this over a 75cm long plate free stream temperature is 35^0C, so t_∞ is 35^0 and surface temperature so surface is having constant temperature 85^0c, so you need to find out what you to derive and equation for the thermal boundary layer thickness in terms of the Reynolds number so δ t in terms of re you have to find out and then you have to determine the heat transfer coefficient at x = 7.5cm and 75cm.

So h at 7.5 and 75cm you have to find out and finally you have to get the heat transfer coefficient rate for a plate having 50cm width so with this problems is once again flow over a flat plate and this time it is actually forced convection case. So let me see how this problem can be solved so let me first erase the previous one and give the idea how this problem can be solved and in this problem we are having water so your water property is very, very important. You can get the properties from you stream table so we will be also use in data from stream table to get the water properties okay.

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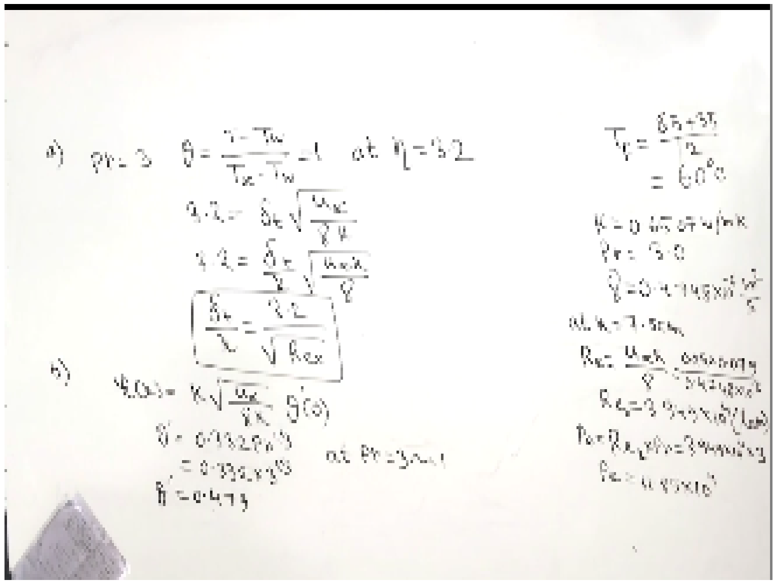

So first let me find out what is the mean temperature so let say the mean temperature is actually mean temperature form the fluid is actually you can see 85 +35 / 2 so you get this is actually 60^0 c okay, so at 60^0 c if you try to find out the properties so k will be come for water from stream table you can get 0.6507 W/m k okay then Pr number if you see from stream table once again it will come as 3 okay. δ it will come as kinematic viscosity it will come as 0.4748 okay x 20^{-6} okay m^2/s okay.

And next let us try to find out first what is the Reynolds number okay so as we are having two cases okay so 7.5 and 75 so let me first try to find out what is that 7.5 so at x – 7.5cm okay, so re is actually u_∞ x okay by δ and u_∞ is nothing but 0.25 okay x is 0.075 okay / δ that is 0.4748 from the preparative will just now we have got 10^{-6}. So ultimately this re comes out to be 3.949 x 10^4, so you see it is actually less than 5 x 10^5 so we can say this is actually a laminar zone okay.

Now if it is laminar quickly we can find out the peclet number, so peclet number is nothing but re by the way this is rex at 7.5cm so rex x pr, so this becomes 3.949 x 10^4 x Pr which is 3, if you do that so peclet number becomes 11.85 x 10^4 okay. So this we got peclet number, now first part let us try to answer so we will have to derive an equation for the thermal δ t we have to derive as a part of as a function of Reynolds number.

So part A let me do it over here, so part a if you try to do so for Pr = 3 okay and if you defined the non dimensional temperature T as t –tw / t_∞ – tw similar type of non dimensional we have done so many times earlier for flat plate case okay. So this will be equals to one at η = 3.2 okay, so this you can find out whenever you solve the energy equation whatever final form we have given and you can find out that at η = 3.3 η becomes one okay.

So if we take this one so we get 3.2 which is the value of η is nothing but δ t √, now the non dimensional of δ t is nothing but u_∞ μ x X okay. Here 3.2 = δ t / x okay if you take x out so it becomes u_∞ x / μ okay which is nothing but actually Reynolds number. So you get δt / xis actually 3.2 /√rex so this is the relationship we have actually desire in the part a that what is the relationship between δt and rex.

Remember here I have taken the help of thermal boundary layer equation θ will become one whenever η becomes 3.2 this came from the solution on the boundary layer equation okay. Let me go to the part B so part B over here so need to find out the heat transfer coefficients so let me write down the heat transfer coefficient. So hx okay heat transfer coefficient can be written as k x n then u $_\infty$ μ x X okay x θ' is 0 okay so θ already we have find over here. So θ' is 0 this also we have derived in our lecture.

So if we will taking the help of this okay, so let me try to find out what is θ' first, so we know θ' is actually 0.332 x Pr $^{1/3}$ okay as our Pr = 3 which is in the range of 1. We have seen three different cases pr =1 and then we have seen Pr ˂ 1and Pr more than 1, so we are taking the pr = 1zone but as it is exactly not equals to 1 it is 3, so we have taking pr$^{1/3}$ which actually we have seen in case of higher pr number zone.

So constant we have keeping same but pr $^{1/3}$ we are keeping from pr > 1 cases okay. So this is θ' to be have got so in our case θ' will become 0.332 x $3^{1/3}$ so this becomes θ' becomes 0.479 okay. So we have obtain θ', so next task is to put the value of x and θ' over here to get the value of hx are different level okay. So if you do so, so let us do it over there okay so if you do so, so for the second part we will be using the formulation whatever we have just now derived okay. So let me come over here.

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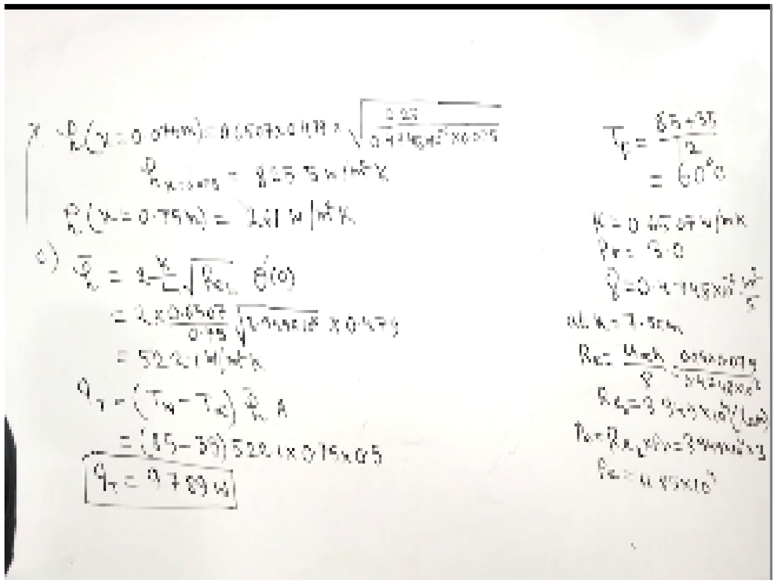

From here to here so if we see that h okay heat transfer coefficient at okay x = first let me do it for 7.5 cm so 0.075m okay that becomes obviously this formula we will be using a value of k is actually we have found out as 0.6507 so let me take that value. So 0.6507 x 0.479 is the value of θ', so this will be writing over here. So 0.479 and then multiplied by √ here we are having u_∞ the value of u_∞ is 0.25m/s given in the sum okay and then divided by µ x X, so µ is nothing but 0.4748 x 10^{-6} okay.

And then we are having x, x is nothing but 0.075 okay so if you calculate this one so h at x = 0.075 turns out to be 825.5 w/m^2 Kelvin okay. Just the same thing can be found out for x =75cm which is nothing but 0.75m the value of last one it will be changing and you can do the same short of calculation you can find out this turns out be 261w/m^2 Kelvin okay. So first two parts already we have answer so let me show you the last part in the last part it is asked determine the heat transfer rate for a plate of 50 m wide.

So here we need to find out the heat transfer rate as a part of C okay, so let me show you how that can be done so c is over here so for c as we have already found out what is h let me do what is h bar or average heat transfer coefficient average heat transfer coefficient will be 2k/l x √ Rel x θ'(0). So this also we have shown the lecture so from here we will be finding out the value of h bar so h bar is nothing but let us put the values. 0.6507 is the K, l is nothing but 0.75m rel we have found out Rel we have found out over rel is actually 3.949 x 10^5, so that we will be putting over here 3.949 x 10^5 okay.

And then we are having θ'0 which is nothing but 0.479, so if you calculate this one so h bar becomes 522.1 w/m^2 Kelvin okay. So we have got h bar this will be using for finding out the heat transfer rate so qt is the heat transfer rate this becomes $T_w - T_\infty$ x h bar x a okay. So let me put the values so T_w is nothing but 85-T ∞ is 35 free steam temperatures, h bar we have just now find out 522.1 and area is nothing but 0.75 x the width the width is actually 50cm, so 0.5. So ultimately this QT becomes something around QT become 9789w okay.

So this is the last answer part C okay so let me show you all three answers over here as question two so this is the first answer we have got δ t = 3.2 / √ re_x x X, second answer we have got for both the levels at 0.075 and 0.75 and last C we have got 9789 as we have shown over here okay. Let me show you the, another problem the problem is like this.

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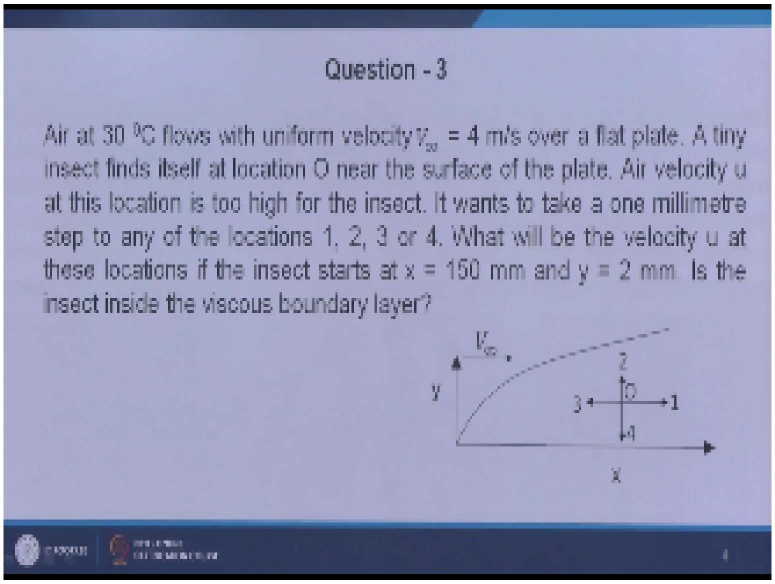

Here at 30^0 c flows with uniform velocity 4m/s over a flat plate okay. A tiny insect this tiny insect find itself at location o over here location O near the surface of the plate okay, air velocity u at this location is too high for the insect, so the velocity whatever it is facing that is too high for the insect, it once to take 1mm step to any of the locations so it wants to move 1mm so it is having four options to go in this directions to move in up to move down and to move in the left hand side 1, 2, 3, 4 respectively.

What will be the velocity u at this locations if the insects starts that means o point is 150mm, 2mm x and y respectively, then I have asked is the insect inside the viscous boundary layer though we have shown the figure like this but is the insect inside viscous boundary layer okay. So this is typical problem a flow over a flat plate okay and we will try to see this one here nowhere heat transfer is involved we will be doing this sum for only for the fluid mechanics velocity boundary layer okay, only the properties we need to take at 30^0C for the er okay.

So let me show you this one very simple fluid mechanics related problem, so let me show you the solution of this problem many of you can readily do it because already you have knowledge of fluid mechanics so we will be using the same over here and try to find out the solution of the present problem okay.

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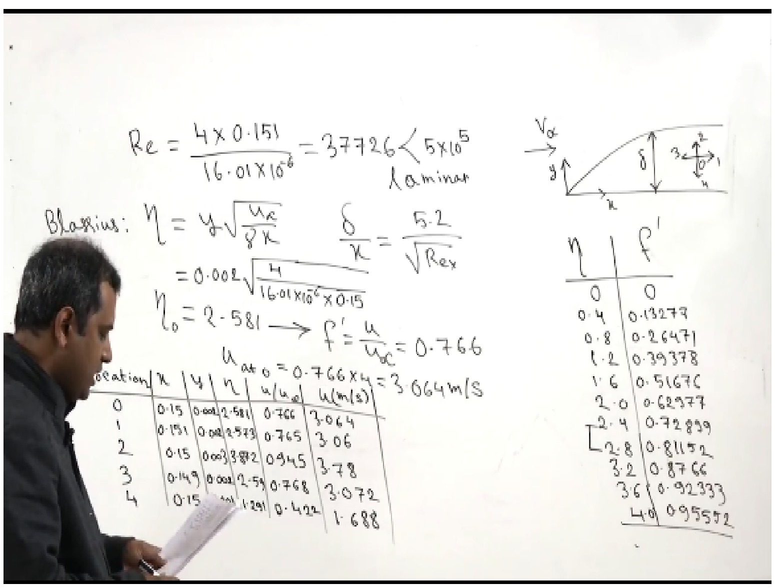

So as I said we are having actually flow over a flat plate so let us say this is a case we are having a flat plate like and there is some sort of in flow okay so let us say the inflow velocity is $v \propto$ okay so this is my x direction okay and this is my y direction so here we will having a velocity boundary layer let us say the boundary layer thickness is actually δ okay and we are having the in set at the beginning over here at O position okay and it is having 4 different options to move in 1, 2, 3 and 4 respectively.

1, 2, 3 and 4 respectively okay so the question is actually at different locations what velocity it will be getting so to solve this problem first we need to understand weather it is in laminar zone or turbulent zone, so let me first check whether it is laminar or turbulent so first we will finding out the Reynolds number okay so Reynolds number is nothing 4 x first let me see what it is getting at 1 position.

If it is at 1 position then definitely your x will be 150 + and as it is taking 1mm lea, so it is 151 mm actually, so let me put 151 for the x for the 1 position first so 0.151 because that is the extreme limit so that will be having the highest Reynolds number, so that we try to find out divided by 16.01 x 10^{-6} if 1 point is laminar then obviously this 2, 3, 4 will be laminar okay so if we try to see this, this come by the way this 1 16.01 10^{6} is actually the convective viscosity of here at 30^{0}C okay.

So if you see that one it will come out as 37726 okay which is definitely < 5 x 10^{-5} okay which is the limit for this one, so from here we have understood as it is laminar okay so we can actually use our Blasius law okay we can actually use our Blasius law whatever we have learnt in fluid mechanics, so let me start using Blasius okay, so first we know for Blasius the similarity parameter is η which is nothing y x √u ∝/ ν x okay so this is my η similarities variable.

So from Blasius also we know that δ/ x is actually 5.2/ Rex okay so this also we have see in our fluid mechanics small h from Blasius equation, so this is from Blasius okay so if we try to use this let me first find out the value of η for 0^{th} location, now 1 by 1 we have to do for all 5 locations first let us see what happens at 0^{th} location so if you see at 0^{th} lactation so it becomes y is nothing but 0. It is actually 2mm, so 0.002 002 √ over of u ∝ is given as 4 so 4 divide by ν, ν already just now we have used 16.01 this you need to find out from air property it will 10^{-6} and then we are having x at 0 location is nothing but 150 mm.

So that means 0.15 okay so if we use this η comes out to be at 0^{th} locations so η at 0 we can write down this comes out to be 2.581 okay next task is to find out what is the value u/ u ∝ and sub sequently we can get the value of u because velocity is required so to get the value of u /u∝ we need to see the solution of your Blasius equation which is nothing but f’’’ + f’’ is = 0 okay with it is corresponding boundary condition.

So let me not go over that solution over here but let me try to give you a table for different η values and subsequently different f’ values okay because f’ is nothing but u/ u ∝ as per Blasius we know okay, so let me give you those values so at 0 boundary condition we know that η0 means f’ 0 okay from your Nusselt boundary condition it is coming then let me give certain intervals so 0.4 is 0.13277 okay then 0.8 is actually 0.26471 and then 0 1.2 is actually 0.39378 then 1.6 is actually 0.51676 then 2 is actually 0.62977 and then 2.4 is actually 0.72899 then if you proceed further 2.8 is actually 0.81152, 3.2 is actually 0.8766 and then 3.6 is actually 0.9233 and finally let us write down up to 4 only.

At 4 0.95552 okay so this list can be length further but for our present case up to this will be sufficient so you see our η value at 0 is 2.581 which lies in between these two so if we do little bit interpolation then we will be finding out this at this ηf’ which is nothing but u/ u ∝ is = if you do the interpolation between this 2 you will be getting this is nothing but 0. 7 66 and now as u ∝ or v ∝ those are same actually so that is known to us which is nothing but your 4m/ s then from here we can get u at 0 at x= 0 okay.

Let me not write down write down x0 so let me write down at 0 okay because x is having some other value at 0 so u at 0 is actually 0.766 x 4 0.766 x 4 which is nothing but 3.064 m/ s okay now if you proceed in same way for η1 η2, η3 and η4 which will be only changing the value of x so x and y okay for example for 1 position y remains 0.002 but x will be 0. 051 okay for 2 position y will be 0.003 and x will be 0.15.

For 3 position x y will be 0.002 and x will be 0.149 and sub sequently at 4 position y will be 0.001 and x will be 0.15, so if you do like that you will be finding different values of η and using this table by our interpolation you have to get the value of f’ which is nothing but u/u ∝ and sub sequently multiplying f’ / u ∝ which = 4m / s we can get the velocity so let me show you the finial table what we obtain so let me give you this is the location in the first column then we are having the corresponding x values corresponding y values okay.

The we are having η values okay then you are having corresponding u/ u ∝ values and finally if you multiply by 4 it is becoming u for different locations, so if you try to construct a table like for location 0 already we have done x was 0.15 y was 0.002 then η we have found out as 2.581 okay u/u∝ we have got as 0.766 and finally u k mass 3.064 m/s let us give you the final answer for all 1, 2, 3, 4 for 1 it will be 0.151 for 2, for 1 it will be 0.151x y is 0.002 for η you will be getting this is nothing but 2.573 u/ u∝ f' comes out to be 0.765 and finally u come out be 0. 3.06 Similarly if you do the rest at 2 position x will remain 0. 15 y will be become 0.003 and then η will become 3.872 and then f' it will become 0.945 and sub sequently u become 3.78 m/s.

For location 3 it will be 0.149 and then y is 0.002 and then η becomes 2.59 and then u / u∝ f' becomes 0.768 and finally u becomes 3. 072 and for the last location 4^{th} location you can get the x is 0.15 y is 0.001 okay and then u∝ f' is 1.291 subsequently f' is 0.0.422 and finally the velocity comes out to be 1.688 now as the inset is not loving the velocity so from here at different locations from the velocity you can find definitely 4^{th} location is preferable for the inset, so it is better suggested that it can move down 1m left and it will be facing least amount of velocity okay so this answer we have found out the last part of this answer is actually weather the inset is inside the boundary layer or not.

To find out that position let me first calculate what is the boundary layer thickness okay, so that I will be doing it over here so for vending out the boundary layer thickness we know from fluid mechanics equation here also we have shown.

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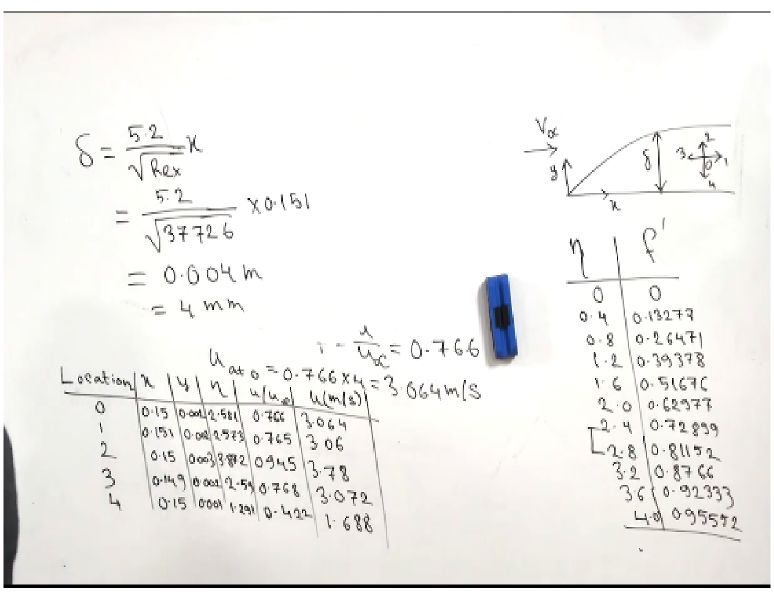

δ is actually 5.2/ √ Rex okay into x okay so this equation already we have seen so let me put the values so here you see the boundary layer as it will be growing up so maximum boundary layer thickness will be somewhere at 1 okay so let me put the value of x at 1 to get the maximum boundary layer thickness so you can find out this is nothing but 5.2/ √ Rex for 1 already we have shown you the value came out 37 okay 726 right and then your x value is 0.151 okay so ultimately you get your boundary layer thickness at 1, 0.004 m.

So that means 4mm now you see the insect is now where moving it is starting from 2mm at the most it can go if it takes 1 leap up so it can take up to 3mm which is obviously lesser than 4mm so that the insect will be always remaining in the boundary layer zone okay so this is the answer for this question let me show you the answer over.

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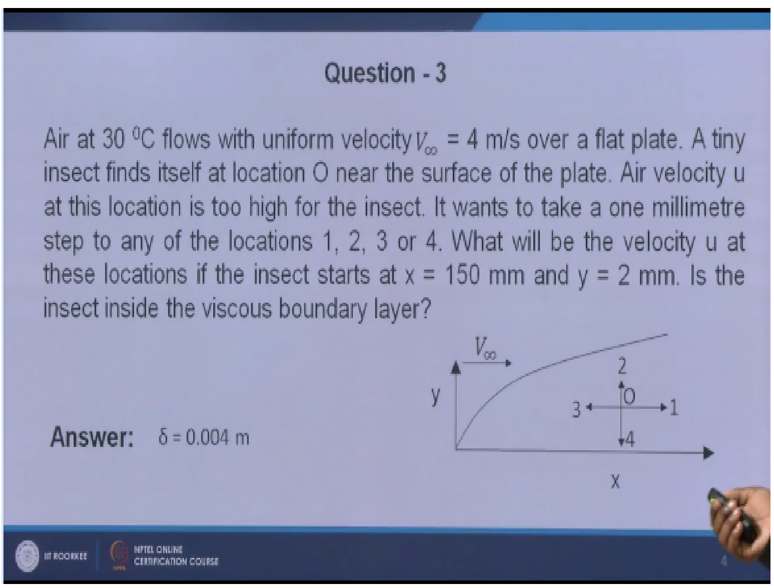

So first obviously the velocities I have shown over here in the table I have not shown that table over here but the boundary layer thickness I have shown over her as δ – 0.004 okay so with this I will be ending this lecture in our next lecture we will be starting a new thing internal floating so we will be actually discussing about forced convection induct okay, so if you have any query related to flow over flat plate or any other generalized questions about convection heat transfer please keep posting on this discussion forum thank, thank you very much.

For Further Details Contact

Coordinator, Educational Technology Cell
Indian Institute of Technology Roorkee
Roorkee – 247667
E Mail: etcell.iitrke@gmail.com. etcell@iitr.ernet.in
Website: www.iitr.ac.in/centers/ETC, www.nptel.ac.in

Production Team
Sarath K. V
Jithin. K
Pankaj Saini
Arun. S
Mohan Raj. S

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