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Numerical Study of non-Newtonian Inelastic Fluid Flow in a 2D Bifurcation at Ninety Degrees

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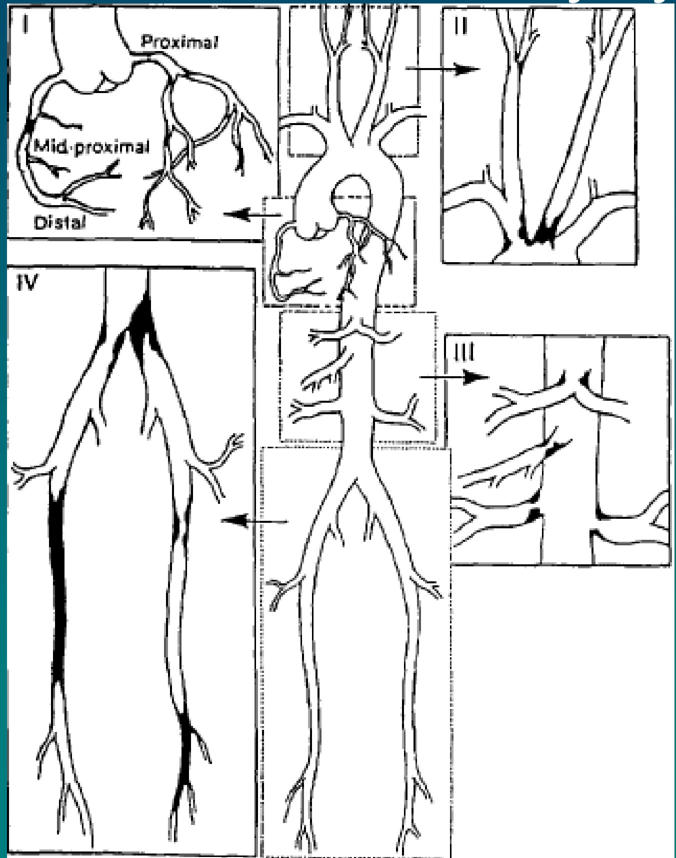
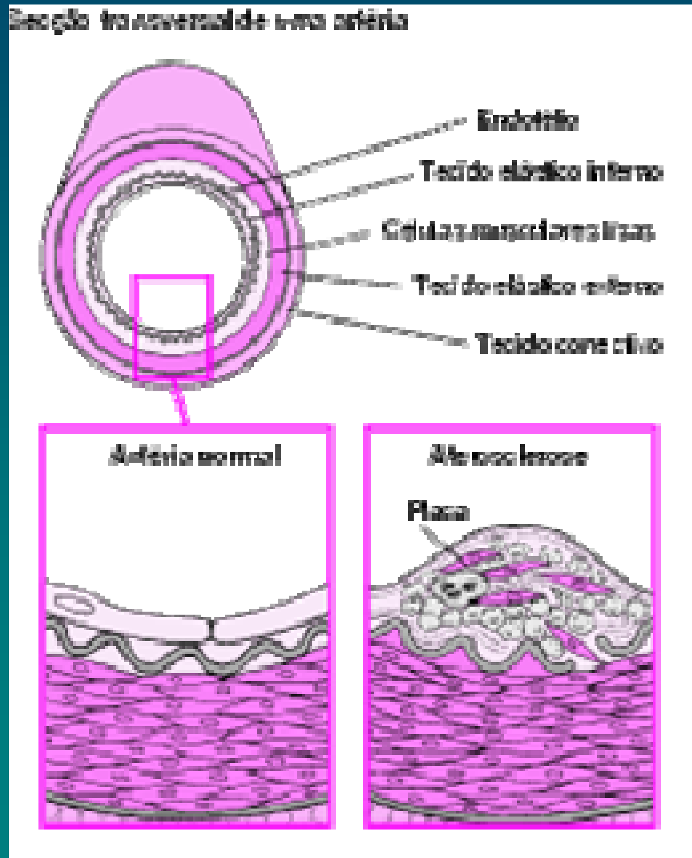
1 - T-JUNCTION FLOWS

- The human circulatory system (many bifurcations)





2 - OBJECTIVES

- Evaluate the effect of **inertia** and **flow rate ratio** in flow through a T-junction (dividing flow arrangement) for Newtonian and non-Newtonian inelastic fluids (fixed n).

$$\mathrm{Re} = \frac{\rho u_1 H}{\eta_0}$$

$50 \leq \mathrm{Re} \leq 1000$

$$\beta = \frac{Q_3}{Q_1}$$

$0.1 \leq \beta \leq 0.9$

2 - OBJECTIVES

- Evaluate the effect of inertia and flow rate ratio in flow through a T-junction (dividing flow arrangement) for Newtonian and non-Newtonian inelastic fluids (fixed n).

- Evaluate the effect of power law exponent ***n*** variation in the Carreau-Yasuda model for this kind of flow.

3 - EQUATIONS

- Conservation of mass

$$\nabla \cdot \boldsymbol{u} = 0$$

- Conservation of linear momentum

$$\rho \frac{D\boldsymbol{u}}{Dt} = -\nabla p + \nabla \cdot \boldsymbol{\tau}$$

Newtonian

$$\boldsymbol{\tau} = \eta \dot{\gamma}$$

non-Newtonian

$$\boldsymbol{\tau} = \eta\left(\left|\dot{\gamma}\right|\right)\dot{\gamma}$$

3 - EQUATIONS

- Conservation of mass

$$\nabla \cdot \boldsymbol{u} = 0$$

- Conservation of linear momentum

$$\rho \frac{D\boldsymbol{u}}{Dt} = -\nabla p + \nabla \cdot \boldsymbol{\tau}$$

GNF fluid ← **non-Newtonian**

$$\boldsymbol{\tau} = \eta\left(\left|\dot{\gamma}\right|\right)\dot{\gamma}$$

Carreau-Yasuda model

3 - EQUATIONS

- Carreau-Yasuda model

$$\eta = \eta_\infty + (\eta_0 - \eta_\infty)\left[1 + \left(\lambda\left|\dot{\gamma}\right|\right)^a\right]^{\frac{n-1}{a}}$$

- Blood parameters (Banerjee et al. 1997)
  - Power law exponent, $n=0.3568$ (for results with fixed n);
  - Carreau parameter, $a=2$;
  - Zero shear rate viscosity, $\eta_0=0.056\ Pa.s$;
  - Infinite shear rate viscosity, $\eta_\infty=0.00345\ Pa.s$;
  - Time constant $\lambda=3.313\ s$.

4 - NUMERICAL METHOD

- Finite-volume method for discretization of equations.
- Nonstaggered mesh arrangement.
  - Pressure-velocity coupling: Rhie e Chow, 1983.
  - Stress-velocity coupling: Oliveira et al., 1999.
- Convective terms: CUBISTA scheme (Alves et al. 2003).
- Pressure-correction SIMPLEC algorithm with time-marching.
- Convergence tolerance for iterative process when norm of residuals less than 10^{-8}.

5 - FLOW GEOMETRY

Flow rate

$$\beta = \frac{Q_3}{Q_1}$$

Outlet

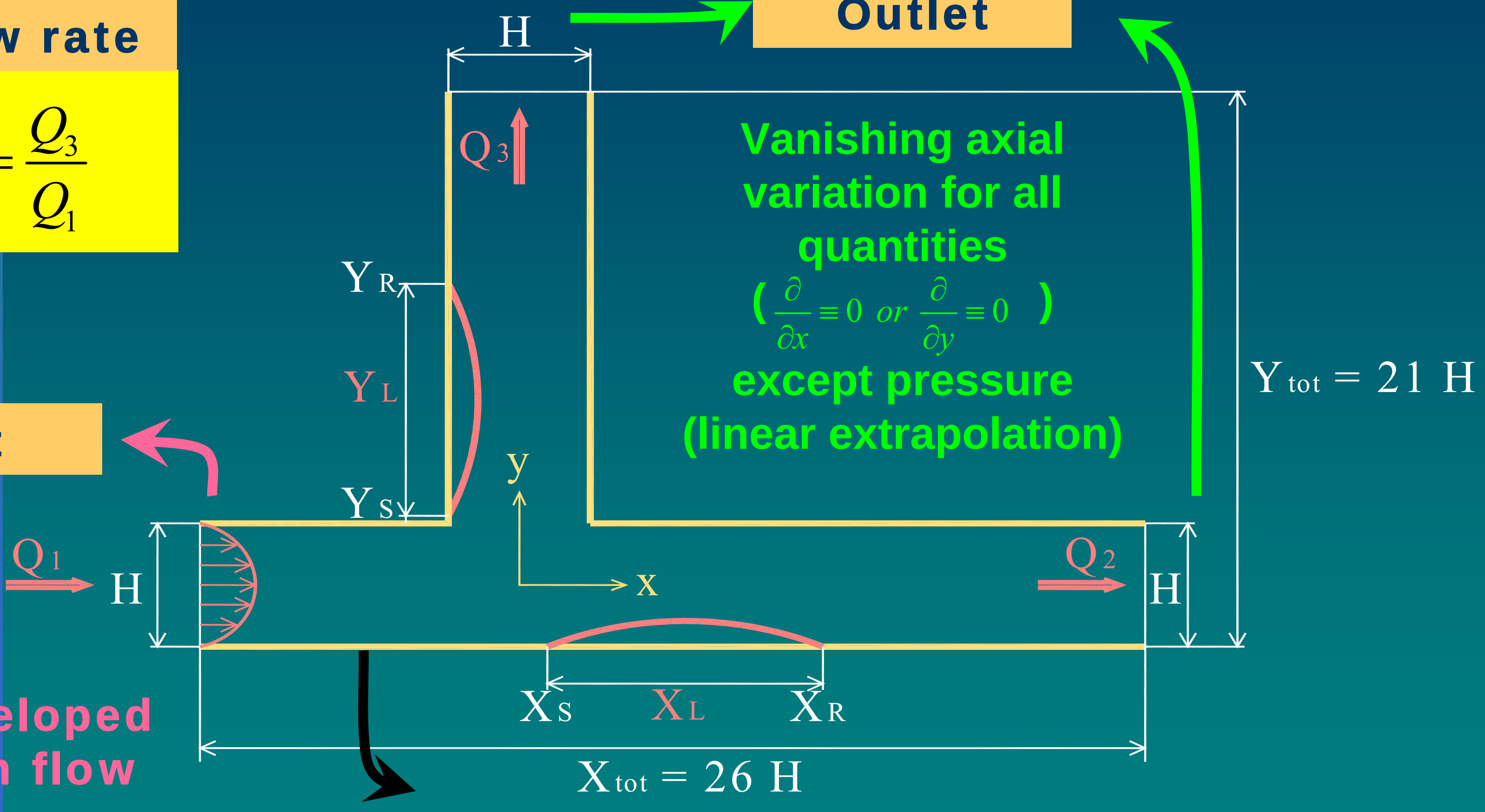
Vanishing axial variation for all quantities

$$\left(\frac{\partial}{\partial x} \equiv 0 \;\; or \;\; \frac{\partial}{\partial y} \equiv 0 \right)$$

except pressure (linear extrapolation)

Inlet

Fully developed upstream flow



Walls

No slip condition u = v = 0

6 - MESHES

- Orthogonal but non uniform meshes

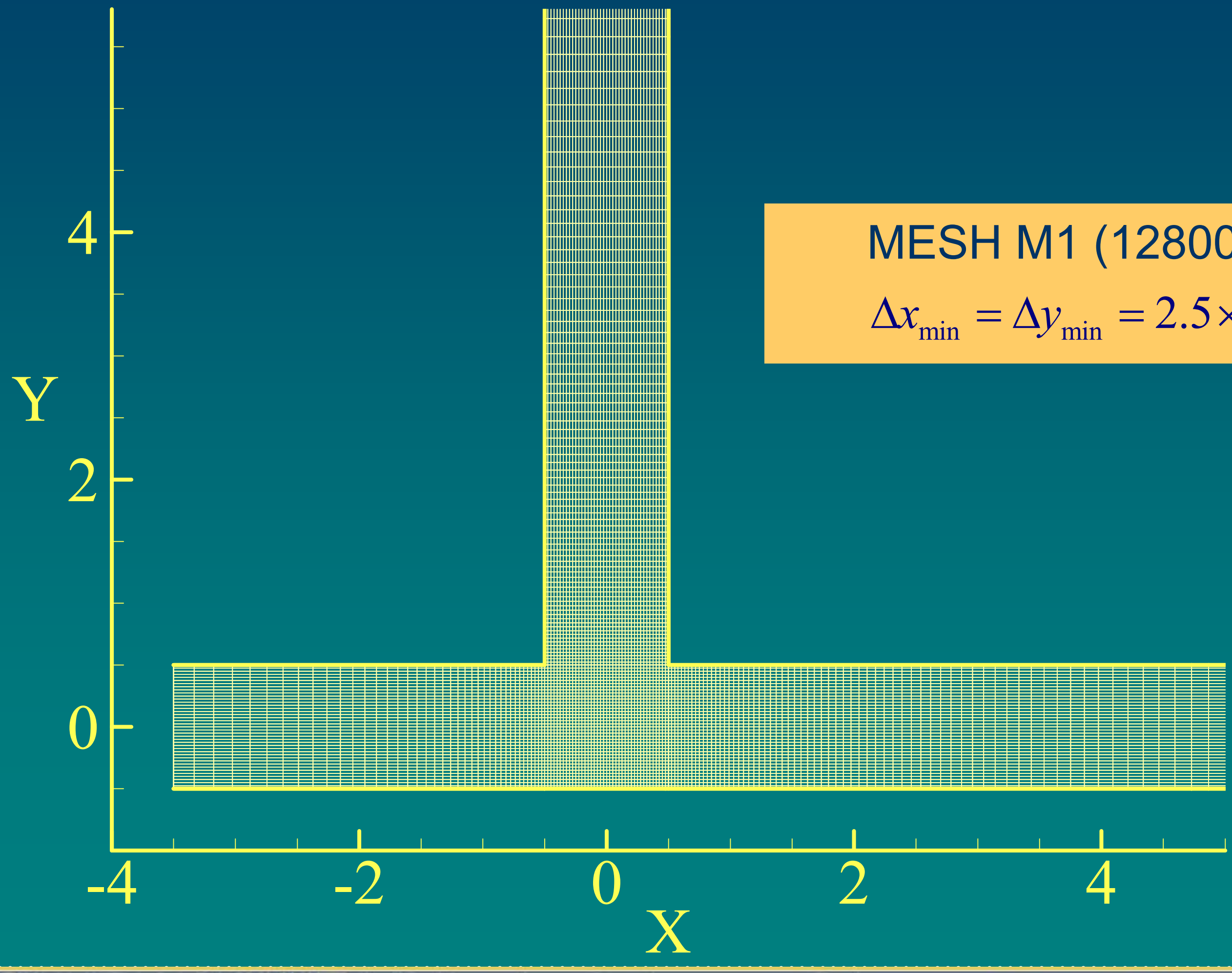
  – MESH M1, 12800 VC (X_{tot}=26H Y_{tot}=21H)

  $$\Delta x_{\min} = \Delta y_{\min} = 2.5\times10^{-2}$$

  – MESH M2, 22400 VC (X_{tot}=66.5H Y_{tot}=60.5H)

  $$\Delta x_{\min} = \Delta y_{\min} = 2.5\times10^{-2}$$

6 - MESHES

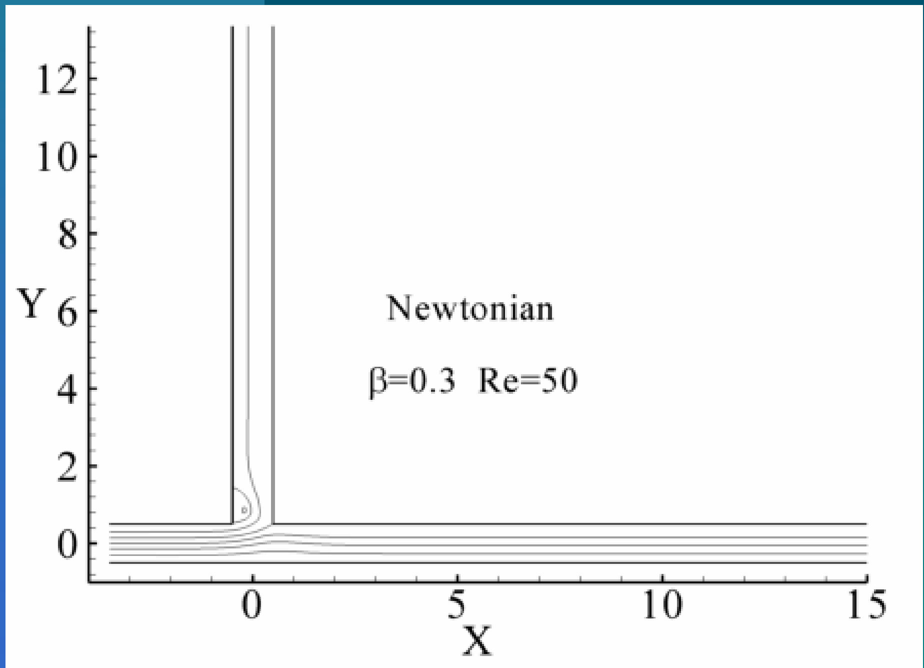


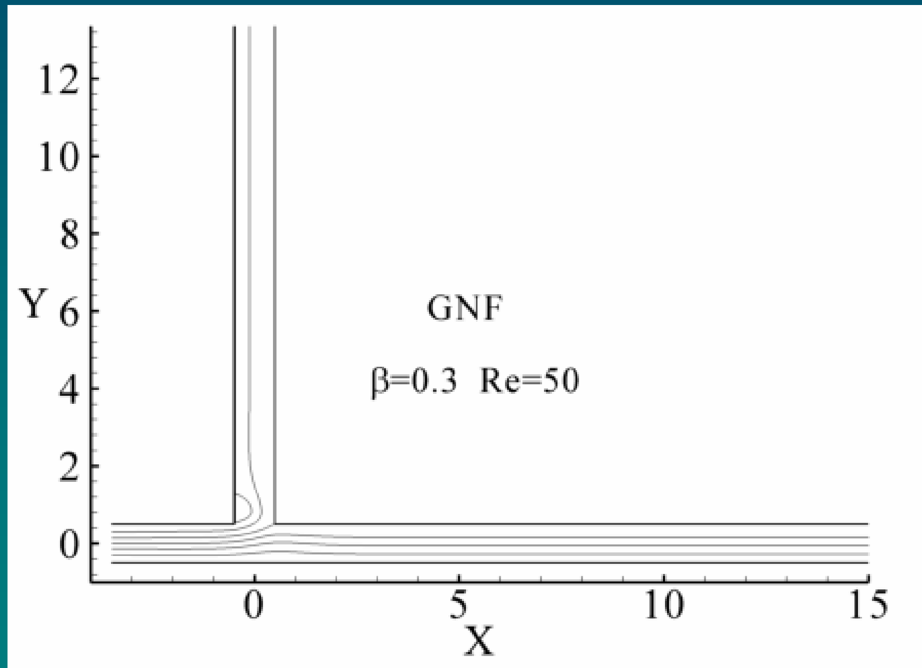
MESH M1 (12800 VC)

$$\Delta x_{min} = \Delta y_{min} = 2.5\times10^{-2}$$

7 - RESULTS

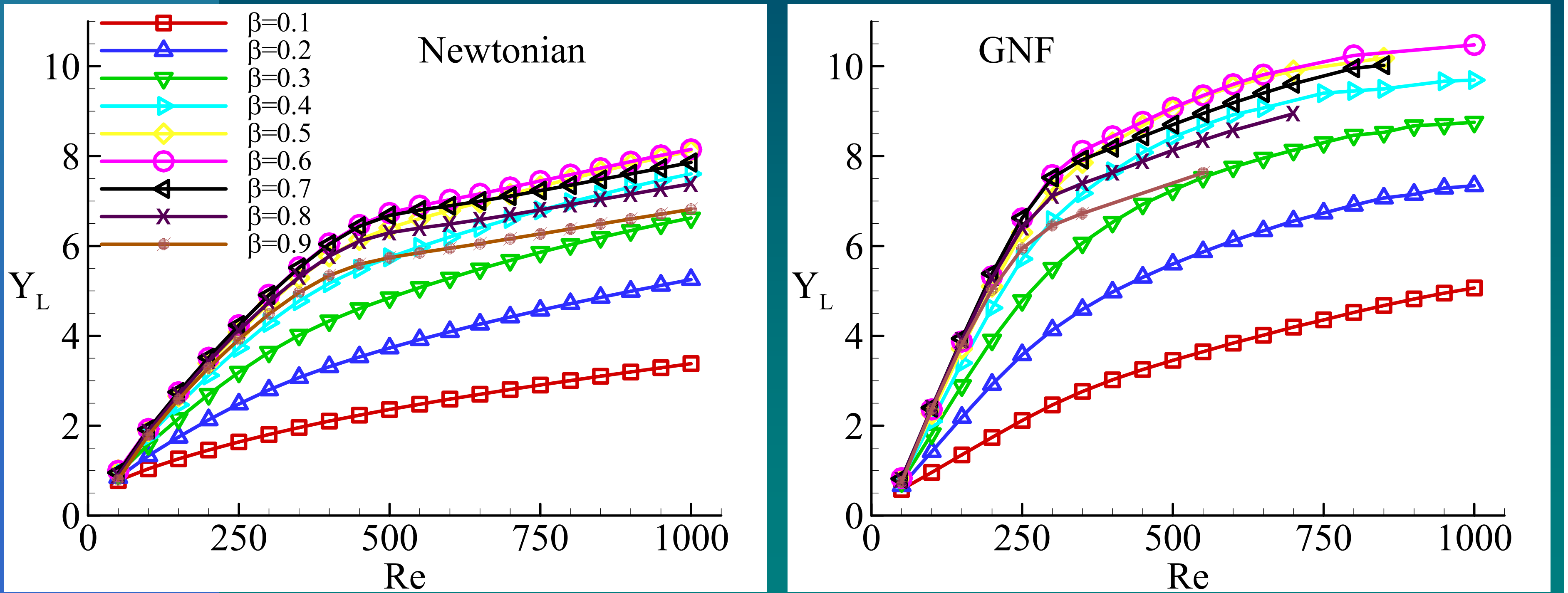
- Streamlines for increasing Reynolds number





7 - RESULTS

- Vertical recirculation length



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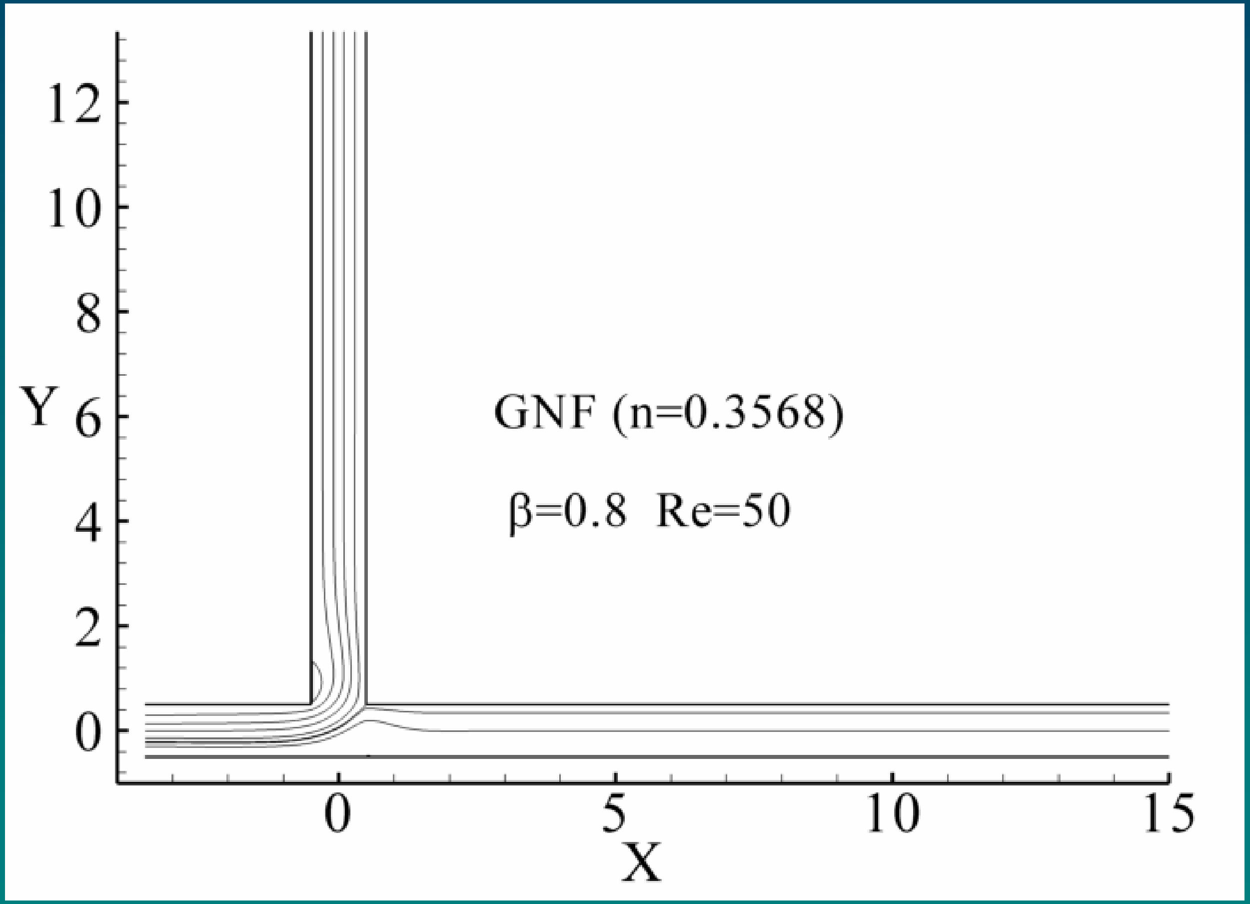
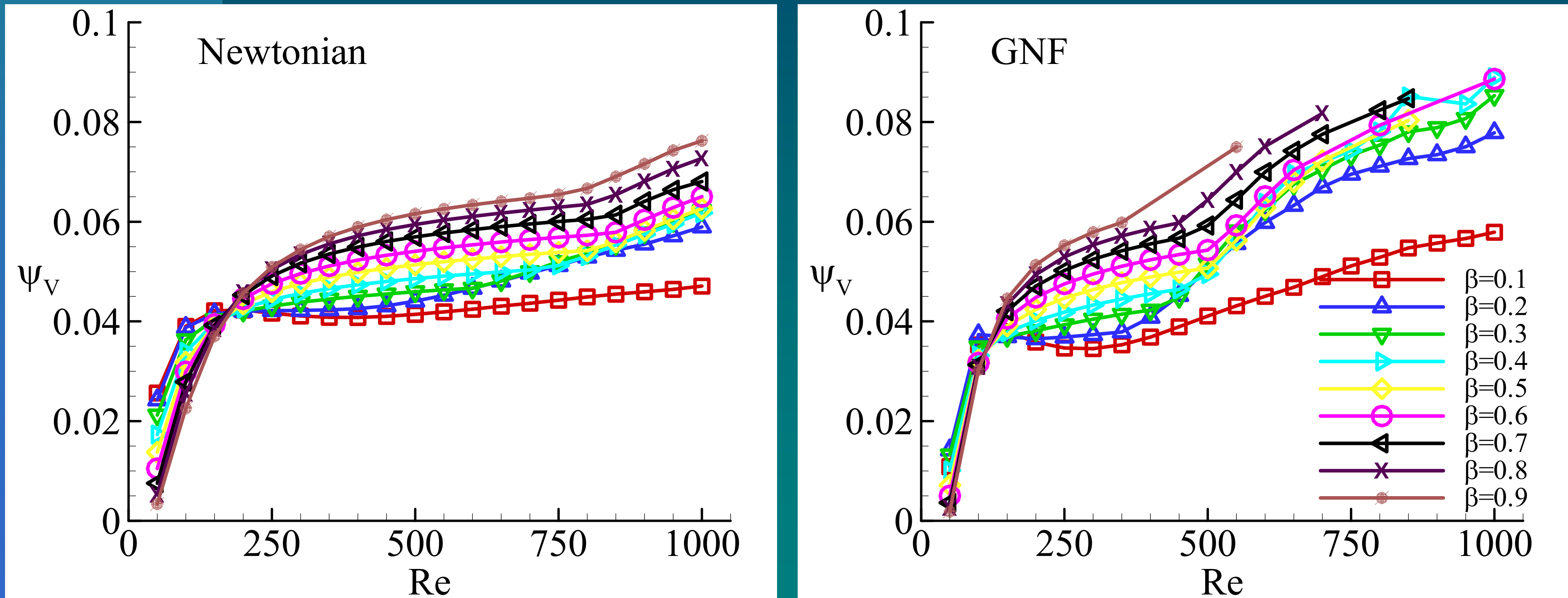


7 - RESULTS

- Vortex strength of vertical recirculation



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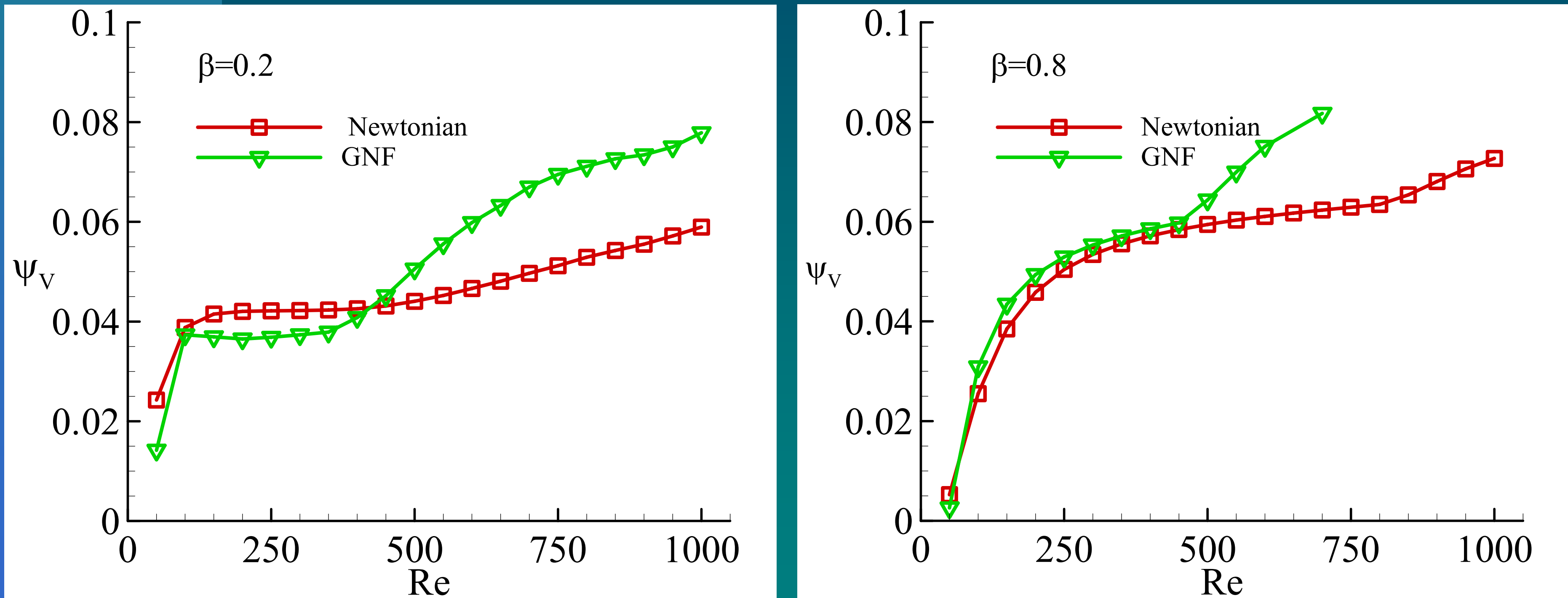
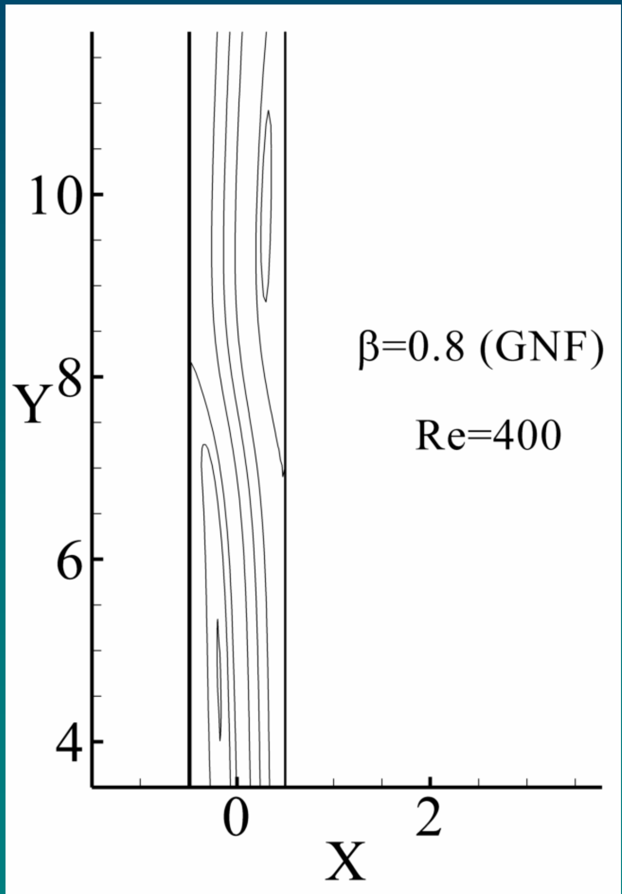
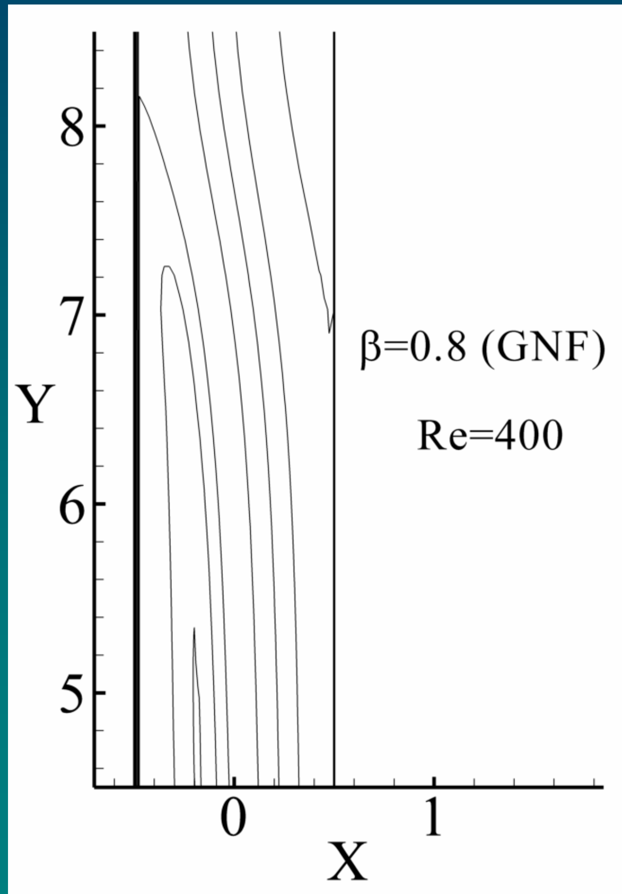


7 - RESULTS

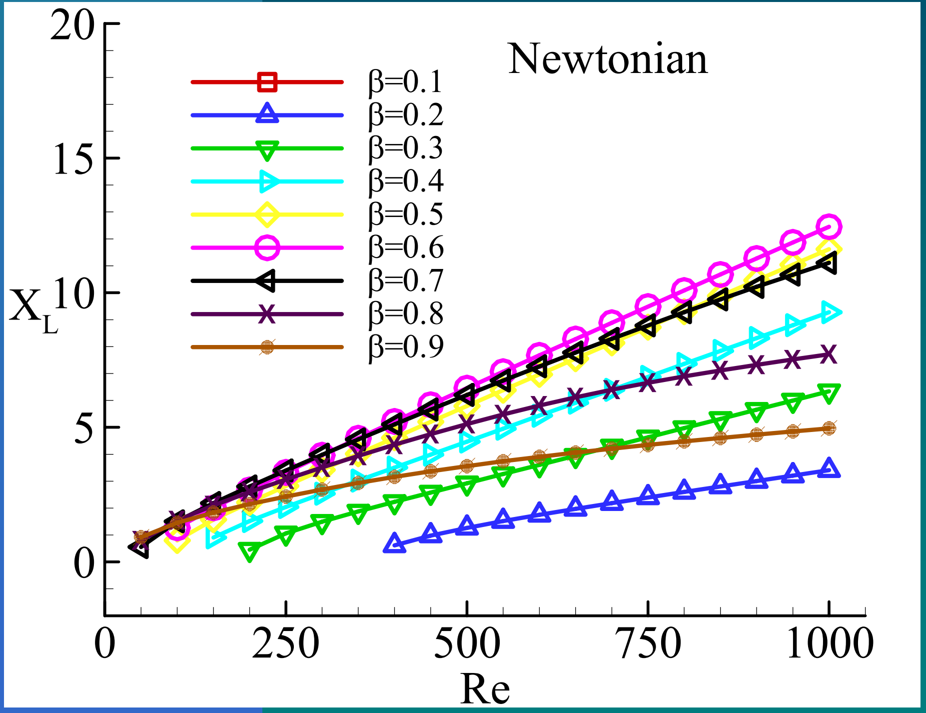
- Streamlines (secondary branch)

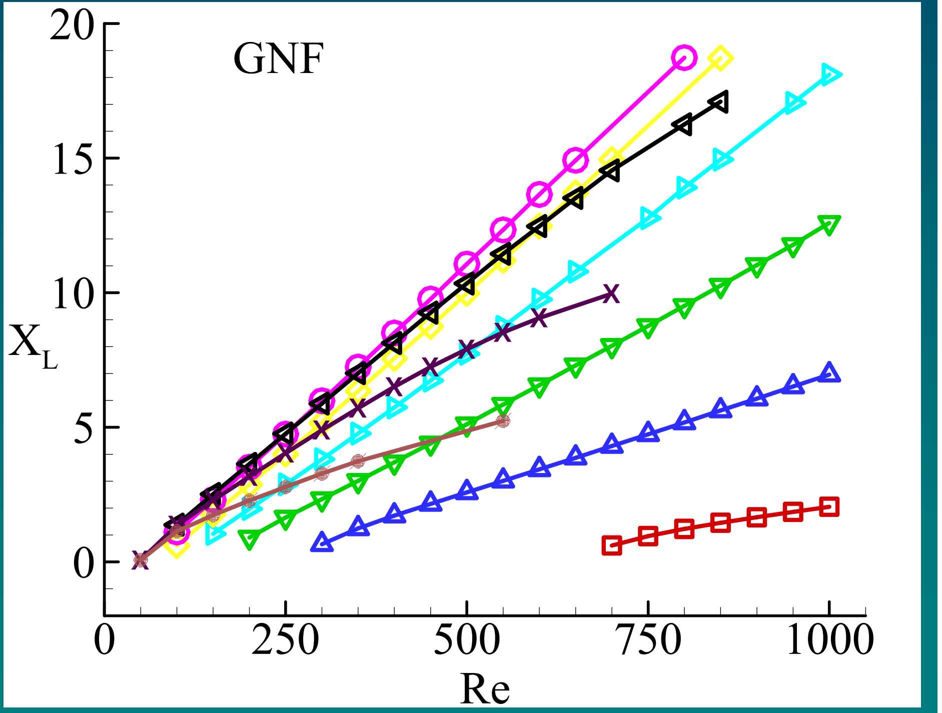




7 - RESULTS

- Horizontal recirculation length





7 - RESULTS

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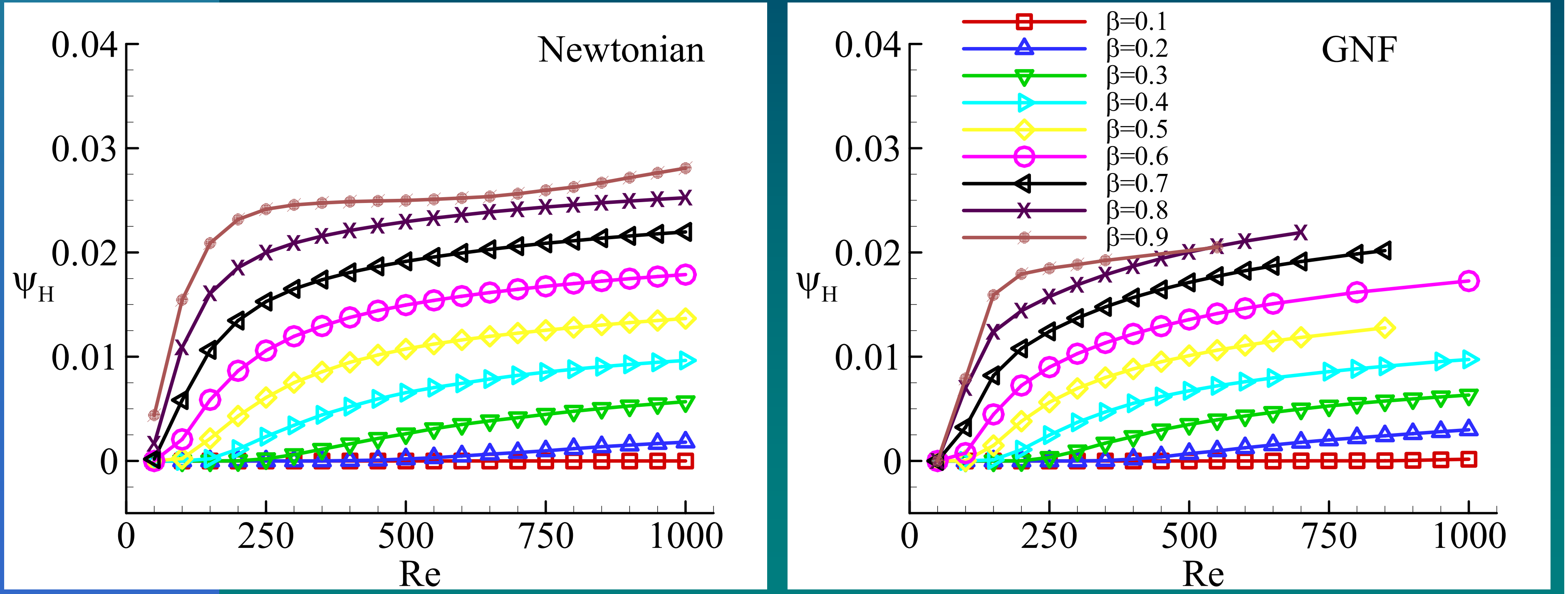
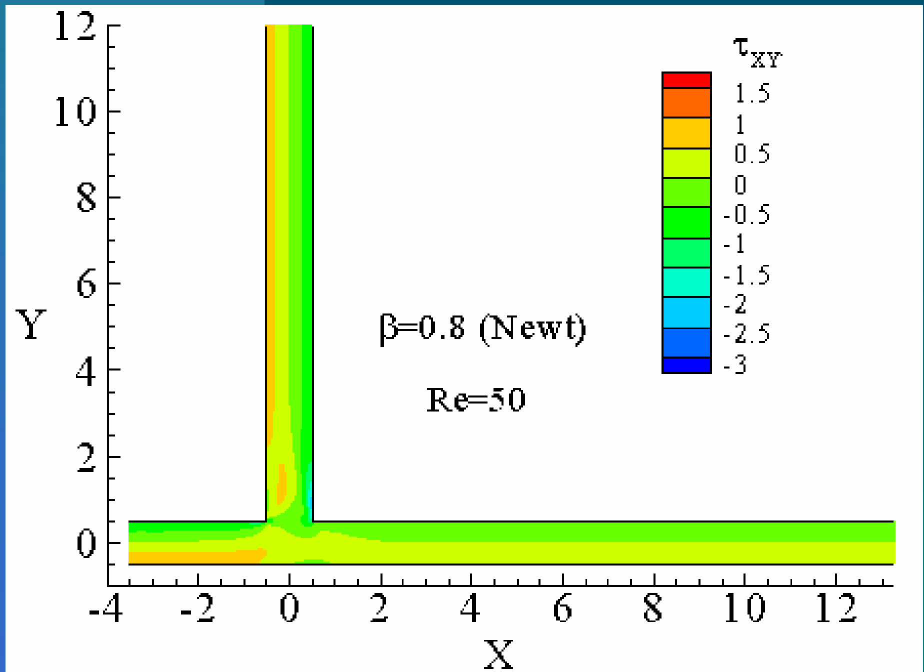
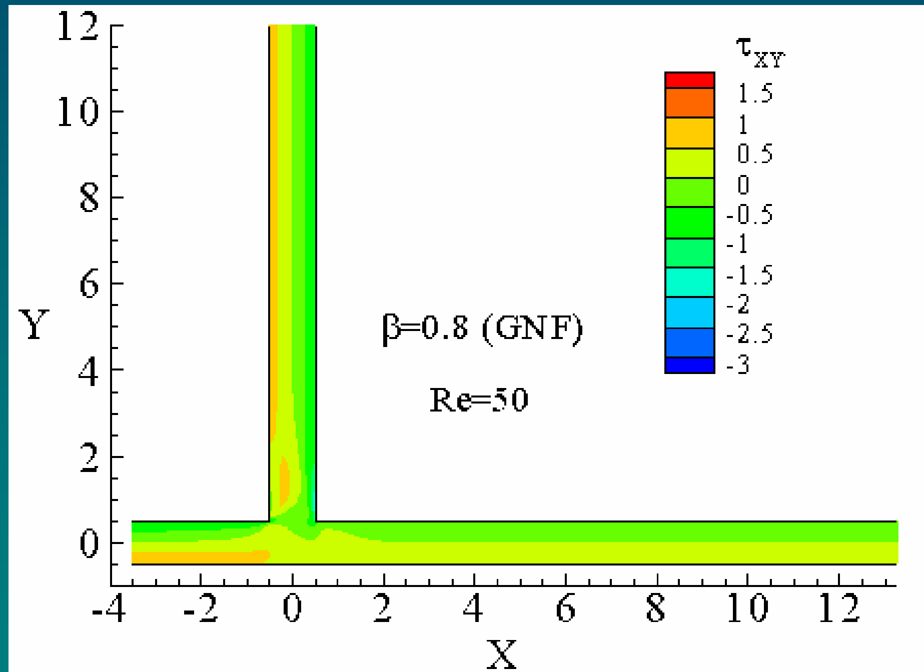


7 - RESULTS

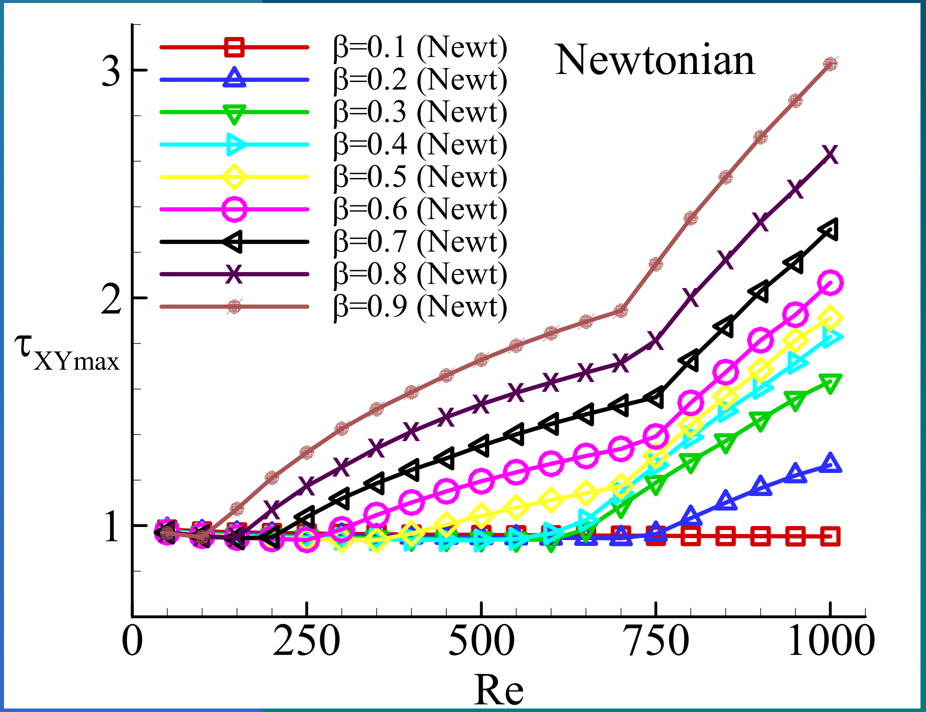
- Shear stress field: variation with Re

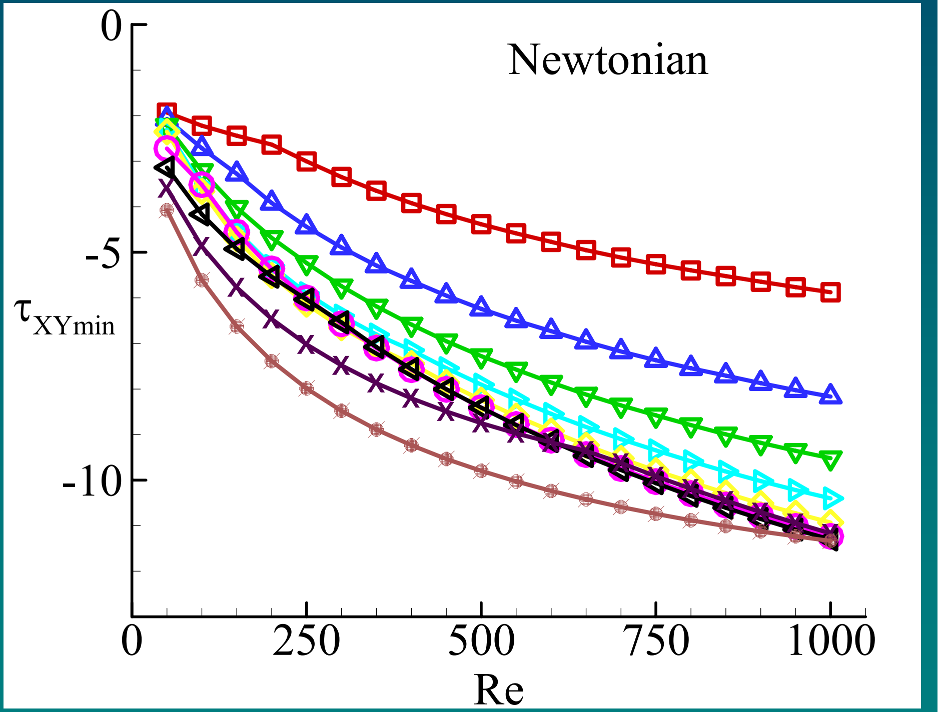




7 - RESULTS

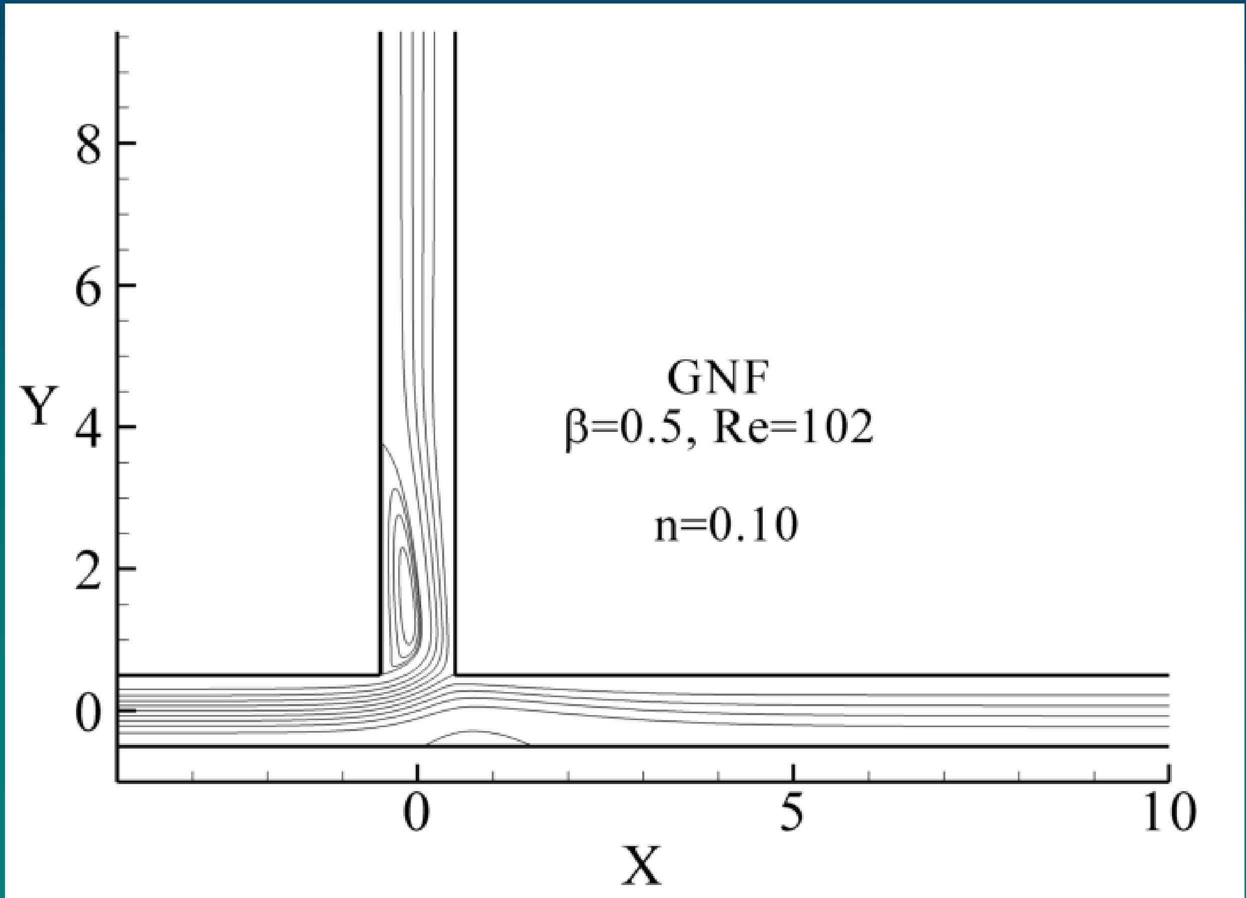
- Maximum values of shear stress





7 - RESULTS (variation with *n*)

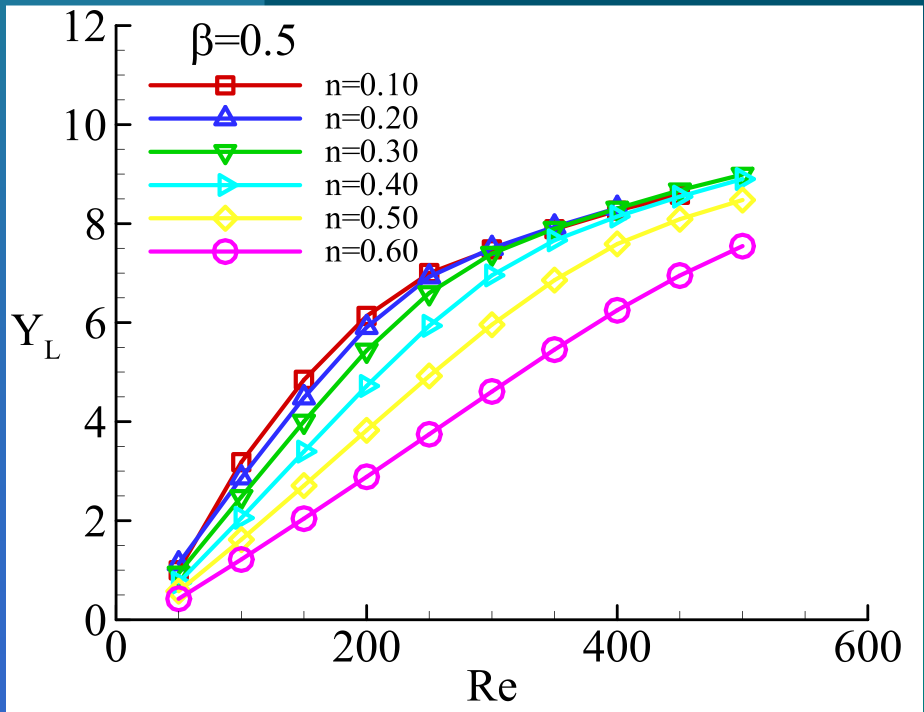
- Streamlines for increasing power law index

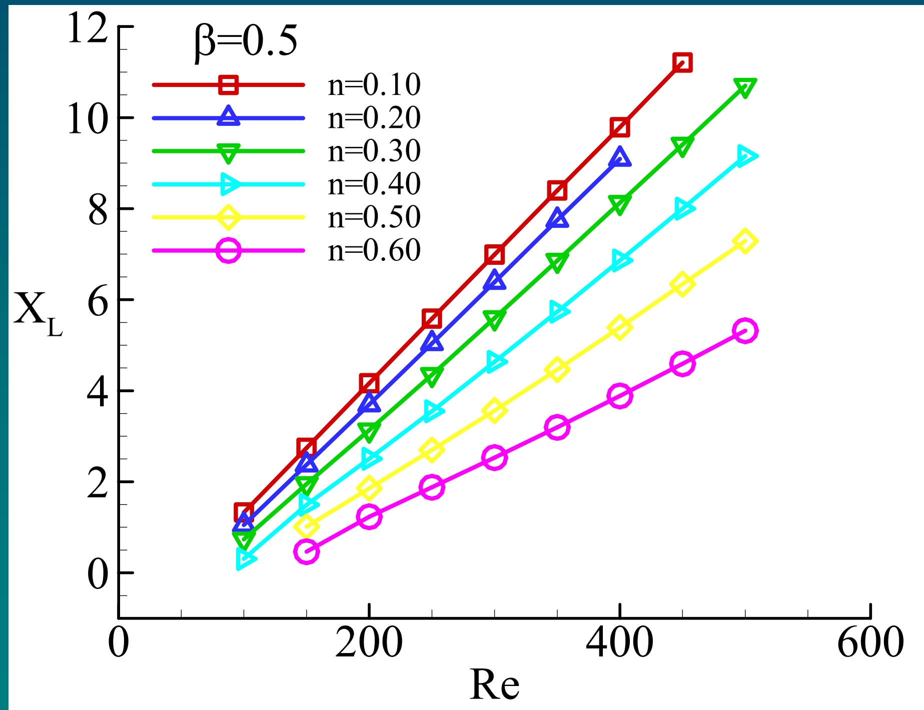


7 - RESULTS (variation with *n*)

- Recirculation length (fixed β)

Vertical ***Horizontal***





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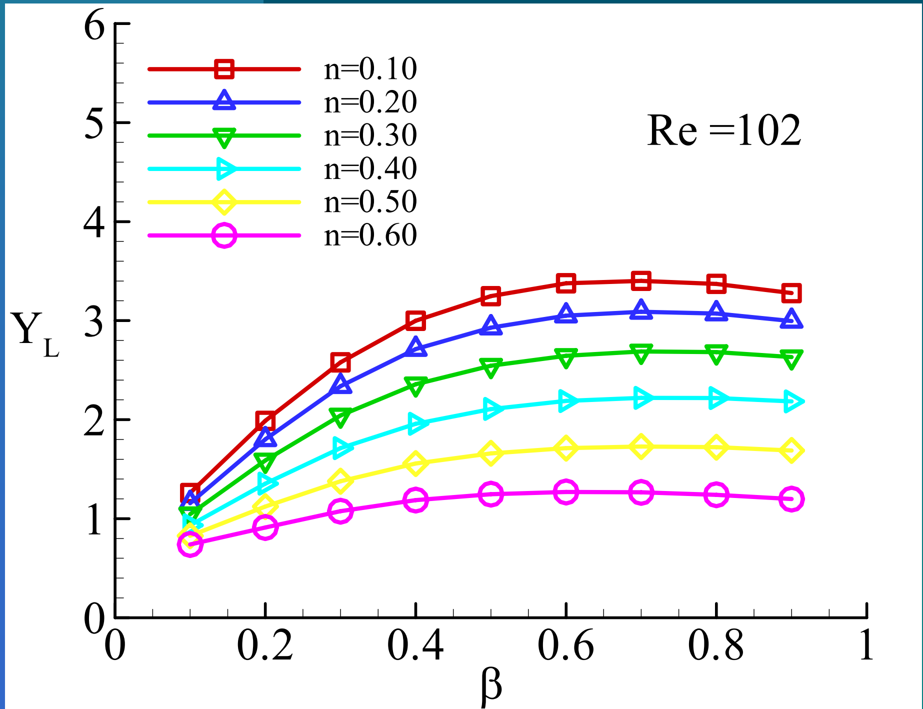
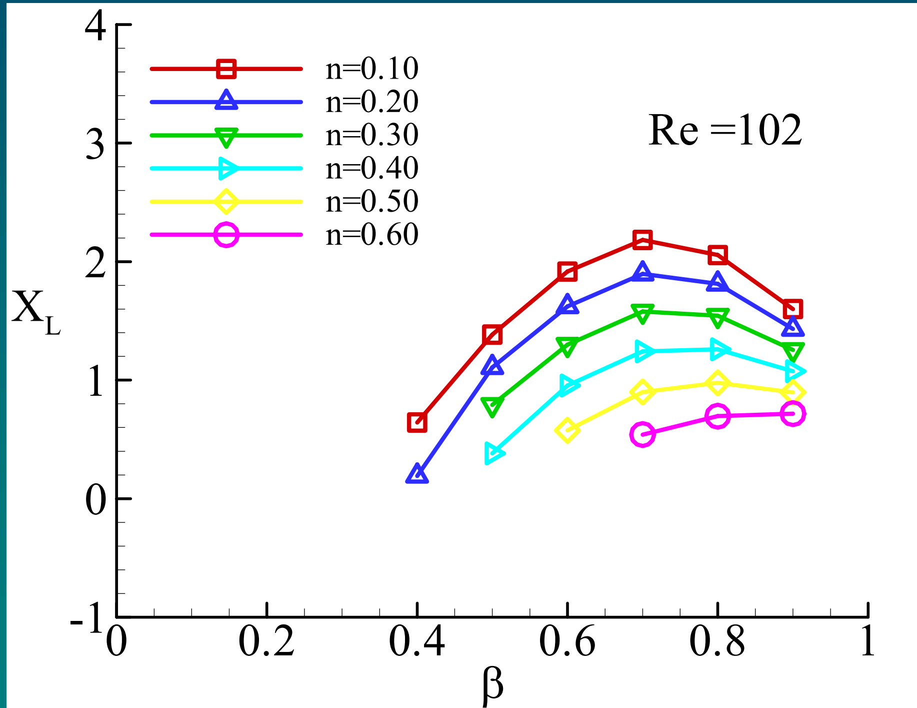
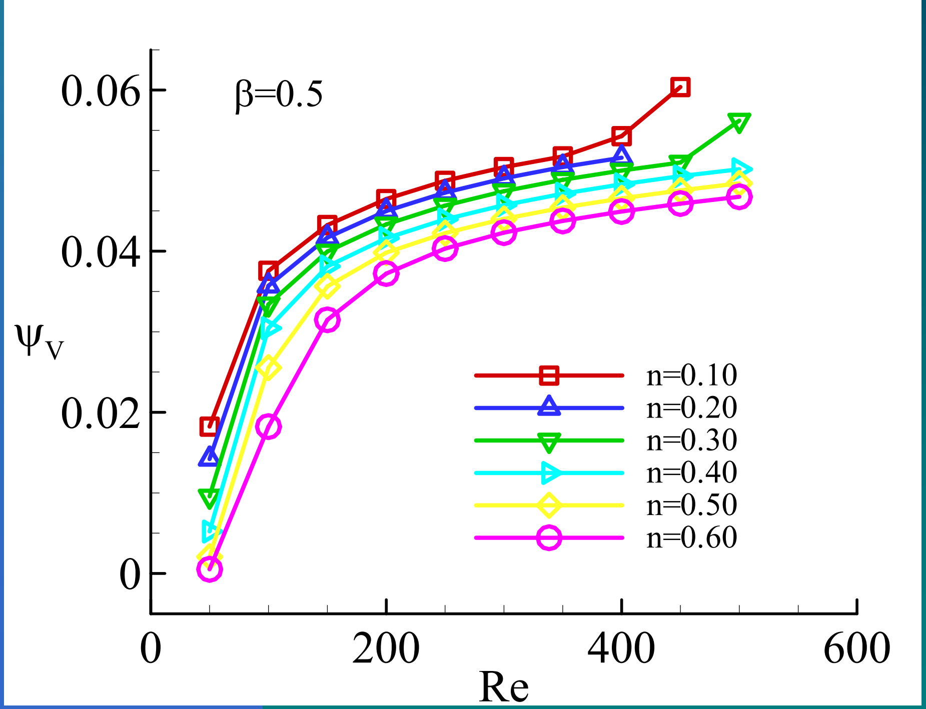




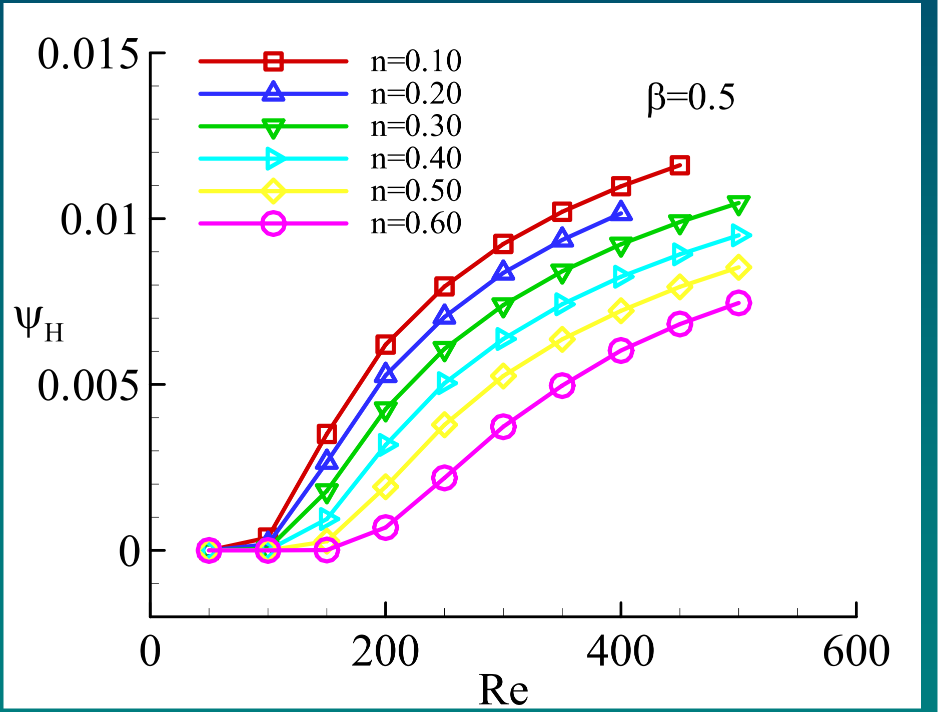
7 - RESULTS (variation with *n*)

- Vortex strength of recirculations (fixed β)

Vertical

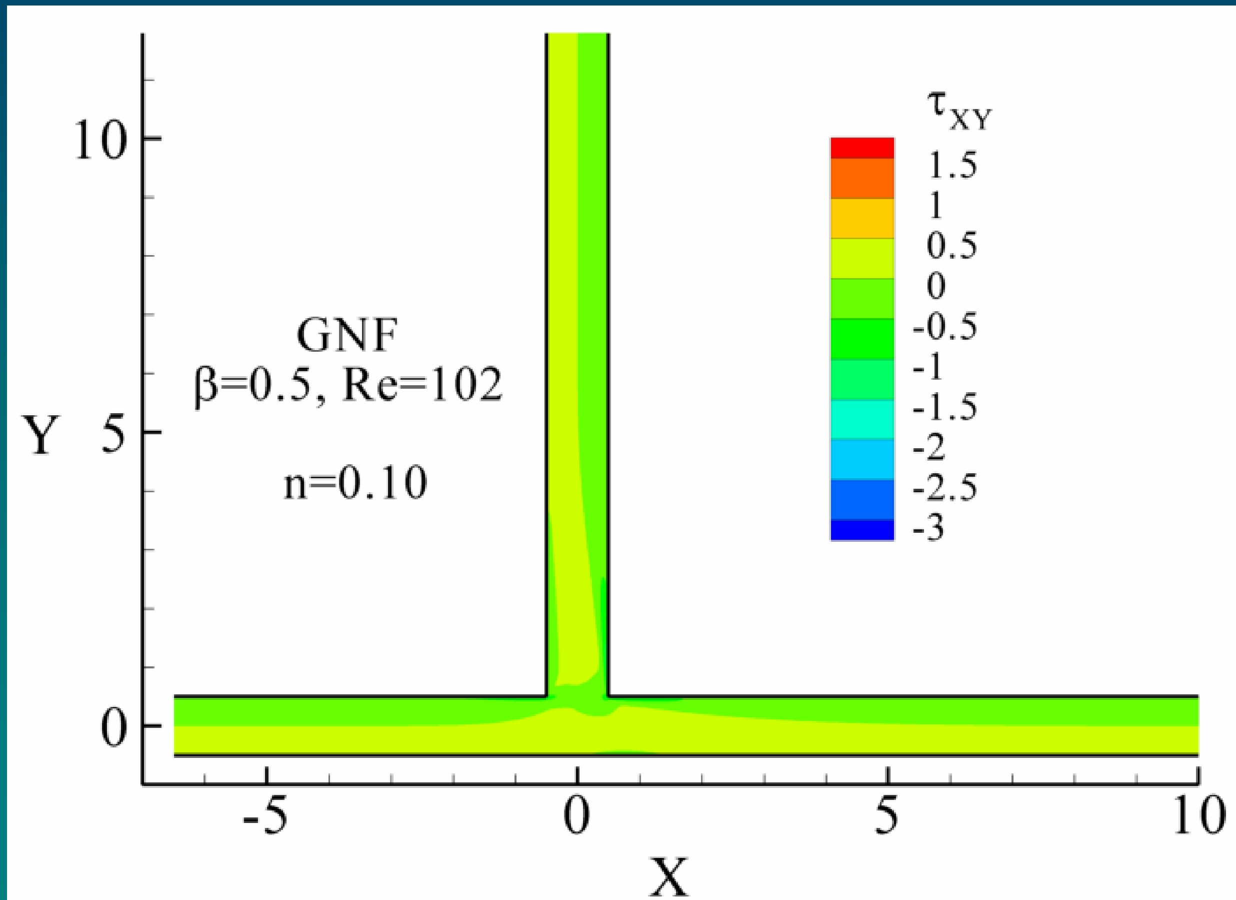


Horizontal



7 - RESULTS (variation with *n*)

- Shear stress field: variation with *n*



8 - CONCLUSIONS

- The length and intensity of the recirculations increase with Re for both fluids.
- The recirculation lengths Y_L and X_L increase with β for $\beta \leq 0.6$ and decrease for $\beta > 0.6$, for both fluids.
- Non-Newtonian fluids show larger recirculation lengths.
- Reduction of growth rates of X_L and Y_L with Re after a new recirculation is formed at the opposite wall (distal and top walls).
- Sudden increase of ψ_V with Re due to the division of the vertical recirculation into two vortices.

8 - CONCLUSIONS

- Decrease of ψ_V with β, for low Re numbers and vice-versa. Increase of ψ_H with β.
- Low stresses inside recirculating zones and high stresses in the re-entrant corners of the bifurcation.
- Larger stress maxima with Newtonian fluid.
- Stress increase (in modulus) with Re and β .
- Length and intensity of recirculations decrease with increase of power law exponent (n).
- Stress increase (in modulus) with increase of power law exponent (n).

9 - ACKNOWLEDGEMENTS

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EUROPEAN COMMUNITY ON COMPUTATIONAL METHODS IN APPLIED SCIENCES

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- ***ECCOMAS Scholarship***

- ***University of Beira Interior (Portugal)***