Hands-on session 8 – Tight Lattice Triangular Fuel Bundle

Abstract

This session will show an application of the Non-Linear Eddy Viscosity Models (NLEVM) in Fluent, or quadratic closure of the Reynolds stresses, to a classical nuclear-related benchmark, that is to say the triangular fuel lattice arrangement. As explained in the previous lectures and laboratories, the disposition of rods creates anisotropy of turbulence which results in the creation of secondary flows. The secondary flows intensity represents around few percent of the main flow velocity, however it is strong enough to affect the main flow pattern and the wall shear stresses having an effect on the cooling and total pressure drop in the core region. The present study refers to the experimental work performed by Mantlik et al. in 1976 (in Russian).

Goal

The aim of this hands-on session is to simulate the flow field in a sub-channel of a typical triangular rod arrangement and confirm the importance to employ a quadratic closure model for the correct prediction of this particular flows. The Hands-on session is also useful to the student to consider the concept and the geometry of a sub-channel.

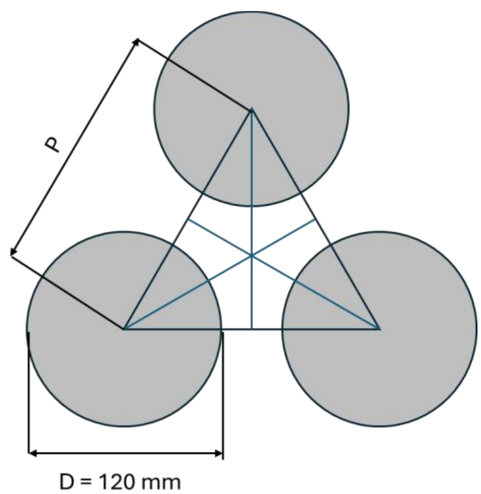
1 Introduction

We have seen that turbulence is fundamentally anisotropic, which means it behaves differently depending on the direction fundamentally because of geometric constraints. Anisotropy of turbulence can influence the flow field which can have a non-negligible in the evaluation of the main values such as the pressure drop in a nuclear core. We have seen this concept adapted to a square duct. In this hands-on session we will apply the quadratic closure of the Reynolds stresses to a classical case in nuclear engineering, that is to say a triangular fuel rod bundle comparing against the experimental data of Mantlik et al. 1976. The student will learn how to draw a bit more complex geometry than the previous cases and confirm the effect of the quadratic closure on the velocity as well as the wall shear.

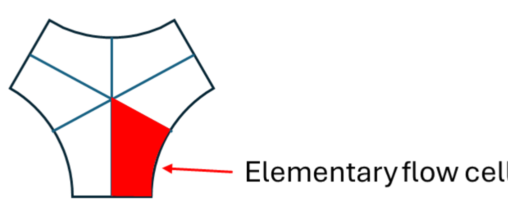
Note: *It is advised to prepare an excel file to summarize the fluid properties and boundary conditions for the resolved variables (pressure, x- and y-velocity, temperature). Some of these data may require calculation depending on the information given in the case description.*

2 Geometry

The present Hands-on session deals with a triangular fuel lattice. Triangular fuel lattice is typical of metal-cooled nuclear reactors were the coolant has large thermal conductance and rods can be packed more tightly to increase the core power. In the center of the fuel bundle, far from the channel wall, the three rods create a space defined "sub-channel" as shown below.



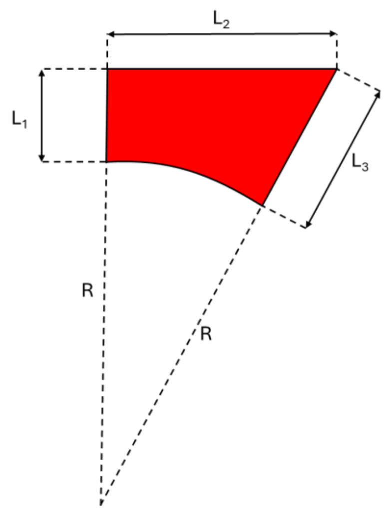
The subchannel is characterized by the rod diameters (D) and the distance between the center of two neighboring rods, named pitch (P)t. In the present case the rod diameter is 120 mm and the P/D ratio is equal to 1.17. The subchannel region is shown below:



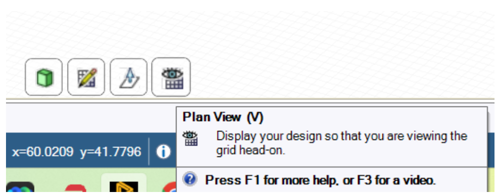
From the figure above it is clear that the sub-channel has a symmetrical shape, hence the flow will also have a symmetrical configuration. We can consequently study only the elementary cell shown above in red employing symmetrical boundary conditions.

2.1 Draw the geometry in SpaceClaim

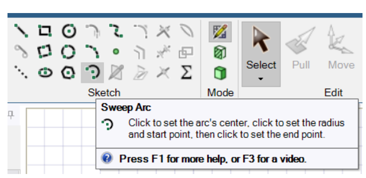
Before starting drawing the geometry, it is suggested to draw a sketch of the geometry and evaluate all the dimensions of the elementary flow cell which will be necessary to draw the domain.



In SpaceClaim click the PlanView to move the plane orthogonal to our view. 

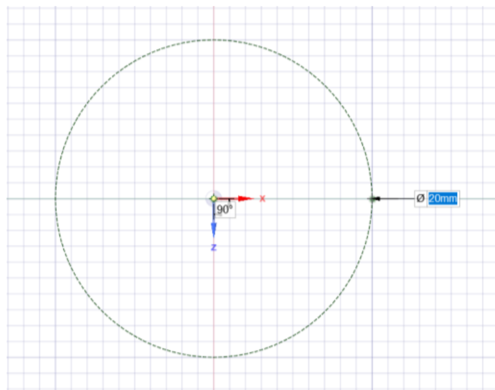


To draw this geometry first select "Sweep Arc" in the Sketch menu at the top



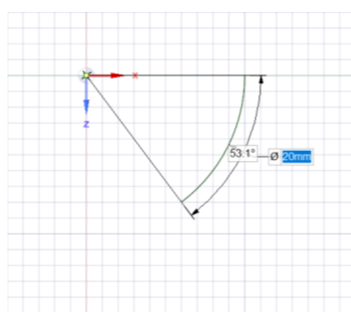
This function lets you define first the center of the arc, the radius of the arc and the angle. First select the center of the arc as below. Move along one grid line if you want one edge parallel to the *x-axis* and press the space bar to input manually the length of the radius.

Note: the numbers below DO NOT REPRESENT the numbers of the real geometry. They are just given as example! You should evaluate the correct numbers.

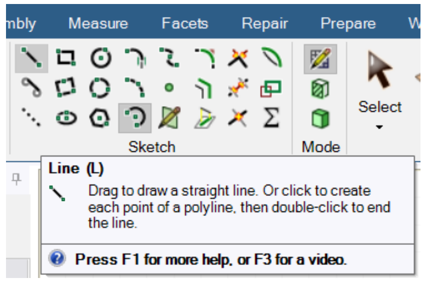


After selecting the length of the radius, moving the mouse above or below the *x-axis* shows the angle of the arc. Select the appropriate one by pressing the spacebar as usual.

The arc, which represents the wall of our domain will be created as below:

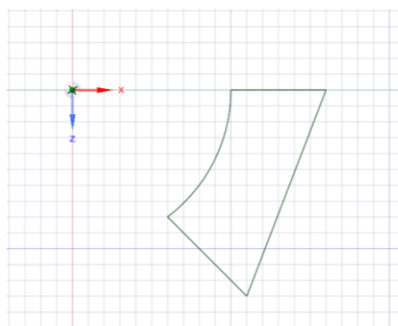


To complete the geometry, use the command “Line” in the Sketch menu at the top.



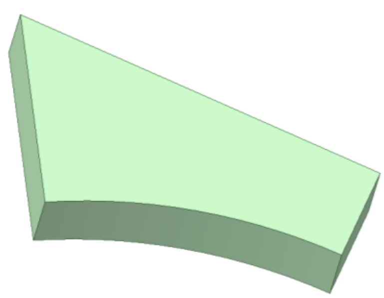
Space claim will help you in the drawing by aligning lines to the grid and showing orthogonality between the line and the arc. To define the length of each line simply press the spacebar as usual. After each line is defined SpaceClaim will start a new line from the previous selected point. If you want to draw a line from a different point, simply press Escape (Esc).

Your sketch might look like the one below:



To create the volume simply press Pull as it was done in the previous Hands-on sessions.

Finally, your geometry (now with the real dimensions) should look like the one below.

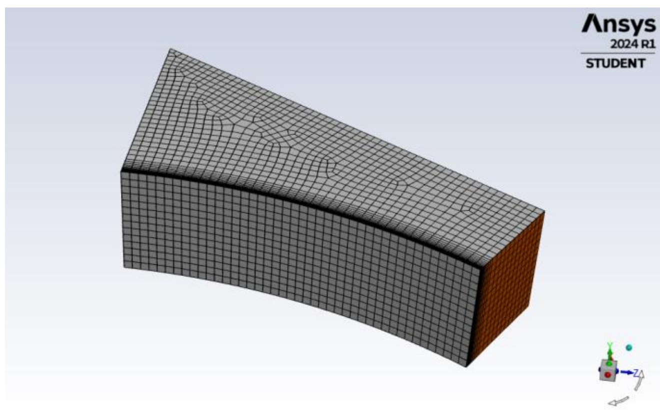


Assign the boundaries as done in the previous sessions and name them as Periodic1, Periodic2, Wall, Symmetry1, Symmetry2, Symmetry3.

3 Mesh Generation

As we are going to use the k-ω SST model there is technically no requirement for the y^+ at the wall. However, we have seen in the square duct case that being able to resolve the viscous sublayer increases the accuracy in the prediction of the secondary flows and the overall velocity profile.

Create the geometry according to the discussion done in the previous Hands-on sessions. You should obtain a grid which looks like the grid below:



4 Set-up the model

4.1 Boundary conditions

The boundary conditions should be set up similarly to what was done in previous Hands-on sessions. Hence, define a wall surface and select two periodic surfaces where you can input the mass flow rate. Every other surface will by a symmetry plane. To select, right-click on one of the boundaries and select “symmetry”.

4.2 Turbulence model

In this Hands-on session we will compare again the linear and quadratic closure of the Reynolds stresses. To define the model, double click on “Viscous” and select “k-omega (2 eqn)” in Model. Select “SST” in “k-omega model” and select or unselect the “Corner flow corrections” in the “Options” below.

4.3 Define monitors

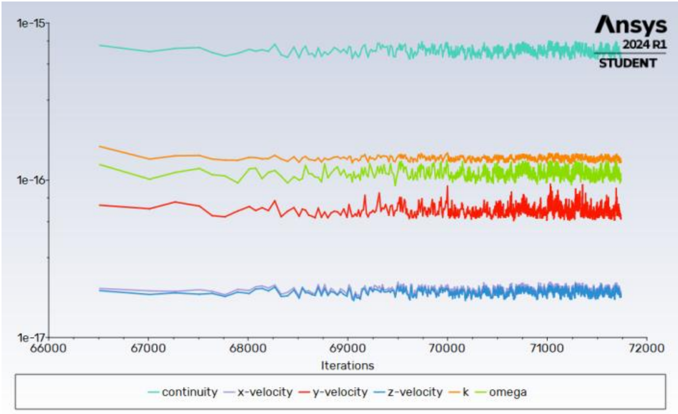
Define the monitors you consider more representative of the convergence. You can select the average velocity, mass flow rate and the Reynolds number as in this case.

5 Results

Hereafter we will present the results for the main experimental data by Mantlik et al. 1976 and comparing the prediction of the linear k-ω SST model and the quadratic correction.

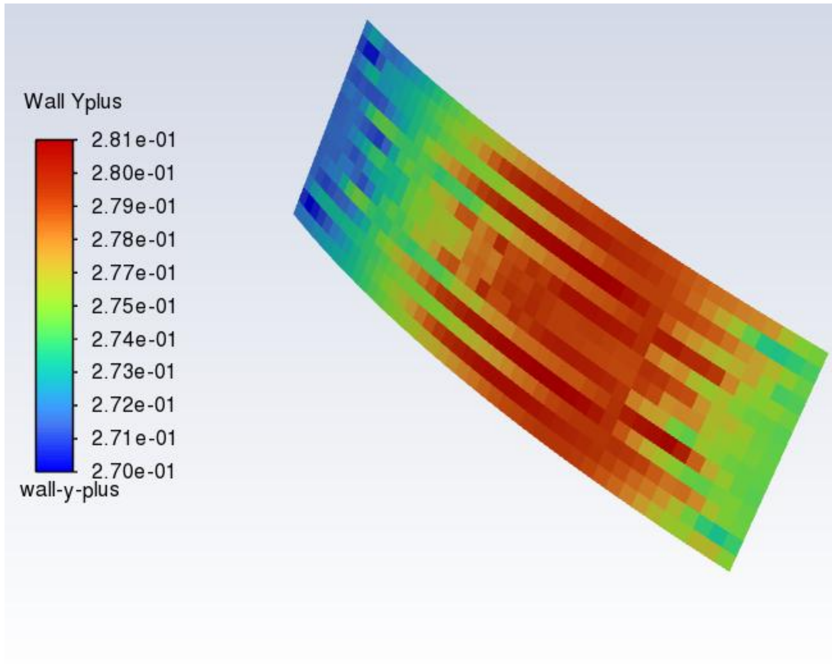
5.1 Confirm the converge of the simulation

The plot below shows the residuals. The best practice would require waiting until the residuals reached a plateau value. However, for this particular case the value of residuals is so low that we can accept the results up to this point.



5.2 Show y^+ at the wall

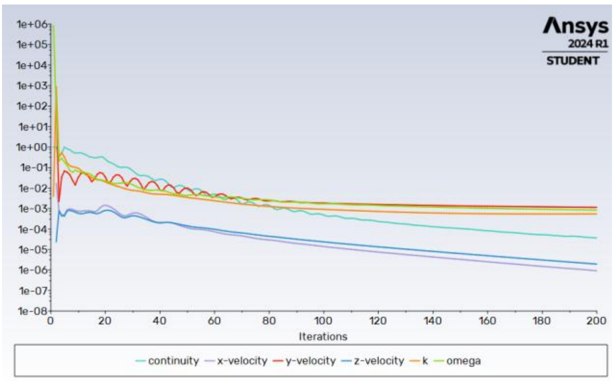
The figure below shows the y^+ values at the wall. As expected from the analysis y^+ in each cell is below 1, indicating that we are solving the flow well below the viscous sublayer.

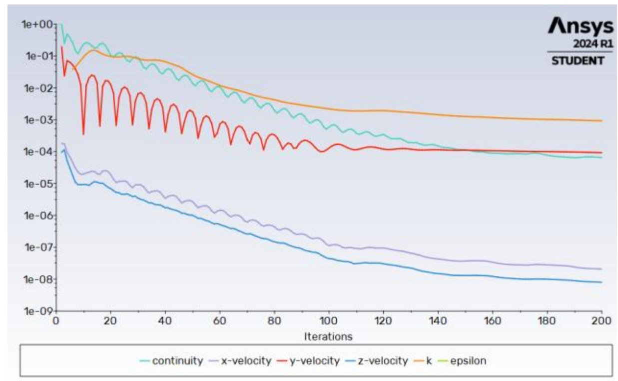


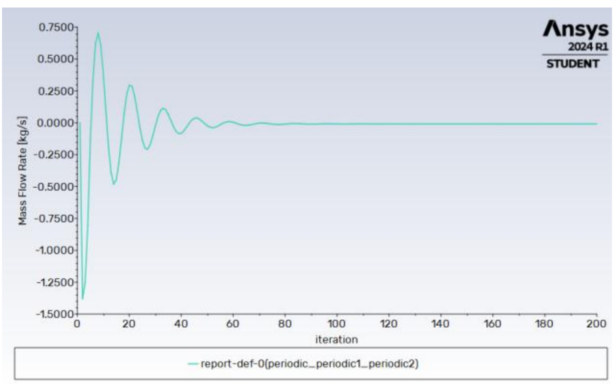
5.3 Plot monitors of main quantities

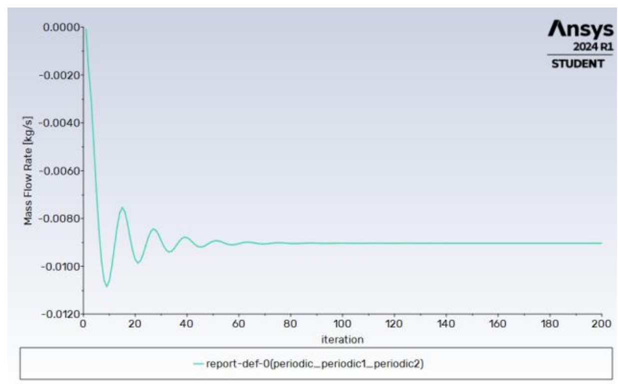
In some simulations, even when initializing with zero initial velocity, an initial large flow rate and velocity can be established. This is not worrying result but it might delay the achievement of the solution. This might be solved by reducing the turbulent kinetic energy and increasing the specific dissipation rate or the dissipation rate. Let's compare below 200 iterations of the same case with different initialization of k. The student could proof that the two cases eventually will converge to the same solution.

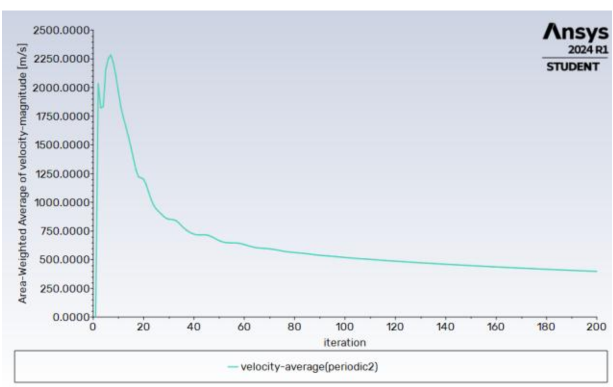
k-ω SST (initial k = 1 m2/s2, ω = 1/s)	k-ω SST (initial k = 1e-10 m2/s2, ω = 1/s)

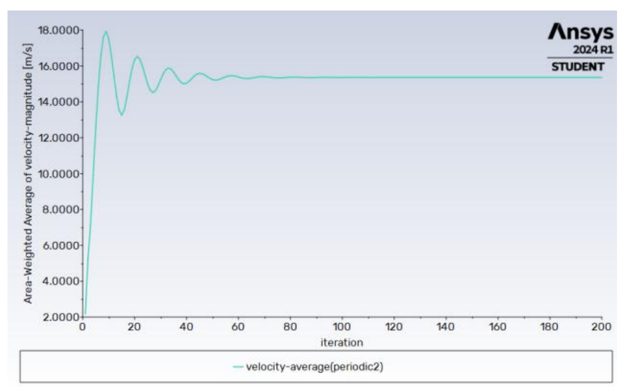








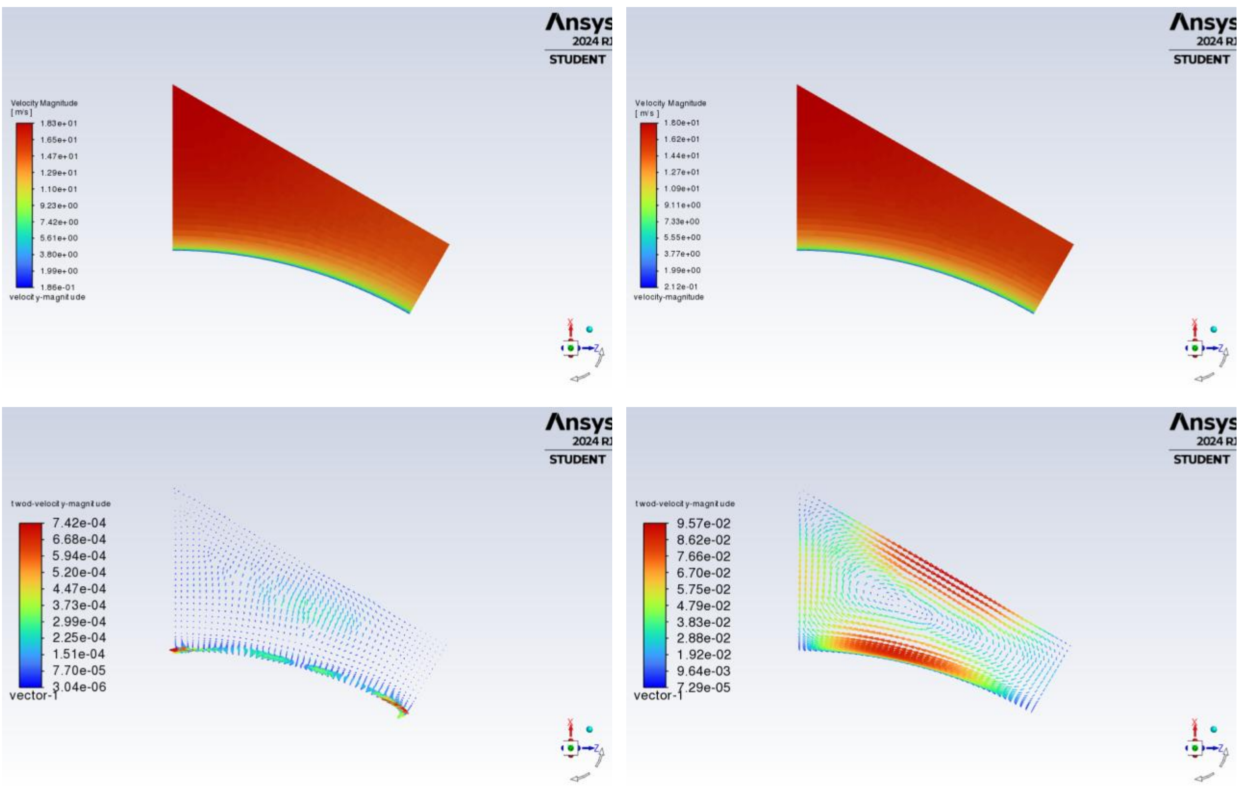




5.4 Qualitative comparison of streamwise and cross-stream velocities

As expected there is no secondary flow predicted in the linear case.

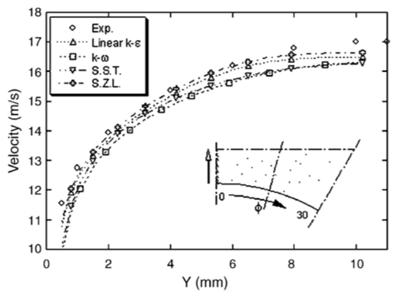
k-ω SST (linear) k-ω SST (quadratic)



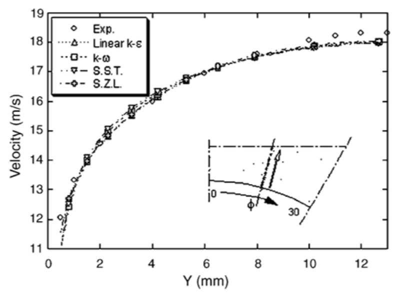
5.5 Quantitative comparison of velocity and shear stress

Hereafter we report the comparison between the experiment by Mantlik et al. in three gaps of the subchannel and the wall shear stress. The location is presented in the picture below from Baglietto et al. 2005.

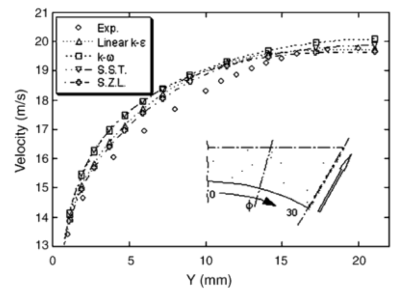
Small gap



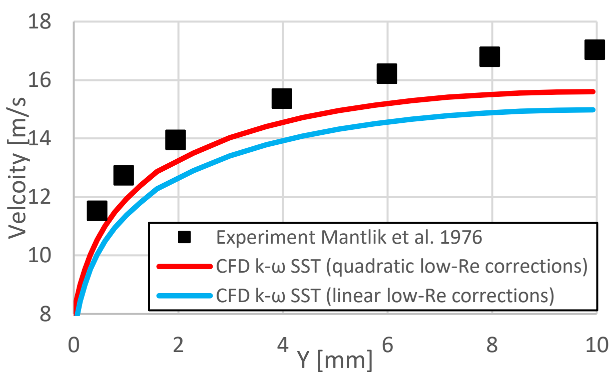
Middle gap



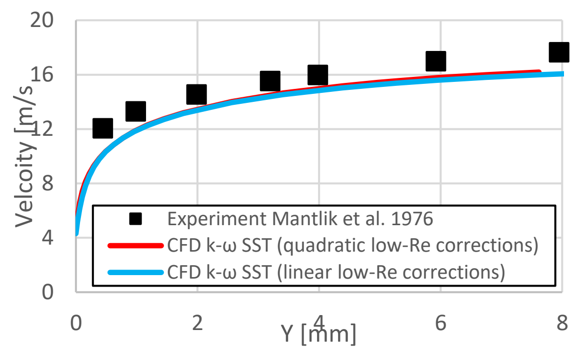
Large gap



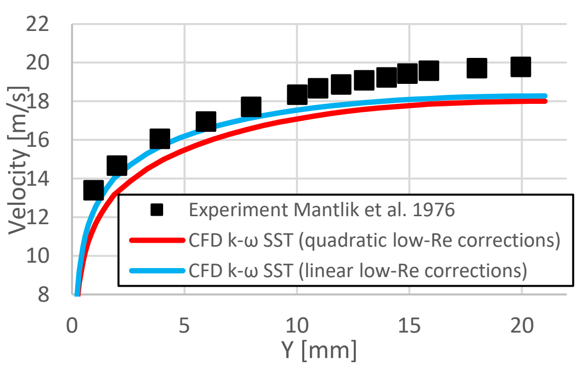
Small gap



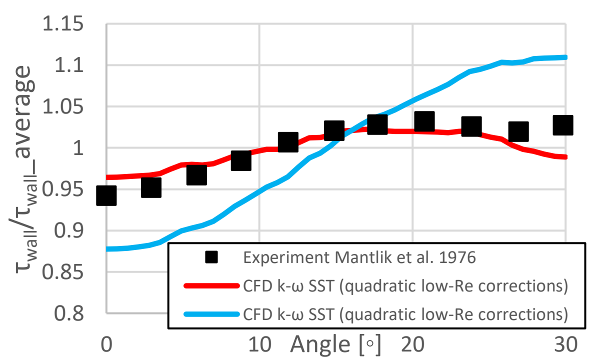
Middle gap



Large gap



Wall shear stress



6 Conclusions

It is interesting to see that, while the quadratic model gives a clear better prediction of the wall shear stress, the improvement effect on the velocity is relatively minimal in part in the location of the large gap. The student could try to consider why this is occurring.