A meshless direct pressure-velocity coupling procedure is presented to perform Direct Numerical Simulations (DNS) and Large Eddy Simulations (LES) of turbulent incompressible flows in regular and irregular geometries. The fundamental idea of this proposal lays on several important inconsistencies found in three of the most popular techniques used in CFD, segregated procedures, streamline-vorticity formulation for 2D viscous flows and the fractional-step method, very popular in DNS/LES. In all methods studied, the mathematical basement was found to be correct in most cases, but inconsistencies were found when writing the boundary conditions. In all methods analyzed, it was found that it is basically impossible to satisfy the exact set of boundary conditions and all formulations use a reduced set, valid for parabolic flows only. The proposed procedure is validated in two cases of 2D flow in steady state, backward-facing step and lid-driven cavity. Comparisons are performed with experiments and excellent agreement was obtained in the solutions that were free from numerical instabilities.

A study on grid usage was done. It was found that if the discretized equations are written in terms of a local Reynolds number, a strong criterion can be developed to determine, in advance, the grid requirements for any fluid flow calculation. Additionally, the code was parallelized using a concurrent approach without using any communication protocol.

The 2D-DNS on parallel plates is presented to study the basic features present in the simulation of any turbulent flow. Calculations were performed on a short geometry, using a uniform and very fine grid to avoid any numerical instability. Results suggest that, if no numerical instability is present, inflow conditions alone are not enough to sustain permanently the turbulent regime.

Finally, the 2D-DNS on a backward-facing step is studied. Expansion ratios of 1.14 and 1.40 are used and calculations are performed in the transitional regime. Inflow conditions were white noise and high frequency oscillations. In general, good agreement is found on primitive variables when comparing with experimental data.