Course Name: Turbulence Modelling

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Week - 8

Lecture – Lec42

42. Introduction to wall-resolved simulations - I

Okay, so let us get started. So, we have all seen this graph before where I showed you the RMS data for a wall bounded turbulent flows and we have discussed that there is something called anisotropy where the even in a flow like a turbulent plane co-ed flow or any other turbulent boundary layer you will get this U_{rms}, V_{rms}, W_{rms} are of different not orders of magnitude, but the values are like twice or thrice of that one, but they are of the same order of magnitude that we discussed and why is the wall normal direction. So, now in addition to this anisotropy that we discussed ok. there is something else that you need to look at in this graph. So, as this is the wall at y equal to 0, this is the wall.

So, as you approach the wall, what do you notice here in the data here? u is the, if I write the coordinates x direction, y direction and z. So, in x direction you have the U_{rms}, this is the V_{rms} and the W_{rms} is the out of plane component. So, what do you notice as you approach wall as y approaches 0 in the 3 graph only as you are coming close to 0 see what do you notice here. Anything very peculiar thing that you observe? Look at the way the data is damping.

You are approaching the wall y is tending to 0 and the graph starts to damp. That means the U_{rms} starts to damp. Similarly, the W_{rms} that is out of plane. V_{rms} is also damping. Are they all damping at the same rate? No? Is it something like one which is damping much much ahead of the other two right which is that one? U_{rms}.

U_{rms}. No. V_{rms}. V_{rms}. See the V_{rms} starts to damp much much higher.

So, this is where the data is not exhibiting any damping right let us say from the y by h 0.5 and above up to the channel centerline. So, here you see it is more or less constant the V_{rms}, W_{rms} and the U_{rms}. But as you come closer the V_{rms} is already started to damp far away from the wall. But the U_{rms} rises and drops very close to the wall.

So, the damping is occurring only from here. Similarly for a W_{rms} also let us say something somewhere here right, but the V_{rms} starts to damp much much ahead right. So, the damping is occurring damping of V_{rms} is occurring much much ahead of U_{rms} and the W_{rms} or in other words the wall normal fluctuations are damping faster than the wall parallel ones right. So, the wall normal fluctuation that is your v' are damping faster than wall parallel ones it is your u'and w'. So, why does this occur? Does this occur in every flow where you have a wall that is we have to see and this feature must be taken into consideration by your model because this is the physics that I am discussing ok.

So, this particular feature is this any doubts on this before I move to the next slide. This is what we see it in the data. that the V_{rms} that is the wall normal rms quantity is damping faster coming to 0 faster because you see it is look at the slope it is coming to 0 faster compared to the wall parallel ones. So, this particular state of turbulence is called a two component limit, two component limit this was discovered by John Lumley. There is also a turbulence theory book written by him.

So, this two component limit what does this say? That means two components are behaving in one fashion in a wall bounded flow rather than the other component that is the wall parallel components are damping in one fashion. and wall normal you know turbulent quantity is damping at a different behavior right. So, this state of turbulence is called two component limit. So, what this means is as we approach wall, the wall normal stress goes to 0 that is v'^2 goes to 0 faster than the wall parallel ones that is your $\overline{u'}2$. and $\overline{W'}2$.

So, this state of turbulence, this state of turbulence is called two component limit. wall normal stress goes to 0 faster than the wall parallel. So, this particular thing happens in two different ways and before that we will see that how general this is because if you want to model this you need to make sure that this is occurring for all types of flows where a boundary layer is present a wall is present and this is true exception for this can be where you have stratification or Coriolis force. So, this occurs note here. occurs in all turbulent boundary layers except when Coriolis force or stratification is present So, this is common right not everybody uses Coriolis force in their calculations except let us say you are doing turbo machinery or atmospheric flow right special cases or not everybody is looking into a flow where there is stratification.

So, in general this is common you can say right. So, in general this occurs this phenomena two component limit is more generic compared to whenever you have a Coriolis force or a stratification effect. So, that means this has to be considered for modeling and does does your model models this. So, eddy viscosity model has a problem because the isotropy is enforced through eddy viscosity and turbulence kinetic energy in the Boussinesq right. So, EVM models have you can say eddy viscosity models has an issue here.

since isotropy isotropic behavior is you can say encouraged, encouraged by your eddy viscosity nu t. and the turbulence kinetic energy k in the boussinesq right. you have minus 2 third k in the Boussinesq you have also have eddy viscosity which is lumping turbulence as a scalar quantity and we clearly see that V_{rms} has to damp. So, turbulence kinetic energy when you are computing it is a sum of all the three stresses where some isotropic behavior is enforced means that it may give higher turbulence than what is necessarily there because V is now much smaller it is damping much faster also. So, the actual turbulence kinetic energy can be much lower than what your turbulence model a eddy viscosity model is predicting.

Therefore, it requires something to be done ok. So, this particular two component limit occurs due to two different reasons right. So, two component limit or you can say two component state of turbulence occurs due to two factors. One so there are two types of damping that is occurring here one is that there is of course viscous damping for all the three components. So, there is something special that is occurring for the wall normal component that is the.

So, this wall normal fluctuation or the V_{rms}. So, this feels the wall far away from the wall. So, the wall parallel ones that is your U_{rms} and the W_{rms} they feel the wall as it approaches the wall very close due to viscous effects. So, there is viscous damping for the wall parallel stresses or wall parallel turbulent components. But the wall normal one feels the wall far away from it because of the pressure field.

So there is a pressure damping that is occurring for the wall normal fluctuation. But the wall parallel fluctuation gets only viscous damping and viscous damping is present for all the three components. So it is the pressure damping that is the major reason for wall normal stress to go to 0 faster. that is why the curve starts to damp much much ahead. So, that is far away from the wall the curve is already started to damp for the V_{rms}, but the U_{rms} and W_{rms} very close to the wall it is dropping.

So, first thing is damping of damping of v’$\overline{v'}$2. occurs far from the wall that is you can say about y plus about less than approximately equal to 200. So, it is much much away from the wall through the pressure field or pressure damping. The second one is of course, the viscous damping that is present viscous damping occurs close to the wall that is about y plus less than to approximately 20 that is let us say in the middle of the buffer layer to the linear sub layer when it is dominant viscous effects and that is dominant for all the three rms quantities. So, this first one is the critical for the $\overline{v'}$2 average component ok.

So, this has to be considered by your model right. So, all models all models must ah capture this behavior capture or predict or even accommodate may not be able to predict or you can say account for this behavior. Capturing is possible only when we are actually calculating all the three stresses. So, in eddy viscosity models we are computing only turbulence kinetic energy. So, it must account for this behavior.

If you are solving Reynolds stress equations then it must also predict or capture that behavior. So, how is this achieved in the RANS models is there are three ways of doing this. The first is in the eddy viscosity models, in the eddy viscosity model. In this one we need to do what is called a low Reynolds number formulation ok. So, low Reynolds number you can say LRN models.

So, what this low Reynolds number models this is that they introduce a damping function a damping function is used in use to account for this phenomena in low Reynolds number models. So here low Reynolds number does not mean as I we have seen in the wall function description low Reynolds number only means locally low Reynolds numbers. Low Re refers to locally low Reynolds numbers that is in your near wall zone. We are not talking about the global Reynolds numbers, your Re delta and so on. And this is this damping function is now used for all types of eddy viscosity models that is your typical k epsilon, k omega all this type of models.

So, another option that we have is to go into this is also an eddy viscosity model. So, I can say this is A where you are having this is for the two equation models. two equation eddy viscosity models that is your k epsilon, k omega etc any other type of two equation models. The other option in an eddy viscosity model is actually to solve one more transport equation for the V_{rms}.

So, this is called a V^2-F model. this is actually a four equation turbulence model. So, it is a four four equation that is four transport equations are there that is k epsilon, $\overline{v'}2$ and f four transport equations or k omega V^2-F and so on. So, four equation transport model so you are actually computing for v to f and then v to f is used to participate in computing the eddy viscosity ok. Four equation means like for example, k epsilon V^2-F or k omega V^2-F and so on. So, here what we do is $\overline{v'}2$ is used to compute eddy viscosity.

So, that eddy viscosity is taking into account the this enhanced damping factor and eddy viscosity occurs in everywhere bussiness assumption. So, it occurs in production rate of turbulence kinetic energy calculation wherever eddy viscosity is coming is naturally accounted for. So, that is the philosophy behind this model a four equation transport model. And the other option within the frame of RANS models is to use what is called a Reynolds stress model ok, Reynolds stress model. So, as the name itself says you are solving for the Reynolds stresses So, this will be a 7 equation model there are 6 Reynolds stresses that you have to solve in addition to that we will solve for an epsilon equation I will come to that when we move to RSM.

So, in a Reynolds stress model you are of course computing for all the stresses there is a transport equation for each stress and that means when you are calculating that there is a pressure strain rate term. So, you see in turbulence kinetic energy equation the pressure strain rate term was gone. right the redistribution was not there. So, in when you are computing Reynolds stresses that term is present which will handle this right for this one. So, damping is ensured damping of $\overline{v'}2$ is ensured by the redistribution term or the pressure strain rate term.

So, this will naturally do this when you have Reynolds stress model you are computing for all the stresses and there is a pressure strain rate term. So, before going into this first we will see we already have a k epsilon k omega type of model So, we have already seen in an industrial flow we are do not want to capture near wall effects and near wall effects are displaced away from the wall using wall function and that we call high Reynolds number models HRN or high Reynolds number formulations. As against that when you are capturing the near wall effects we call it low Reynolds number models. The same low there is an LRN k epsilon model or a high HRN k epsilon model. Here of course you should not use wall function, you need to capture the near wall behavior.

So, we will go to what is called a low Reynolds number model. Is this clear so far? The physics and the approach how we have to do this?