WEEK 10 CHALLENGE

Introduction to OpenFoam Development

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27/03/2022

Problem Statement:

Use the backwardFacingStep2D tutorial as described in the lecture and run the case for the following turbulence models:
• SpalartAllmaras
• kEpsilon
• realizableKE
• kOmega
One of these is a one-equation model. Write down the equation and a short note on the turbulence model

Solution:

A brief about the Equations:

1) SpalartAllmaras: Spalart–Allmaras turbulence model - Wikipedia
2) kEpsilon: K-epsilon turbulence model - Wikipedia
3) realizableKE: OpenFOAM: API Guide: realizableKE< BasicTurbulenceModel > Class Template Reference
4) kOmega: k–omega turbulence model - Wikipedia

A short note on the one Equation model (Spalart Allmaras) is attached below.
Also, below is the attached summary + user notes on the simulation:

Summary:

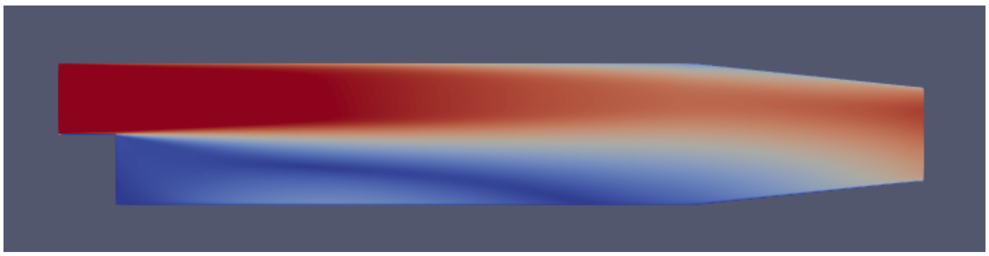
Some key points:
- kEpsilon model is the default model used in this case.
- Sparlart Allmaras model needs an extra term nuTilda to be defined
- kEpsilon and kOmega have similar results which are different from Spalart Allmaras and realizable KE
- kEpsilon and RKE converge in around 300 steps but the other two models go till the end i.e., 2000 iterations

User notes:

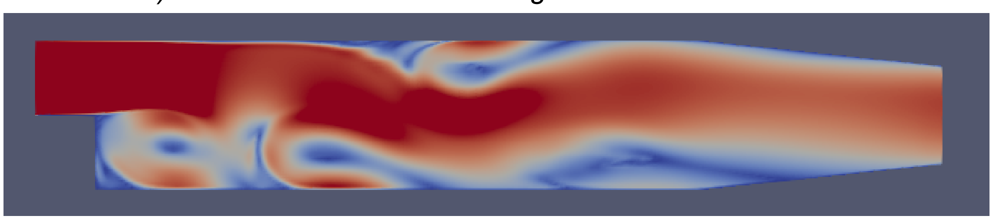
The first issue that I encountered was that the tutorial of backwardFacingStep wasn't present in my openFoam(maybe because of the version). So I downloaded it from the internet and used it. Even after copying the case, it won't run. So I replaced nutUBlendedWallFunction with nutUWallFunction

Then I sticked with pitzDaily case

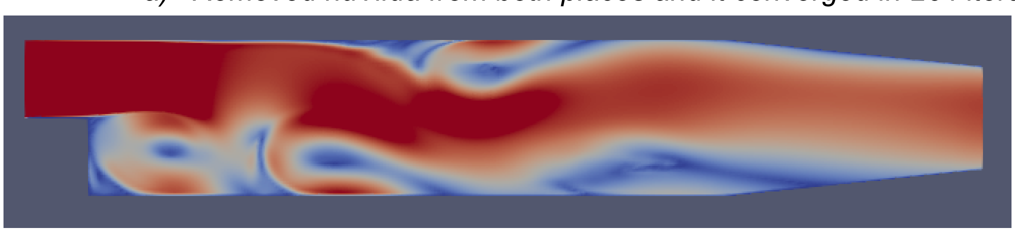
1) *Running with kEpsilon: Two parameter*
    a) *blockMesh followed by simpleFoam results(287 iterations):*



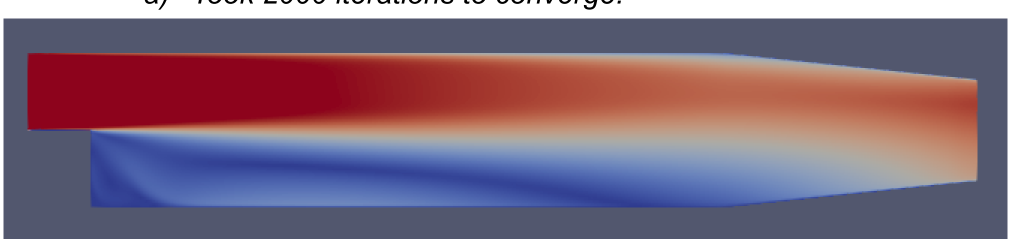
2) *Running with SpalartAllmaras:*
    a) *div(phi,nuTilda) wasn't defined. Same was the case with nuTilda Calc*
    b) *There was an issue with #includeFunc so I commented it out*
    c) *I added both and it converged: Ran for 2000 iterations*



3) *Realizable KE:*
    a) *Removed nuTilda from both places and it converged in 264 iterations:*



4) *kOmega:*
    a) *Took 2000 iterations to converge:*



We will discuss about Spalart Allmaras in a bit detail and the other three models in brief:

A) Spalart Allamaras:

1. Is a one-equation model that solves a modelled transport equation for the kinematic eddy turbulent viscosity.
2. Gives good results for boundary layers subjected to adverse pressure gradients.
3. The model is effectively a low-Reynolds number model
4. It solves a transport equation for a viscosity-like variable $\tilde{\nu}$. This may be referred to as the Spalart–Allmaras variable. In the code, it is called nuTilda

This model uses the following trick:

$$\nu_T = \tilde{\nu} f_{v1}$$

$$\textit{This way, we will have only one transport equation}$$

$$\frac{\partial \tilde{\nu}}{\partial t} + u_j \frac{\partial \tilde{\nu}}{\partial x_j} = C_{b1}[1 - f_{t2}]\tilde{S}\tilde{\nu} + \frac{1}{\sigma}\left\{\nabla.\left[\left(\nu + \tilde{\nu}\right)\nabla\tilde{\nu}\right] + C_{b2}|\nabla\tilde{\nu}|^2\right\} - \left[C_{w1}f_w - \frac{C_{b1}}{\kappa^2}f_{t2}\right]\left(\frac{\tilde{\nu}}{d}\right)^2 + f_{t1}\Delta U^2$$

$$\textit{Then there are some rule of thumb values for these constants.}$$

But that's not the main thing. The main thing is this: Now the equations aren't coupled. It is just a single transport equation that we need to solve and we will be able to find ν_T very easily

And as mentioned above, this algorithm is proved to be very successful in adverse pressure gradients where our k-ϵ model fails.
But, there is a catch. It is a Low Reynolds Number approach, hence, we need a very good mesh for using this model.

Now lets have a peep into other models too:
B) k-Epsilon model:
Very well known.
Underperforms near walls but is good in free stream
Equations:

$$\frac{\partial(\rho k)}{\partial t} + \frac{\partial(\rho k u_i)}{\partial x_i} = \frac{\partial}{\partial x_j}\left[\frac{\mu_t}{\sigma_k}\frac{\partial k}{\partial x_j}\right] + 2\mu_t E_{ij} E_{ij} - \rho\epsilon$$

$$\frac{\partial(\rho\epsilon)}{\partial t} + \frac{\partial(\rho\epsilon u_i)}{\partial x_i} = \frac{\partial}{\partial x_j}\left[\frac{\mu_t}{\sigma_\epsilon}\frac{\partial\epsilon}{\partial x_j}\right] + C_{1\epsilon}\frac{\epsilon}{k}2\mu_t E_{ij} E_{ij} - C_{2\epsilon}\rho\frac{\epsilon^2}{k}$$

$$\nu_T = C_\mu \frac{k^2}{\epsilon}$$

C) Realizable K Epsilon

An immediate benefit of the realizable k-ε model is that it provides improved predictions for the spreading rate of both planar and round jets. It also exhibits superior performance for flows involving rotation, boundary layers under strong adverse pressure gradients, separation, and recirculation. Equations are complex. We should just know that in this model we have added constrains to the k-ϵ model so that the non-realizable values are ruled out.

D) k-ω model:

1) Better near the wall
2) Underperforms in the free stream
3) Equations are similar to k-ϵ except a cross diffusion term

$$\frac{\partial(\rho k)}{\partial t} + \frac{\partial(\rho k u_i)}{\partial x_i} = \frac{\partial}{\partial x_j}\left[\frac{\mu_t}{\sigma_k}\frac{\partial k}{\partial x_j}\right] + 2\mu_t E_{ij} E_{ij} - \rho\epsilon$$

$$\frac{\partial(\rho\omega)}{\partial t} + \frac{\partial(\rho\omega u_i)}{\partial x_i} = \frac{\alpha\omega}{k}P - \beta\rho\omega^2 + \frac{\partial}{\partial x_j}\left[\left(\mu + \sigma_w\frac{\rho k}{\omega}\right)\frac{\partial\omega}{\partial x_j}\right] + \frac{\rho\sigma_d}{\omega}\frac{\partial k}{\partial x_j}\frac{\partial\omega}{\partial x_j}$$

$$\nu_T = \frac{k}{\omega}$$

THE END