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Proceedings in flow modelling around a cod-end net

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CANUM 2006 - Minisymposium Mer - Halieutique

Improving the selectivity of trawling

$\Rightarrow$ By numerical simulations of the the cod-end net

Main advantage : low cost of numerical simulations vs experimental measurements (at sea or in a tank),

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- A model for the fishes : catch model or balls model
- A fluid model

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- A net model : discrete models. High number of meshes $\Rightarrow$ Globalization techniques
- A model for the fishes : catch model or balls model
- A fluid model $\Rightarrow$ but complex geometry of the net ...

Question

How could the net be taken into account in the fluid model ?

Existing fluid models

- Hypothesis of a uniform flow : Landweber's hypothesis
- Model of an axisymmetric porous membrane : B. Vincent (ECN PhD, 1996)
- Ring model : D. Marichal (2005)

Our contribution

- A 3D turbulent fluid model and its mathematical analysis
- Development of an axisymmetric code with the free software Freefem++
- Participation in an experimental campaign to collect hydrodynamical data
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Outline

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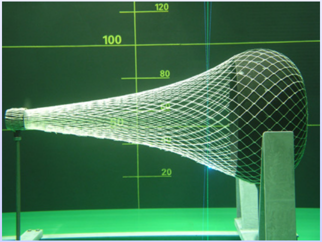
Motivations

Finding a model that could :

- Control the passage of the fluid through the net
- Be applied in the 3D case (i.e. without the hypothesis of axisymmetric flow)
- Be applied to the case of a moving net

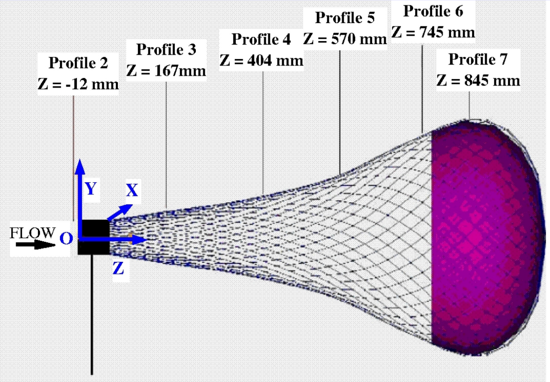
The model built at Boulogne-sur-Mer by G. Germain and J.V. Facq



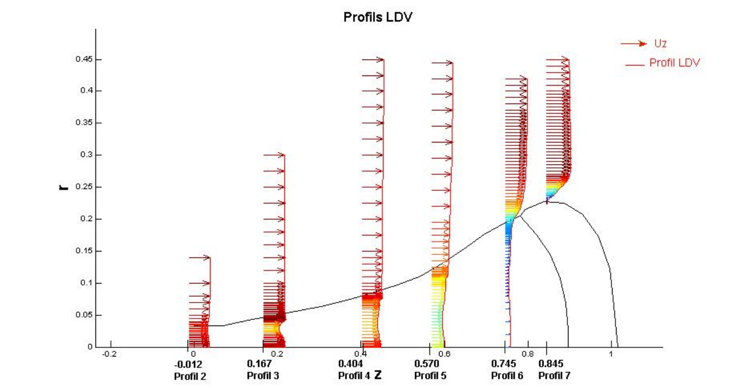
Parameters of the net :

- Side mesh : 30mm
- Number of meshes on the perimeter : 36
- Length per weight : 1200m/kg
- Twine diameter : 1,5mm

Profiles considered for the measures

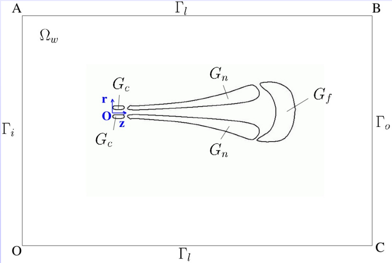


LDV profiles of the velocity component u_z



Three features and their advantages

- A porous membrane model for the net ⇒ No more complex geometry of twines and nodes



- A penalization method to take the net and fishes into account : Navier-Stokes/Brinkman model with eddy viscosity ⇒ Possibility of 3D computations by the means of a Fictitious Domain Method : no complex mesh
- A closure equation for the TKE. This a kind of Reynolds Averaged Navier-Stokes model ⇒ To close the system

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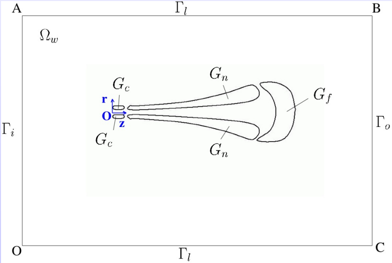

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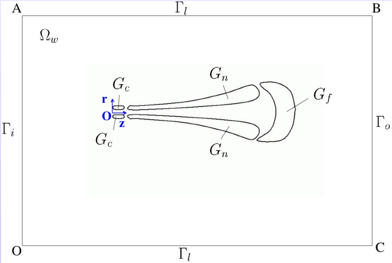

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Averaged incompressible Navier-Stokes/Brinkman equations

- Unknowns : $(\mathbf{u} - P)$ (mean velocity - modified pressure), k turbulent kinetic energy (TKE)
- Averaged incompressible Navier-Stokes/Brinkman equations with eddy viscosity

$$\begin{cases} \dfrac{\partial \mathbf{u}}{\partial t} + (\mathbf{u}\,\nabla)\mathbf{u} - \nabla \cdot \sigma_{\mathbf{t}}(\mathbf{u}, P, k) + \dfrac{\nu_0}{K(\mathbf{x})}\,\mathbf{u} = 0, \\ \\ \nabla \cdot \mathbf{u} = 0, \end{cases}$$

Where :

$$\begin{array}{lcl} \sigma_{\mathbf{t}}(\mathbf{u}, P, k) & = & -P\,Id + (\nu_0 + \nu_t)(\nabla \mathbf{u} + (\nabla \mathbf{u})^t), \\ P & = & p + \frac{2}{3}k, \text{ modified pressure} \\ \nu_0 & = & \text{kinematic viscosity of water.} \end{array}$$

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Where :

$$\begin{aligned} \sigma_{\mathbf{t}}(\mathbf{u},P,k) &= -P\,Id + (\nu_0+\nu_t)(\nabla\mathbf{u} + (\nabla\mathbf{u})^t), \\ \nu_t &= C_1\,\ell(\mathbf{x})\,k^{\frac{1}{2}}, \text{ eddy viscosity coefficient} \\ \ell(\mathbf{x}) &= \text{mixing length.} \end{aligned}$$

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Where : $K(\mathbf{x})$ is the permeability parameter.

$$\begin{array}{llll} K(\mathbf{x}) = \dfrac{1}{\epsilon} & \rightarrow & +\infty & \text{si } x \in \Omega_w, \\ K(\mathbf{x}) = \epsilon & \rightarrow & 0 & \text{si } x \in G_f \cup G_c, \\ K(\mathbf{x}) = K_f & & & \text{si } x \in G_n, \end{array}$$

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Fictitious domain method : the fluid equations hold in the entire domain (C. S. Peskin (1972), Angot et al. (1999), Khadra et al. (2000), Carbou and Fabrie (2003))

System

- Averaged incompressible Navier-Stokes/Brinkman equations with eddy viscosity

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- A closure equation for the TKE

$$\frac{\partial k}{\partial t} + (\mathbf{u}\nabla)k = \nabla \cdot (\tilde{\nu}_t \nabla k) + \frac{\nu_t}{2}|\nabla \mathbf{u} + (\nabla \mathbf{u})^t|^2 - C_3\,\frac{k^{\frac{3}{2}}}{\ell(x)}$$

with $\tilde{\nu}_t \;=\; C_2\,\ell(\mathbf{x})\,k^{\frac{1}{2}}$ and C_2 adimentionalized constant.

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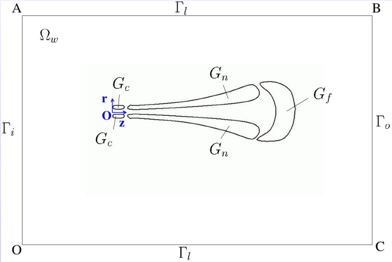
- Coupling parameter : $\nu_t = C_1\,\ell(\mathbf{x})\,k^{\frac{1}{2}}$

Initial and boundary conditions



$$\begin{cases} \forall \mathbf{x} \in \Omega, \quad \mathbf{u}(0,\mathbf{x}) = \mathbf{u}_0(\mathbf{x}) \\ \forall \mathbf{x} \in \Omega, \quad k(0,\mathbf{x}) = k_0(\mathbf{x}) \\ \mathbf{u}|_{\Gamma_i} = \mathbf{u}_l = (u_l, 0), \quad k|_{\Gamma_i} = 0, \\ \mathbf{u}|_{\Gamma_l} = \mathbf{0}, \quad k|_{\Gamma_l} = 0, \\ \boldsymbol{\sigma}_\mathbf{t}(\mathbf{u}, p, k).\,\mathbf{n}|_{\Gamma_o} = -\frac{1}{2}(\mathbf{u}.\mathbf{n})^-(\mathbf{u} - \mathbf{u}_l) + (\mathbf{u}.\mathbf{n})\mathbf{u}_l, \\ \tilde{\nu}_t \dfrac{\partial k}{\partial \mathbf{n}}|_{\Gamma_o} = -(\mathbf{u}.\mathbf{n})^- k. \end{cases}$$

Theoretical result : Theorem

Hypothesis

Assume :

1. $\nu_t \in C^1$ and bounded,
2. $\tilde{\nu}_t \in C^1$ and bounded,
3. $\ell \in L^\infty$ and bounded,
4. $K \in C^1$ and bounded,
5. $\mathbf{u}_0 \in L^2(\Omega), \quad \nabla \cdot \mathbf{u}_0 = 0, \quad \mathbf{u}_0.\mathbf{n}|_{\Gamma_i} = u_\mathrm{I}, \quad \mathbf{u}_0.\mathbf{n}|_{\Gamma_l} = 0,$
6. $k_0 \in L^1(\Omega)$

Theoretical result : Theorem

Then the coupled problem admits a solution $(\mathbf{u}, P, k)$ on any time interval $[0, T]$ in the sense of the distributions, where

$$
\begin{aligned}
&\mathbf{u} \in L^2([0,T],(H^1(\Omega))^2) \cap L^\infty([0,T],L^2(\Omega)),\\
&P \in L^2([0,T]\times\Omega),\\
&k \in L^{4/3}([0,T],W^{1,4/3}(\Omega)) \cap L^\infty([0,T],L^1(\Omega)).
\end{aligned}
$$

Moreover, there exists $F(\mathbf{u}_\mathrm{l}, \mathbf{u})(t)$ such that the following energy equality holds for any $t \in [0, T]$,

$$
\begin{aligned}
&\frac{1}{2}\frac{d}{dt}\int_\Omega |\mathbf{u}(t,\mathbf{x})|^2 d\mathbf{x} + \int_\Omega \nu_t(k(t,\mathbf{x}),\mathbf{x})|\varepsilon(\mathbf{u})(t,\mathbf{x})|^2 d\mathbf{x} +\\
&\frac{1}{2}\int_{\Gamma_o} (\mathbf{u}(t,\mathbf{x}).\mathbf{n})^+ |\mathbf{u}(t,x) - \mathbf{u}_I)|^2 d\sigma(\mathbf{x}) +\\
&\int_\Omega \frac{\nu_0}{K(\mathbf{x})} \mathbf{u}(t,\mathbf{x}).\mathbf{u}(t,\mathbf{x}) d\mathbf{x} = F(\mathbf{u}_I, \mathbf{u})(t).
\end{aligned}
$$

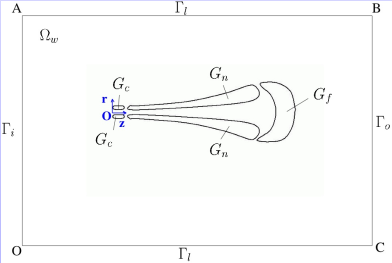
Outline

Axisymmetric problem

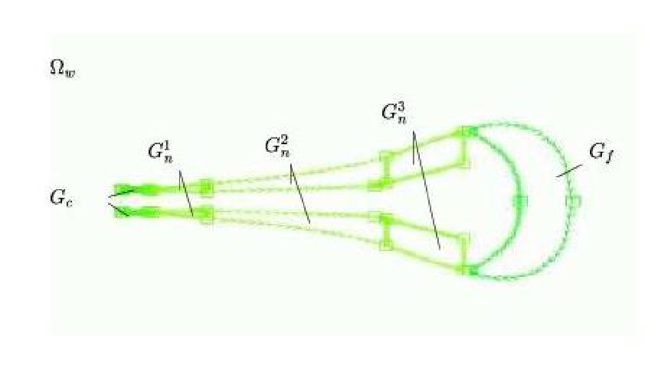
- Hypothesis of an axisymmetric flow
- Cylindrical coordinates

$$\left\{\begin{array}{lll} x & = & rcos\theta, \\ y & = & rsin\theta, \\ z & = & z. \end{array}\right.$$

with $\{(r, z, \theta), r \in [r_{min}, r_{max}], z \in [z_{min}, z_{max}], \theta \in [0, \pi]\}$.



Decomposition of the net domain G_n in 3 parts



$\Rightarrow$ To take into account the difference in permeability.

Numerical methods

- Finite elements method
- Numerical schemes :
  - Implicit scheme for the averaged Navier-Stokes/Brinkman equation
  - Semi-implicit scheme for the turbulent kinetic energy
- Iterative algorithm

Algorithm

1. Initialization of $(\mathbf{u}, P)$ by solving a Stokes problem and k to a constant in the entire domain

2. For m=1, Itmax

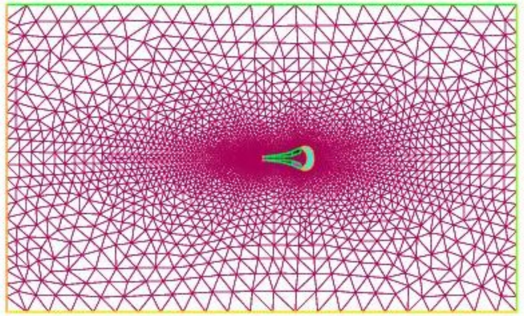
   - Solving of the turbulent kinetic energy problem,

   - Solving of the Navier-Stokes/Brinkman problem.

   End For

Mesh

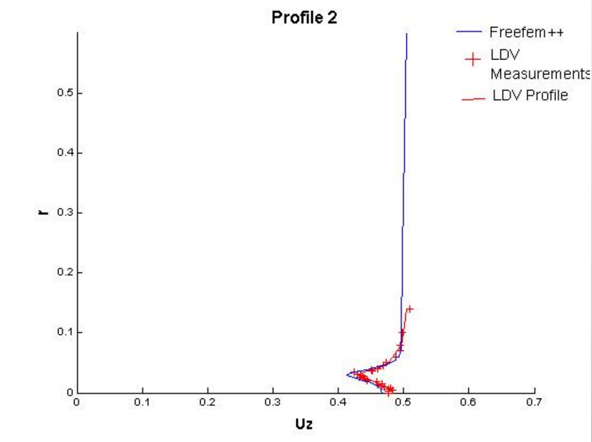
- Example of an unstructured body fitted mesh (10978 vertices - 21862 triangles)



Choice of the parameters

- $K_{\Omega_w} = 10000$,
- $K_{G_f} = 0.000001$,
- $K_{G_c} = 0.000001$,
- $K_{G_1^n} = 1$,
- $K_{G_2^n} = 5$,
- $K_{G_3^n} = 6$,
- Mesh : 10978 nodes ; 21862 triangles,
- Time step : 0.66667 s,
- $\ell(x)$ defined locally on each triangle as its higher side length,
- $C_1 = 0.1$; $C_2 = 0.05$; $C_3 = 0.03$,
- Thickness of the net : given by the minima of u_z given by the LDV profiles.

Experimental vs numerical u_z profiles at it 50



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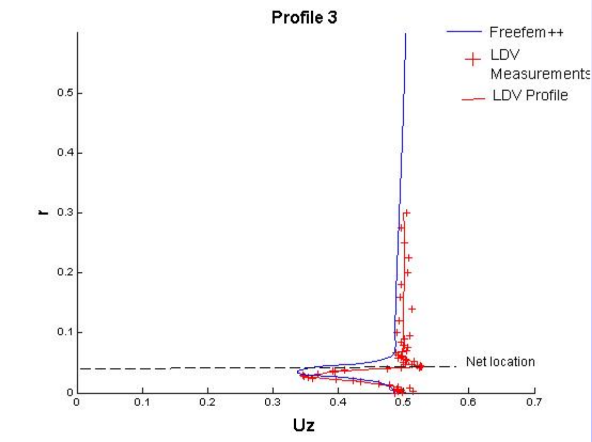

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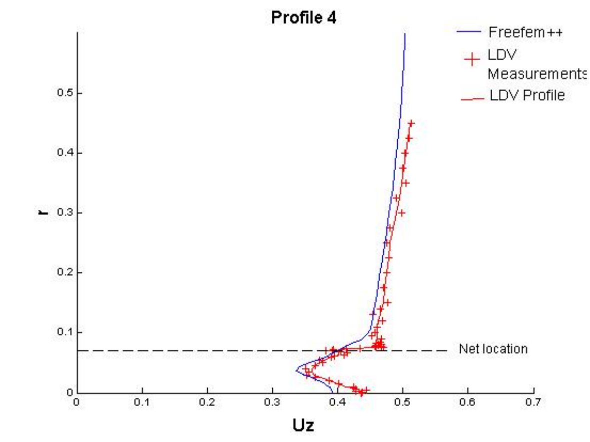

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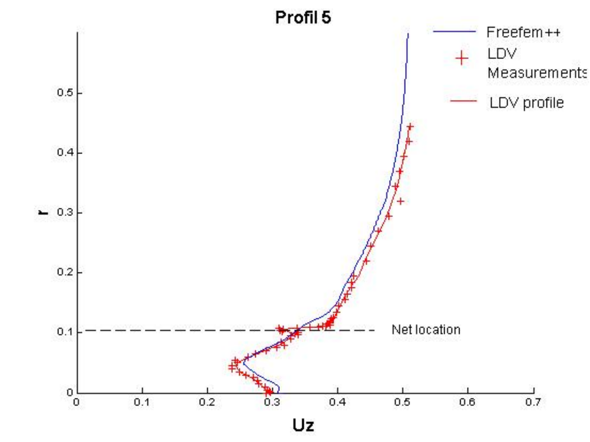

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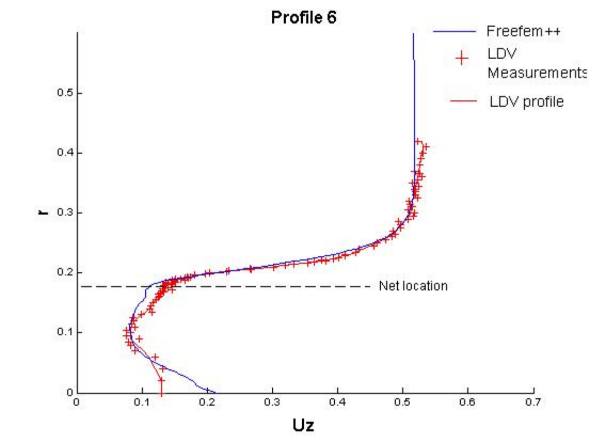

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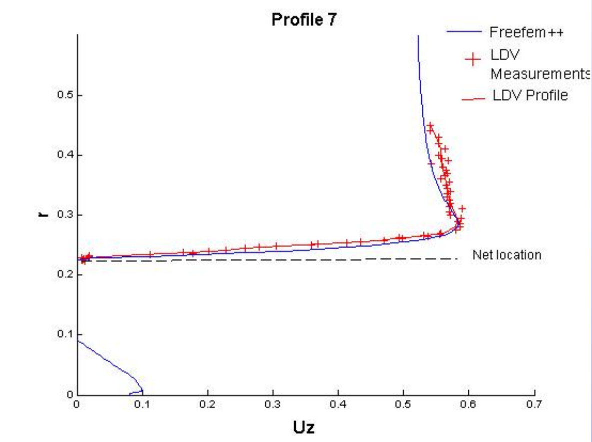
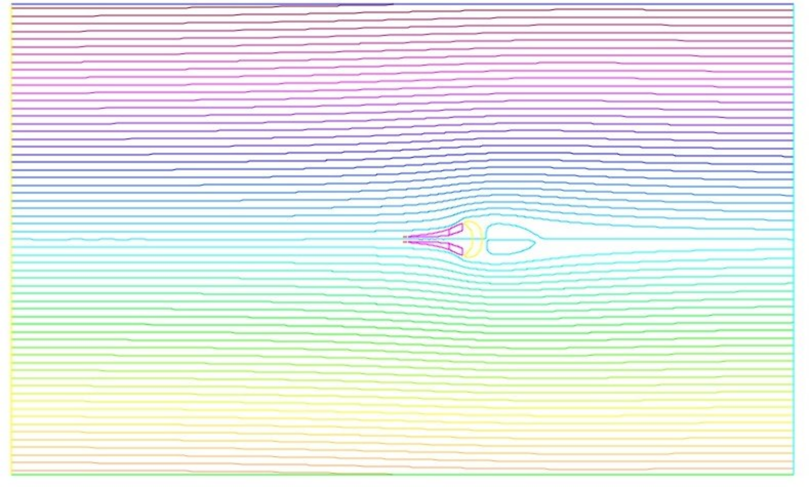
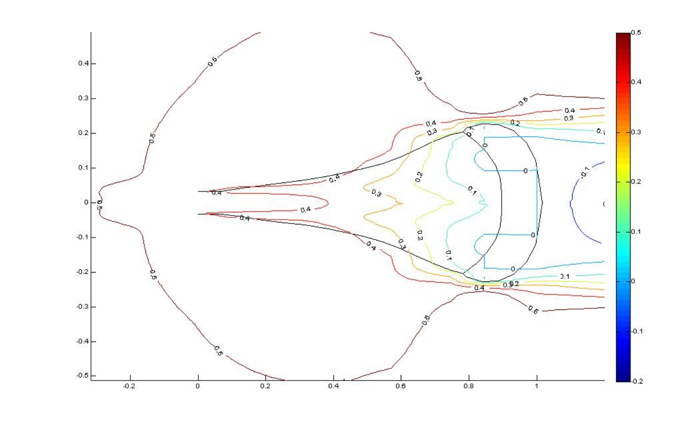


Streamlines



Level curves of u_z



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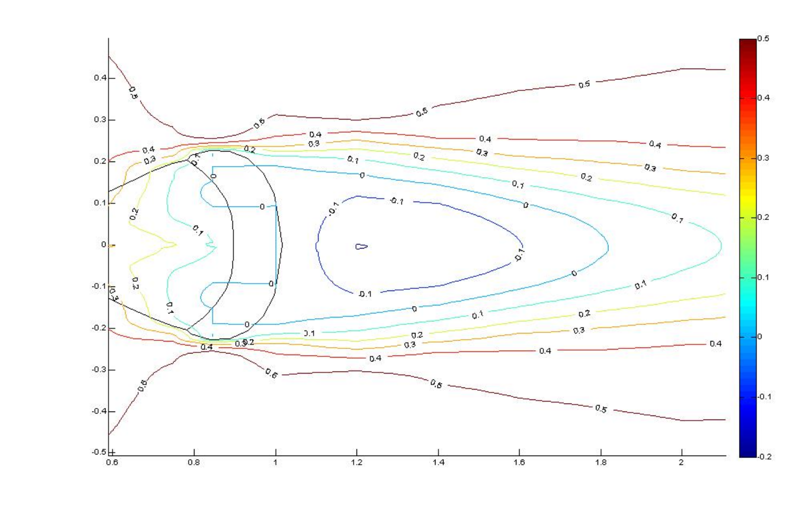
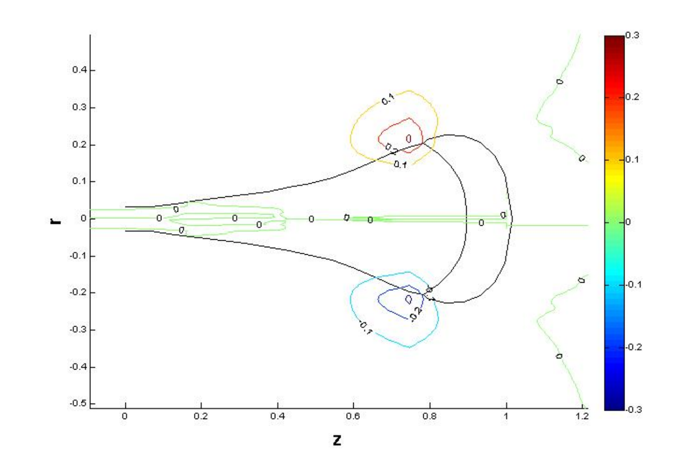
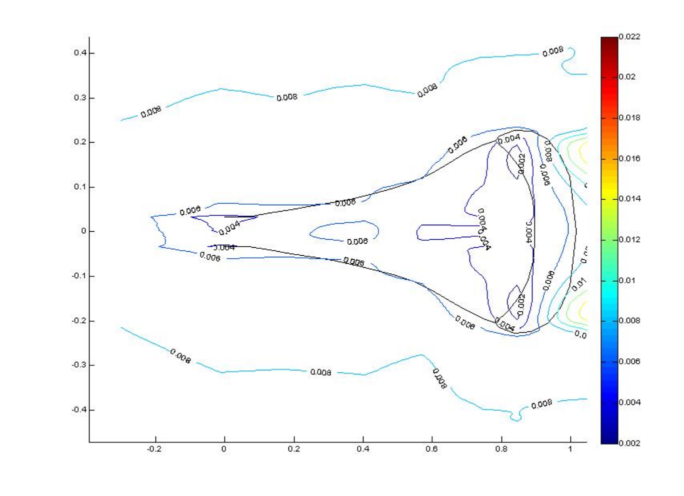


Level curves of u_r



Level curves of k



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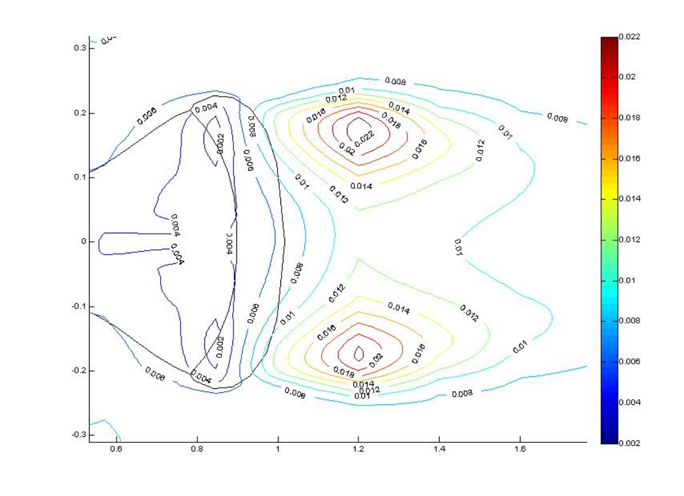
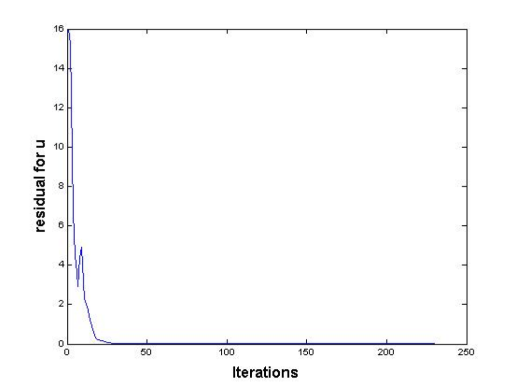


A stationary state is reached

- Residual computed for u



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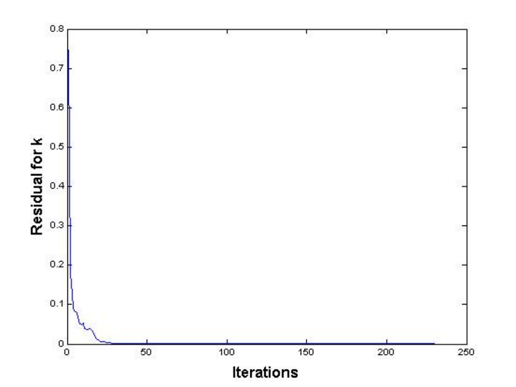

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Conclusion

- We have a model that
  - Leads to satisfactory results in the axisymmetric case
    $\Rightarrow$ Need some more experimental data, especially on the TKE
  - Can be generalized in 3D thanks to the Fictitious Domain Method
  - Make it easier to treat the problem of a moving net
- Current work
  - Implementation of the model in 3D,
  - Finding laws for the physical parameters in the model (depending on the mesh opening, the mesh side, ...)

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Any questions ?