CFM03 Documentation

Release 0.0.1

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March 15, 2016

Contents

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CHAPTER 1

Results

1.1 Problem1 - a

Describe the essential steps of the solution method. Include the discretized equations and implementation of boundary conditions.

$$\frac{\partial u_i}{\partial t} + \frac{\partial u_i u_j}{\partial x_j} = -\frac{1}{\rho}\frac{\partial p}{\partial x_i} + \nu \frac{\partial}{\partial x_j}\left(\frac{\partial u_i}{\partial x_j}\right)$$

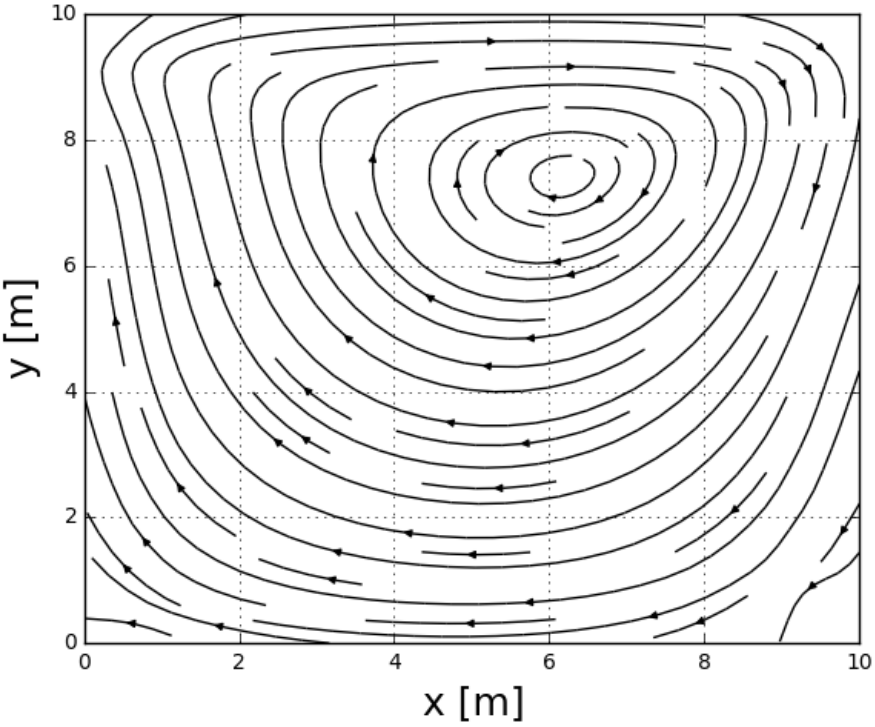
1.2 Problem1 - b, c

Consider the case when $H = W$ (a square cavity). Here, the Reynolds number, $Re = UW/\nu$, characterizes the flow patters. Compute the steady state solutions for both $Re = 100$ and $Re = 500$. Plot the flow streamlines and centerline profiles (u vs. y and v vs. x through the center of the domain). For $Re = 100$, valdiate your method by comparing your results to data from given literature.

1.2.1 Re = 100

- NxN = 20x20
  - u-velocity
  - v-velocity
  - **Observation**
    - Streamlines roughly forms and recirculation zone in the bottom right can be found.
    - This course grid case shows bad estimation of u and v-velocity as compared to the Ghia's data

- NxN = 40x40
  - u-velocity
  - v-velocity
  - **Observation**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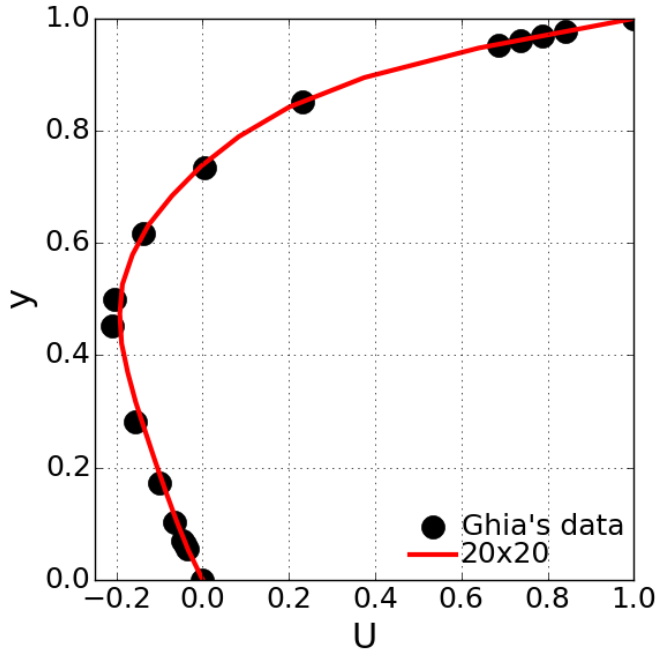
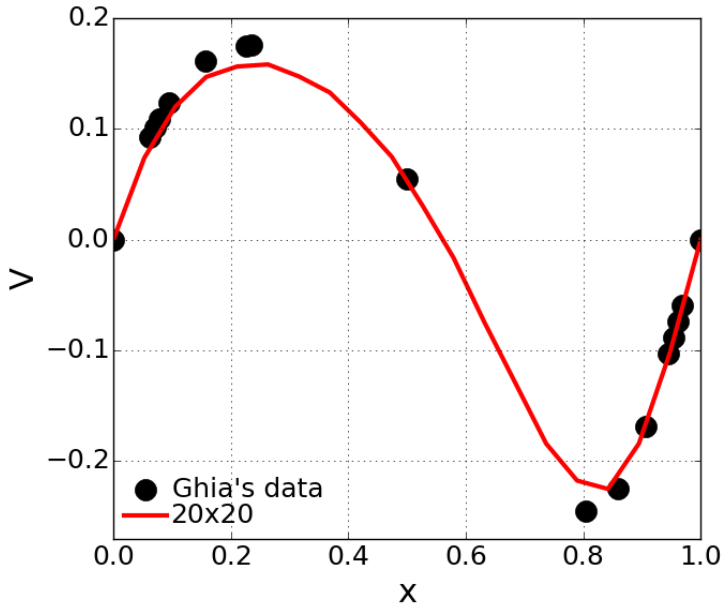
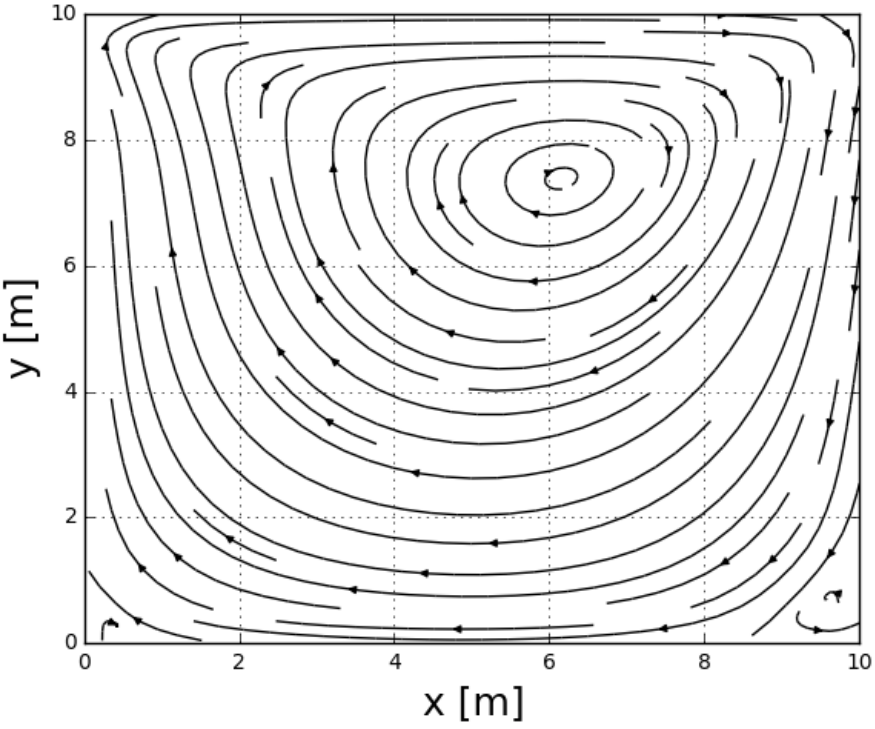
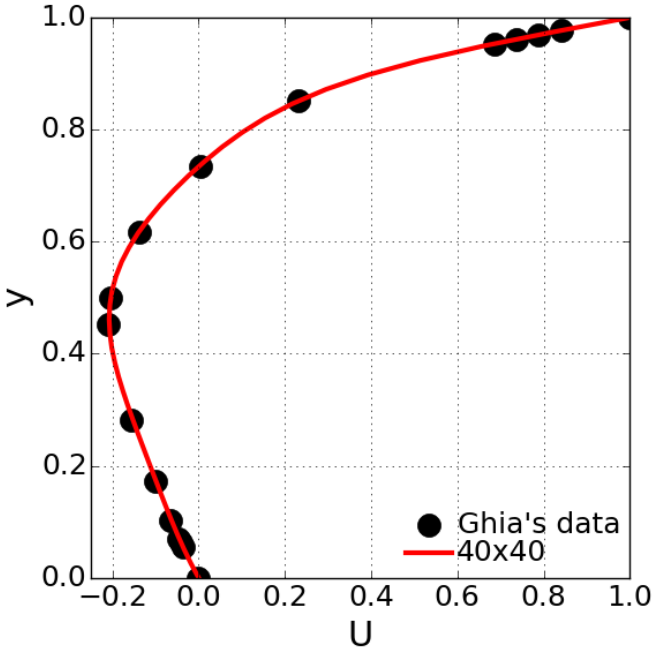
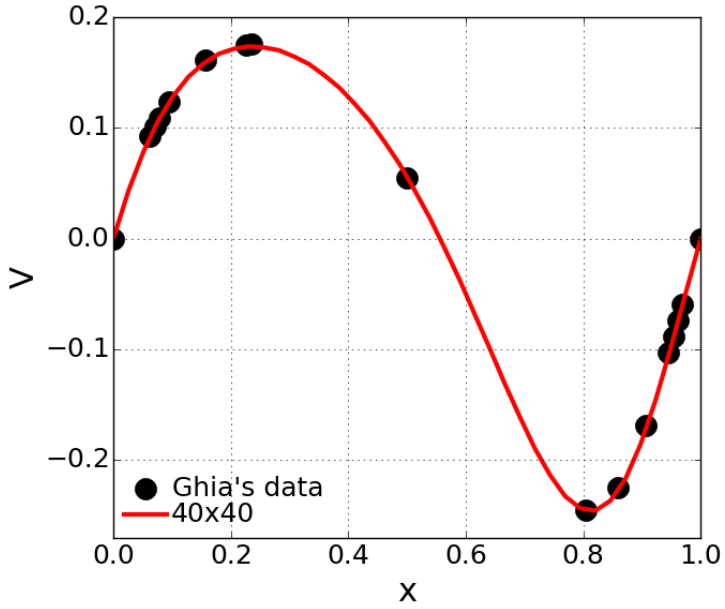
x [m]
0
2
4
6
8
10


y
U
0.0
0.2
0.4
0.6
0.8
1.0
−0.2
0.0
0.2
0.4
0.6
0.8
1.0
Ghia's data
20x20


0.2
0.1
0.0
−0.1
−0.2
V
Ghia's data
20x20
0.0
0.2
0.4
0.6
0.8
1.0
x

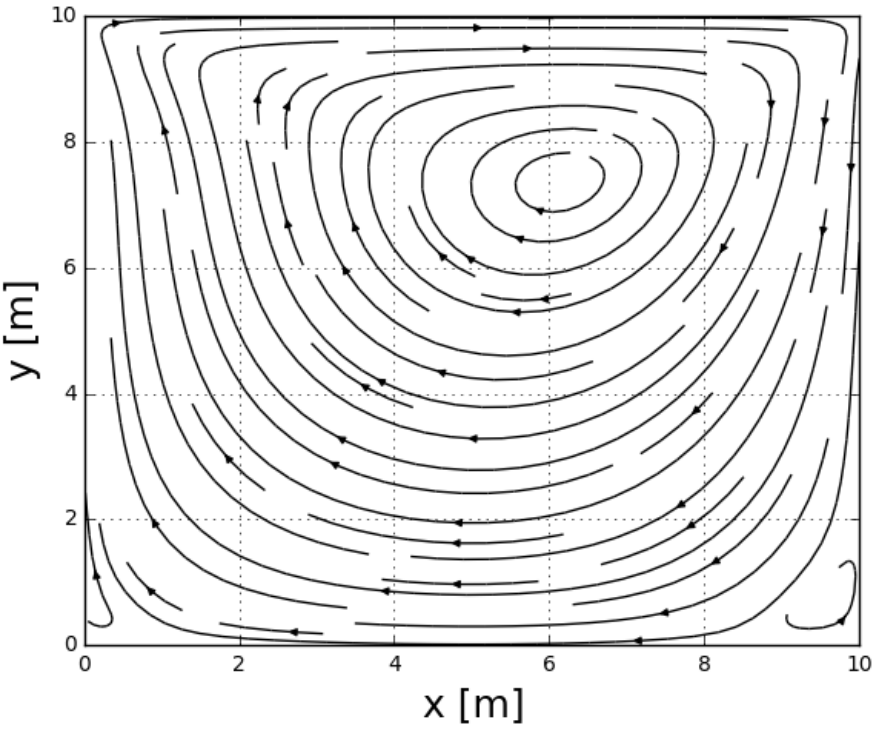

10
8
6
4
2
0
y [m]
0
2
4
6
8
10
x [m]


1.0
0.8
0.6
0.4
0.2
0.0
y
−0.2
0.0
0.2
0.4
0.6
0.8
1.0
U
Ghia's data
40x40


0.2
0.1
0.0
−0.1
−0.2
V
0.0
0.2
0.4
0.6
0.8
1.0
x
Ghia's data
40x40

    * The predicted u- and v-velocity approached closer to the Ghia's data

- NxN = 80x80

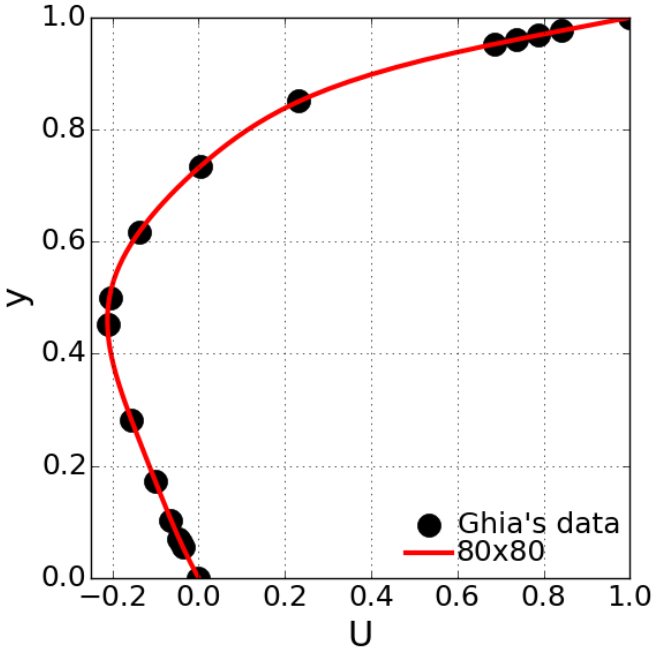


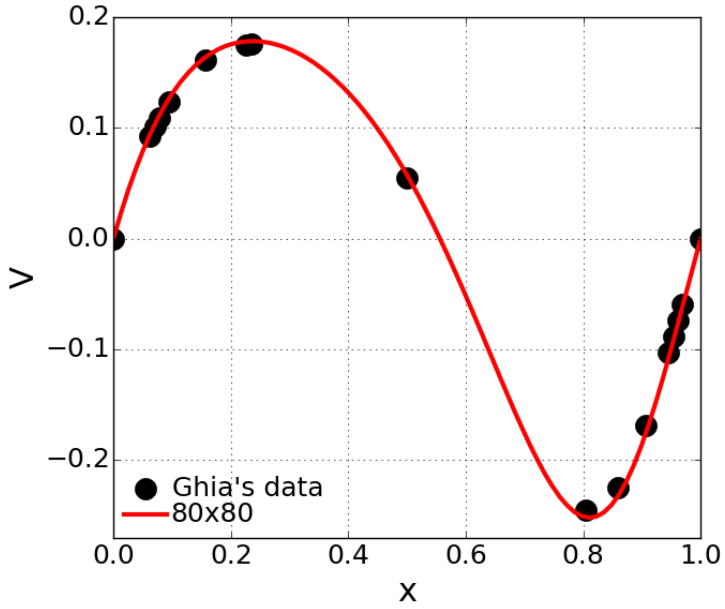
  - u-velocity
  - v-velocity
  - **Observation**
    * The currently predicted data seems to be almost identical with the Ghia's solution.
    * Recirculation zone in the bottom left and right seems more clear than the coarser grid cases.

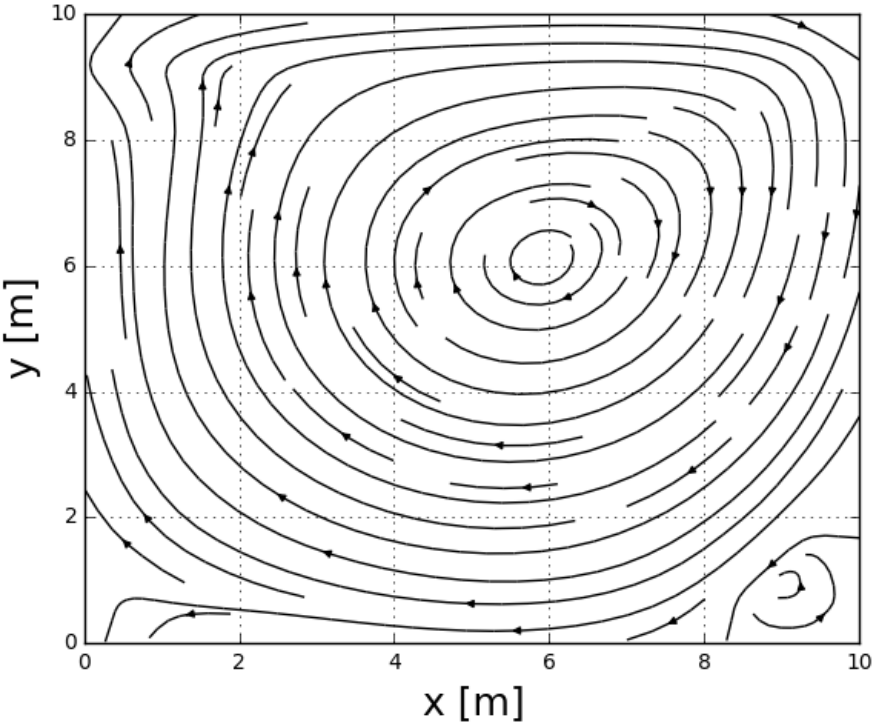
1.2.2 Re = 500

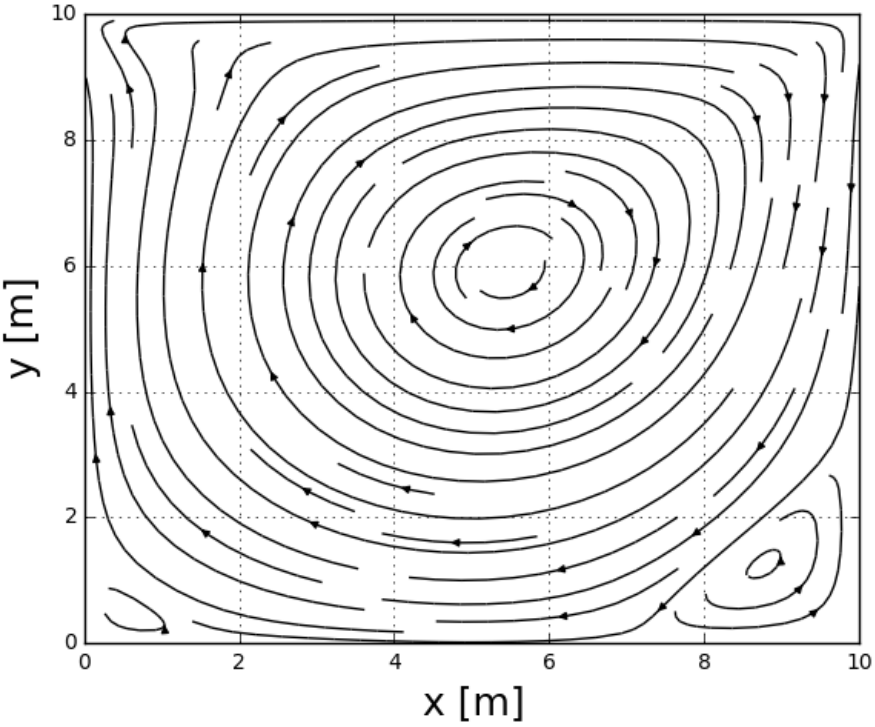
- NxN = 20x20

- NxN = 80x80


1.0
0.8
0.6
0.4
0.2
0.0
y
−0.2
0.0
0.2
0.4
0.6
0.8
1.0
U
Ghia's data
80x80


0.2
0.1
0.0
−0.1
−0.2
V
0.0
0.2
0.4
0.6
0.8
1.0
x
Ghia's data
80x80


y [m]
x [m]
0
2
4
6
8
10


y [m]
x [m]
0
2
4
6
8
10

1.3 Problem1 - d

Examine the method stability with different grids. Determine the maximum time step that leads to a stable solution and compare it to the stability criteria.

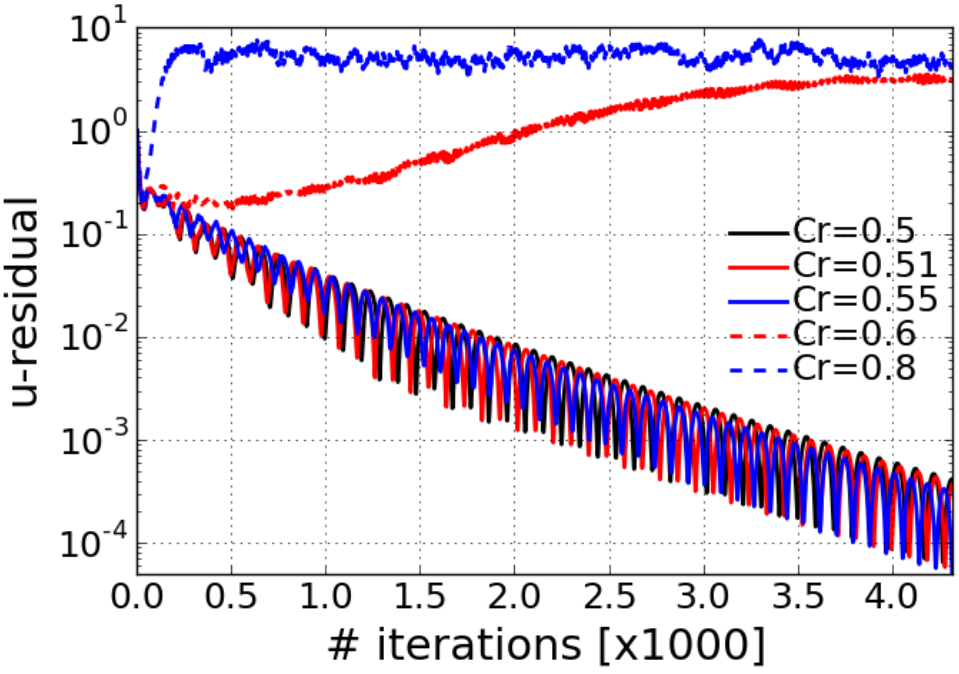
1.3.1 Grid spacing test

Here, the stabilith test is performed with different set of grid spacing. To rule out other effect of numerical setup, *Courant* number and β remain constant whereas only grid spacing changes. Following table shows the stability check. *O* denotes the *stable* condition and *X* represents the *unstable* condition.

NxN	stability
10x10	*X*
15x15	*X*
16x16	*X*
17x17	*O*
18x18	*O*
20x20	*O*

1.3.2 Maximum time step

In this code, the variable time step method is used to maintain stable numerically. Therefore, the code does not run with constant time step. The maximum time step test is performed with different set of *Courant* number condition. The grid spacing is fixed with 20x20 to have fast running of simulation.



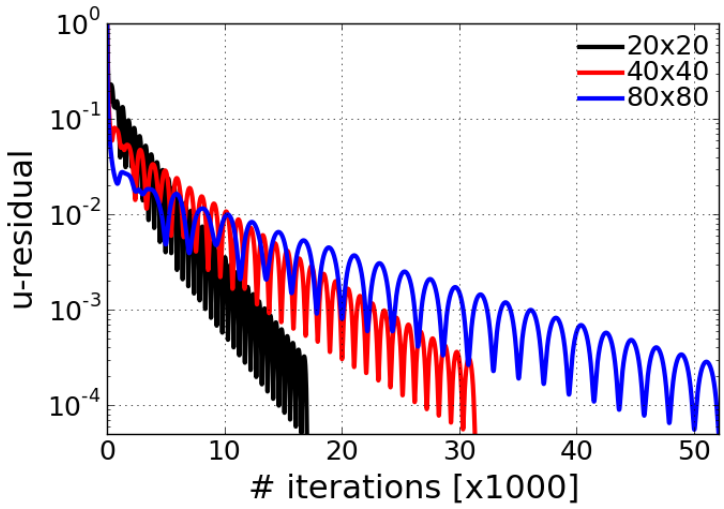
Courant #	dt at last iteration
0.5	0.007470
0.51	0.007620
0.55	0.008218
0.6	0.008653
0.8	0.007761

1.4 Problem1 - e, f

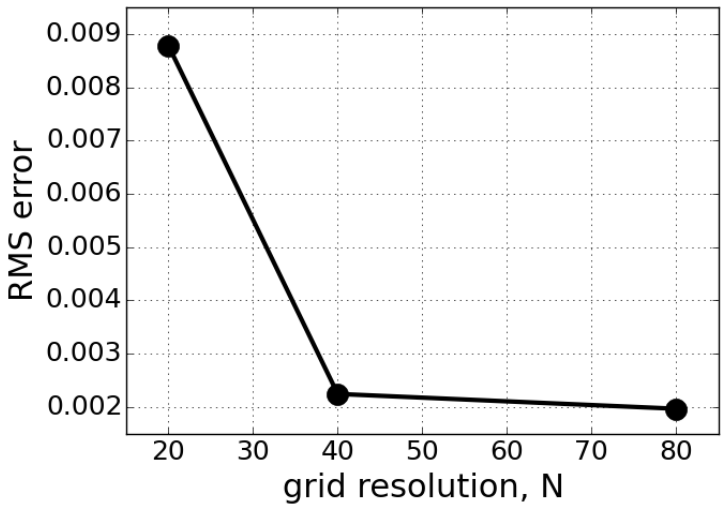
Compare your results with different grid resolutions to evaluate the numerical error and the order of the scheme.

Re = 100

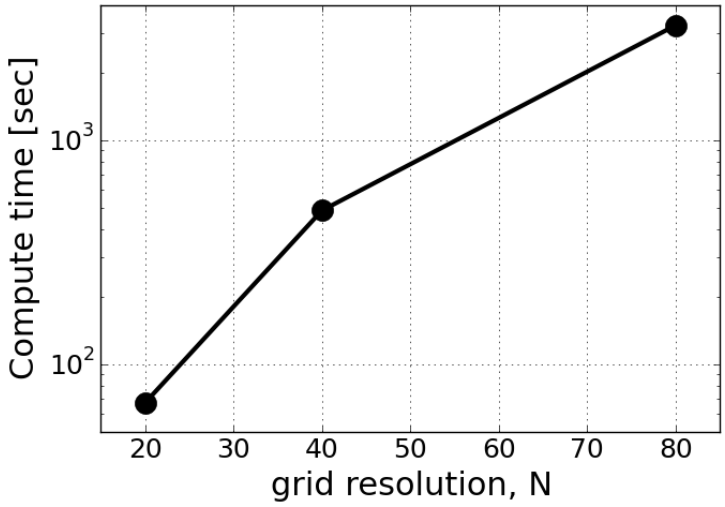
- Residual of u-velocity change in numerical iteration



- RMS error of u-velocity (reference: Ghia's u-velocity data)

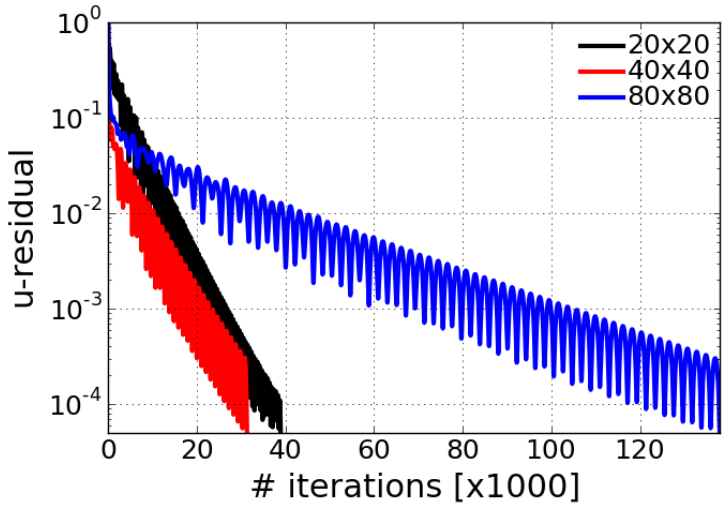


- Computational time with different grid spacing



Re = 500

- Residual of u-velocity change in numerical iteration

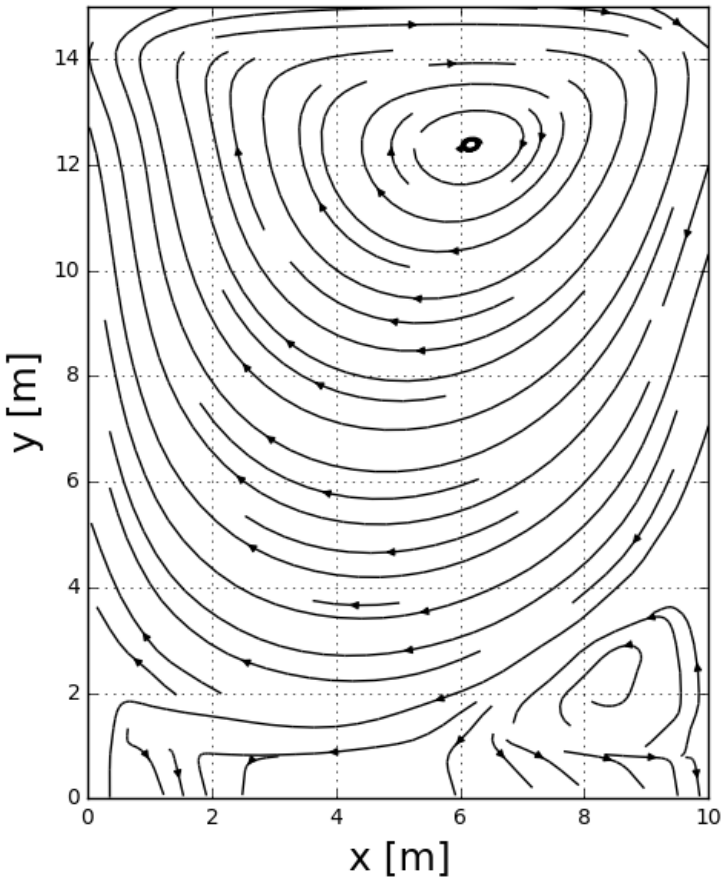


1.5 Problem1 - g

Repeat parts b and c for the case of $H = 1.5W$ (except for validation). How does the flow change in this rectangular cavity as compared to the flow in a sqaure cavity?

1.5.1 Re = 100

- NxN = 20x30
- NxN = 40x60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x [m]
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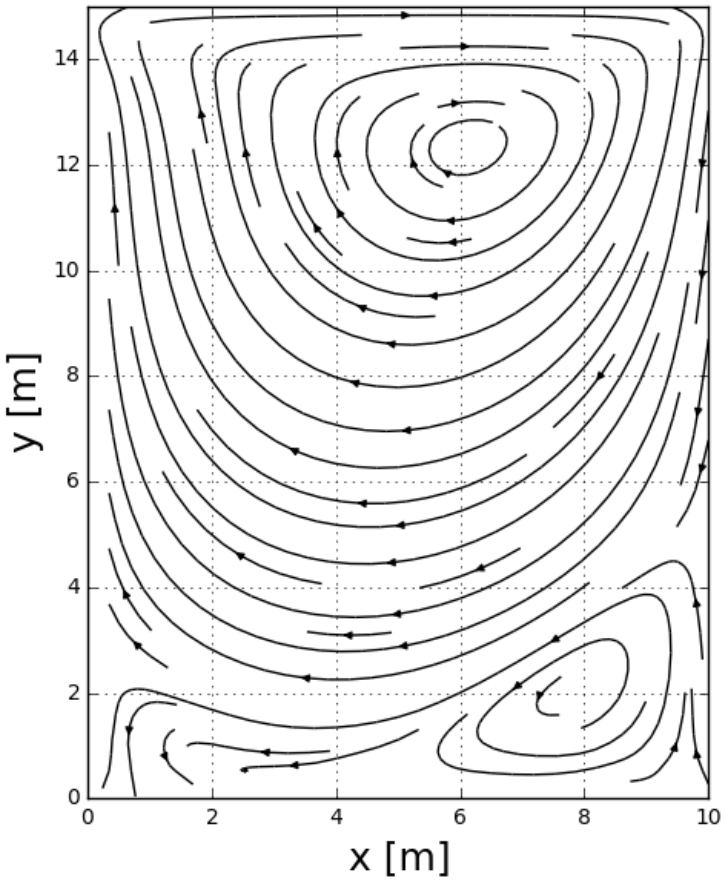
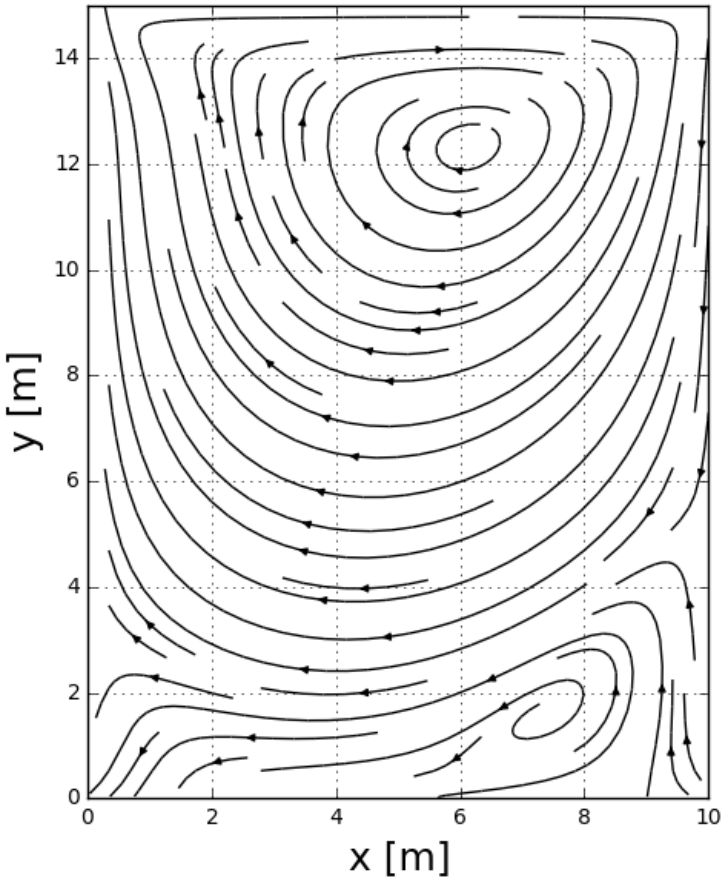
2
4
6
8
10
12
14

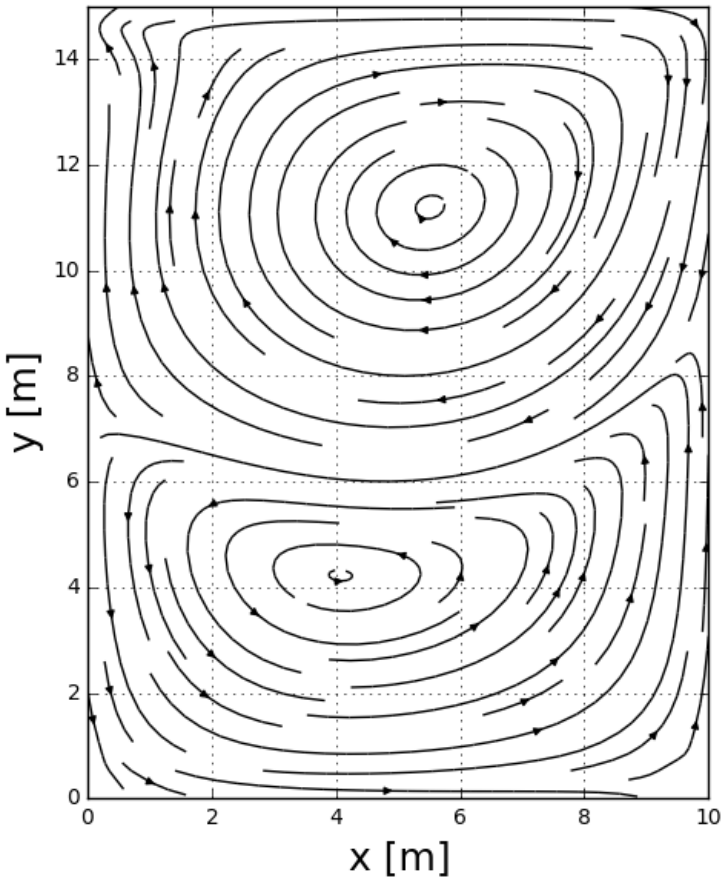

y [m]
x [m]
0
2
4
6
8
10
12
14

- NxN = 80x120



1.5.2 Re = 500

- NxN = 40x60


y [m]
x [m]
0
2
4
6
8
10
12
14