Week 8

OpenFOAM Development

Om Mihani

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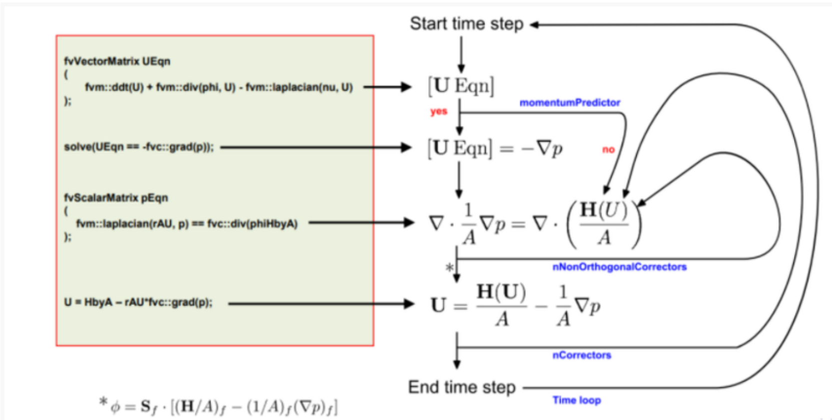
Problem Statement

1. What algorithm does this flow chart represent?



2. Setting the keyword nOuterCorrectors in pimpleFoam to 1 is equivalent to running which solver? What do the outer correctors and inner correctors do in the PIMPLE algorithm?

SOLUTION

1) Let's check all our possibilities:
    a) Observe that we do not have the A^t term in the U correction term. This will eliminate the possibility of a **SIMPLEC Algorithm**.
    b) Next, let's see if it is a **PIMPLE Algorithm.** Observe that there are no nOuterCorrector terms. There is only one loop for the outer corrector. Thus, we can say that it is not a PIMPLE Algorithm
    c) Now, let's check for our favourite **SIMPLE Algorithm.** If we squint and see the penultimate step, we observe that there is a loop of inner correctors. Hence, it is not a SIMPLE Algorithm
    d) As Sherlock Holmes says, "*When you have eliminated the impossible, whatever remains, however improbable, must be the truth.*" Thus, we can safely conclude that the above flowchart is a **PISO algorithm.**

We are not going to leave this question just with what Sherlock said. Let's dive into the flowchart and see what it is made of. But before that, let's discuss the PISO algorithm.

Step 1: **Assuming U**

Whenever we initialise the fields by giving initial values in the 0 folder, we give the first set of assumptions for U_x, U_y, U_z and p. Now these values will be used in this first step.

Step 2: **Fitting in the Momentum predictor**

$$\boxed{MU = -\nabla p}$$

We already have an assumed value of U and p. Just substitute in the above equation and **solve iteratively for U** with p fixed. This is a manipulation of the momentum equation of Navier Stokes.

Step 3: **Finding H**

$$\boxed{H = AU - MU}$$

No manipulations here. Just a simple substitution and find matrix H.

Step 4: **pEqn**

$$\boxed{\nabla.\left(A^{-1}H\right) = \nabla.\left(A^{-1}(\nabla p)\right)}$$

We have a new value for U and the old assumed value for p. Substitute here and **solve iteratively for p.** This is a twist in the continuity equation.

Step 5: **Momentum Corrector**

$$\boxed{U'' = A^{-1}H - A^{-1}(\nabla p)}$$

This gives us a correction term to be added to the value obtained in Step 2 for it to satisfy continuity.

Step 6: **U correction**

$$\boxed{U = U^{*} + U''}$$

This step is simply adding velocity in step 2 with correction in step 5.

Now observe that:

1) U obtained in step 2 satisfies NS, but not continuity and U obtained in step 6 satisfies continuity, but not NS. So we need to somehow run in a loop so that both these values become identical.
2) If the time step is very small, for instance a transient state problem. Then, the matrix M is diagonally dominant and doesn't change much. So, we can save ourselves from the pain of solving equation in step 2 over and over again. So we loop from step 3-6. This is called an innerl corrector.

Thus, in short, we find a velocity from the momentum equation and run a corrector loop over the continuity equation and correction for a specified number of times(nCorrector). This generally allows convergence to be achieved faster and easier. This is the entire explanation of the PISO algorithm. Now observe the flowchart and follow each of the steps.

2) Since we have gone over a lot of details in the previous question, I will be referencing some parts there. Let's first understand what a PIMPLE Algorithm is and then we can answer the question.

In the steps given above, we have mentioned that the time steps need to be really small to use the PISO algorithm. But in case we come across such a situation where time steps need to be huge or in other words, Courant number[1] in more than one, we need to go to a hybrid approach, which uses both the accuracy of the SIMPLE algorithm and the speed of the PISO algorithm.

This is achieved by the following trick:

STEP A: Go through step 1 in answer 1
STEP B: Go through step 2 in answer 1
STEP C: Go through the steps 3-6 in answer 1
STEP D: Repeat step C n1 number of times
STEP E: Repeat steps B-D n2 number of times

Just to keep the nomenclature clear:
N1 = number of inner correctors (since they run over continuity only)
N2 = number of outer correctors(since they run over the momentum equation as well as the inner correctors)

Let's do a thought experiment. Assume N1 = 3 and N2 = 2. Then, the sequence of steps would be: **ABCCCBCCC**

Hope that makes things clear. Now for the question, **if N2 = 1, it will be like a PISO loop.** This can be checked by substituting N1 = 4 and N2 = 1 and writing down the steps.

The explanation of inner and outer correctors is done above, but in short, **inner correctors run through the continuity equation and correct U while the outer correctors run over the momentum equation and the inner correctors to correct U.**

THE END

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[1] Courant number is the ratio of distance moved in one time step and the size of a unit cell. Co = u*(Δt)/Δx