**Class Homework 7: 2D Incompressible Navier-Stoke equation**

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**Exercise N1:**

Figure 1 shows plot error of Q2 and Q1 element

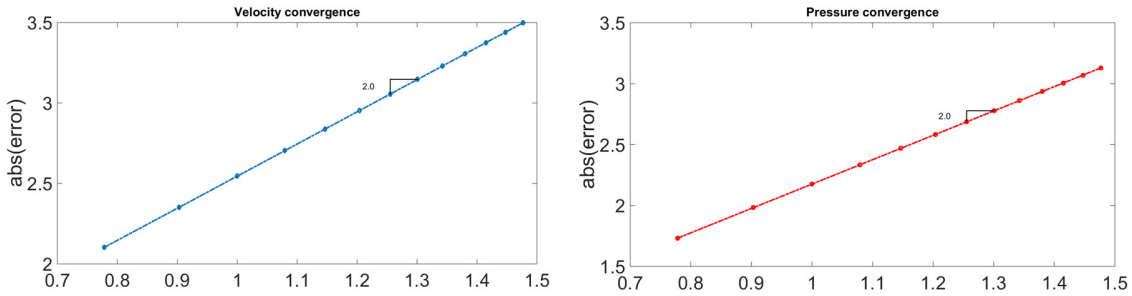


**Figure 1**: Convergence Plot. Left: Q2 element Right: P1 element.

The convergence of Q2 and Q1 is in accordance with theory. It can be observed that Q2 element has an order of convergence equal to 2 and Q1 element has an order of convergence equal to one.

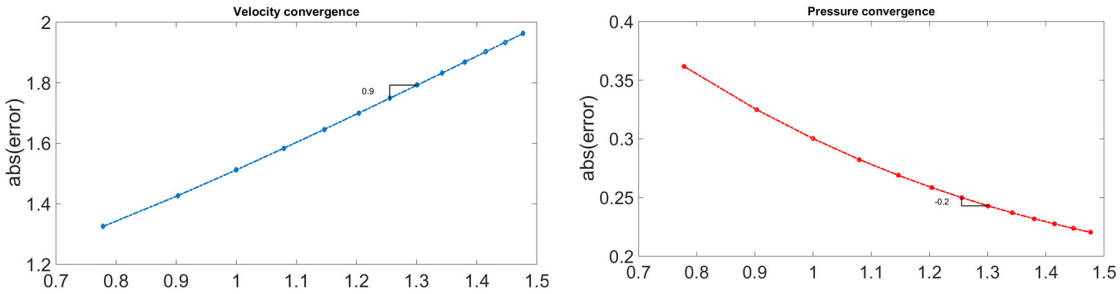


**Figure 2**: Convergence Plot. Left: Q2 element Right: Q0 element.

It can be observed that the convergence of Q2 and Q1 was not that expected. Here, the convergence of Q2 element was equal to 1 and the convergence of Q0 was equal to -0.2.

Next figure shows the convergence of P1P1 elements.

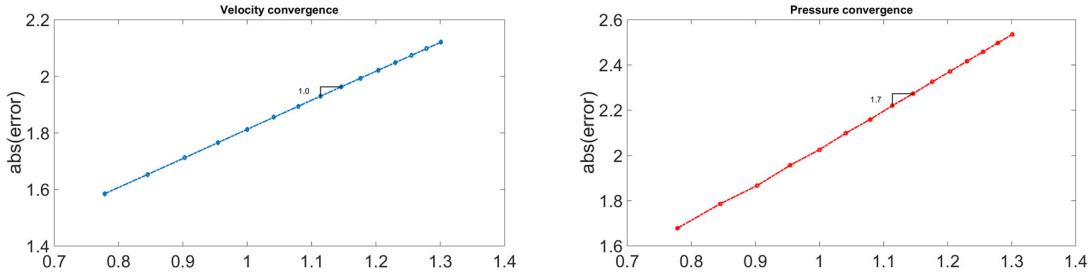


**Figure 3:** Convergence Plot. Left: P1 element Right: P1 element.

It can be observed that P1 for velocity and P1 for pressure have an order of convergence equal to 1.

**Exercise N2:**

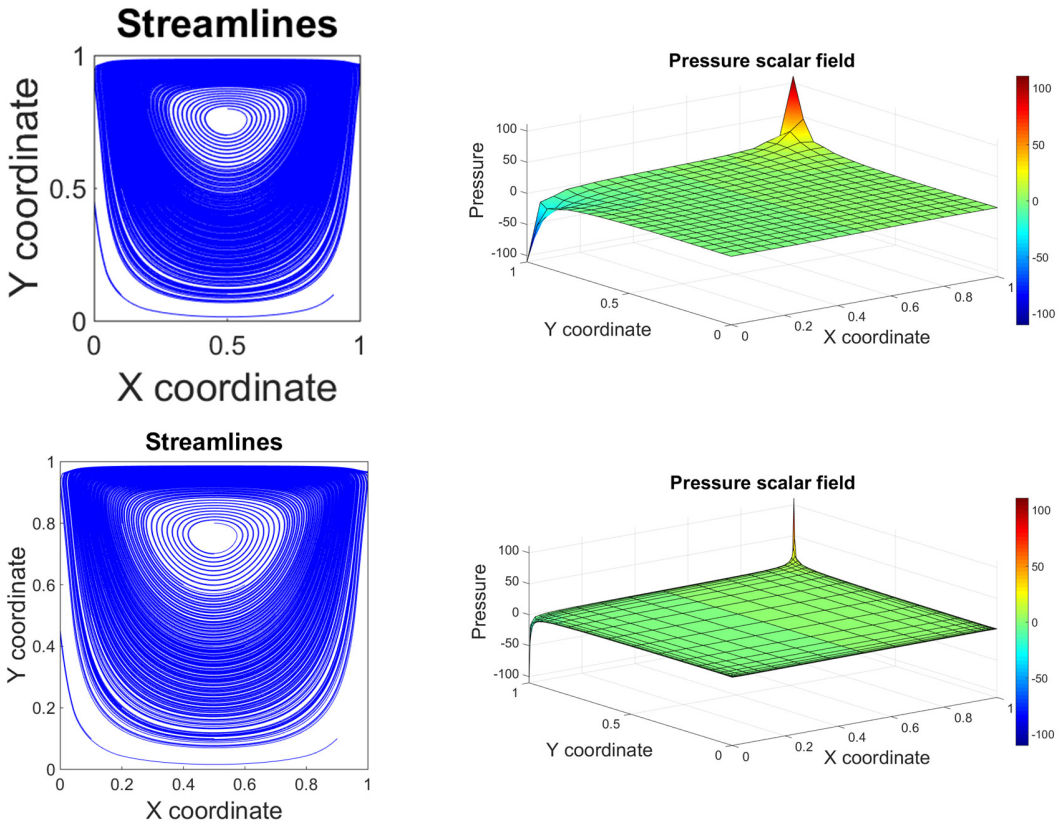


**Figure 4:** Result for 20x20 elements. Uniform mesh: Top left, streamlines. Top right, pressure. Adaptive mesh: Bottom left, streamlines. Bottom right pressure.

It can be observed Q2Q1, which are LBB compliant, show, as expected, reasonable results for pressure. See Figure 4.

The main features are the symmetry with respect to the vertical centreline and the pressure singularity at the two uppers corners. In fact, no shear layers are present in the Stokes problem, but results (the pressure jump between both corners) improve if a nonuniform mesh is employed.

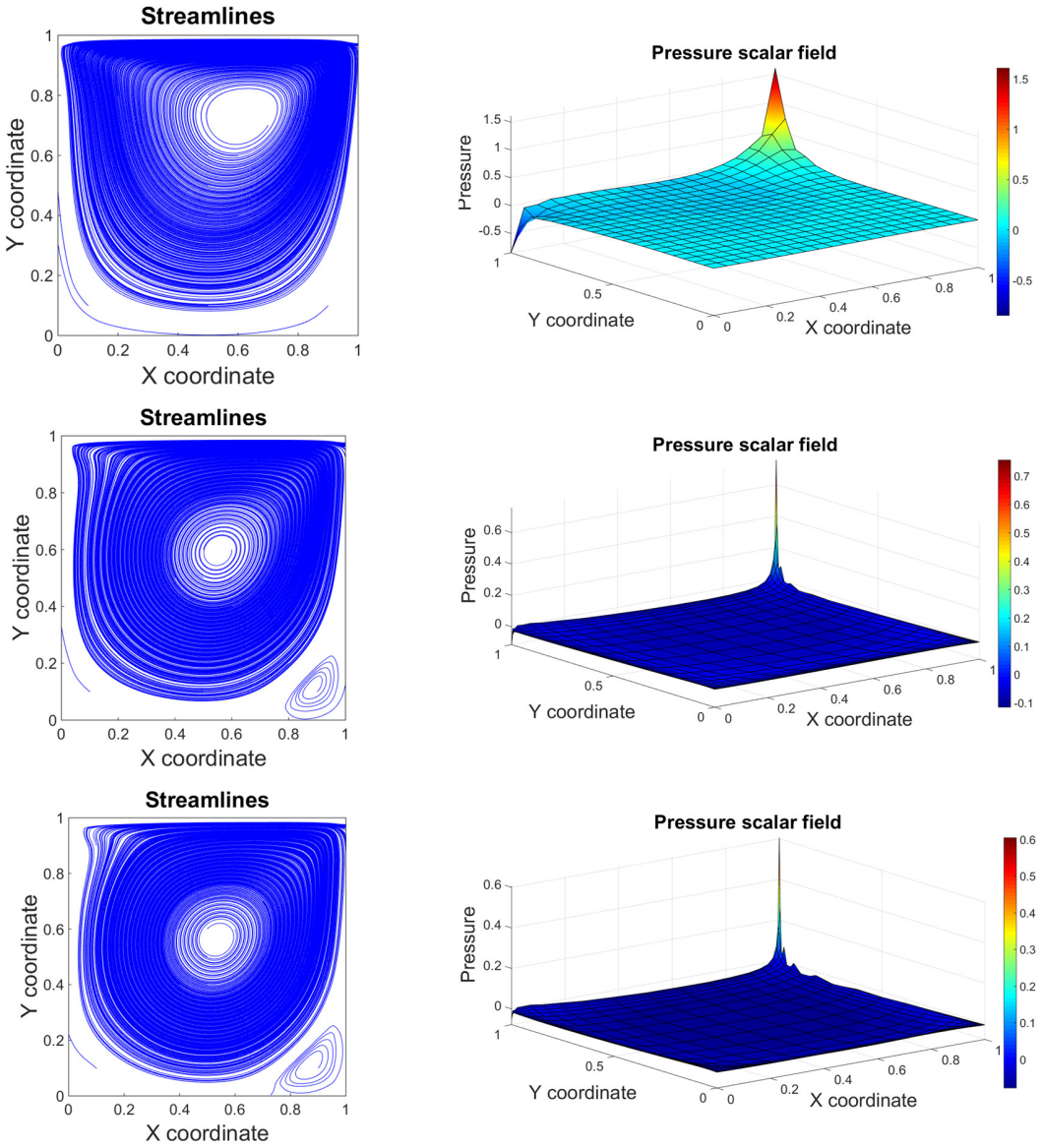


**Figure 5:** Re = 100 (Top), Re = 500 (Middle), Re = 1000 (Bottom).

**Table 1:** Position of the main vortex as function of Reynolds number.

| Square cavity | | X1 | X2 | Stream Function |
|---|---|---|---|---|
| Re = 100 | Present Simulation | 0.60 | 0.72 | 0.107 |
| | Huerta (2003) | 0.62 | 0.74 | 0.103 |
| Re = 500 | Present Simulation | 0.56 | 0.60 | 0.113 |
| | Huerta (2003) | 0.568 | 0.606 | 0.110 |
| Re = 1000 | Present Simulation | 0.54 | 0.56 | 0.114 |
| | Huerta (2003) | 0.540 | 0.573 | 0.110 |

It was necessary spend 13 Picard iterations for Re = 100, 26 Picard iterations for Re = 500 and 68 Picard iterations for Re = 68, in order to achieve to convergence.