OpenFoam Christmas Challenge

Drag determination Suzanne

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Agenda

1. choise of the right solver and turbulence model
2. model verification by simulating a sphere and comparing the results with experimental data
3. convergence analysis and mesh verification
4. drag determination and definitions
5. transient effects at high reynolds numbers
6. ColorfulFluidDynamics

Choise of solver and turbulence model

- SimpleFoam has been used as solver for low Re numbers without vortex shedding and for pre-run of the transient solver for faster convergence
  - Advantages:
    - low computation time
    - good convergence behaviour
  - Disadvantages:
    - static solver, which can't illustrate transient behaviour
      (votex shedding expected, but limited computational power available)

- PimpleFoam solver has been used for high Re numbers, since no convergent solution could be achieved with pimpleFoam solver, due to high oscillations during vortex shedding
  - Advantages
    - transient solver, which can illustrate time dependant behaviour
  - Disadvantages
    - bad convergence behaviour
    - high computation time

Trade-off between turbulence models

K-epsilon model	**k-omega**	**K-omega SST**
- good results for two dimentional problem - poor results for swirling and rotating flows, high pressure gradients	- better results than k-epsilon model for 3D flows, but still worse than k-omega SST - high stability - better results for high pressure gradients	- high computation effort - good results even in 3D, therefore good results for rotating flows, high pressure gradients and high streamline curvature
		chosen model, since high pressure gradients and streamline curvature expected

Determination of model constants as inlet boundary condition:

$$k = \frac{3}{2} \cdot \bar{u}^2 \cdot i^2$$

$$\omega = \frac{k^{0.5}}{C_\mu^{0.25} \cdot l_{char}}$$

$$i = 0.01$$

$k, \omega - model\ constant$

$\bar{u} - mean\ inlet\ velocity$

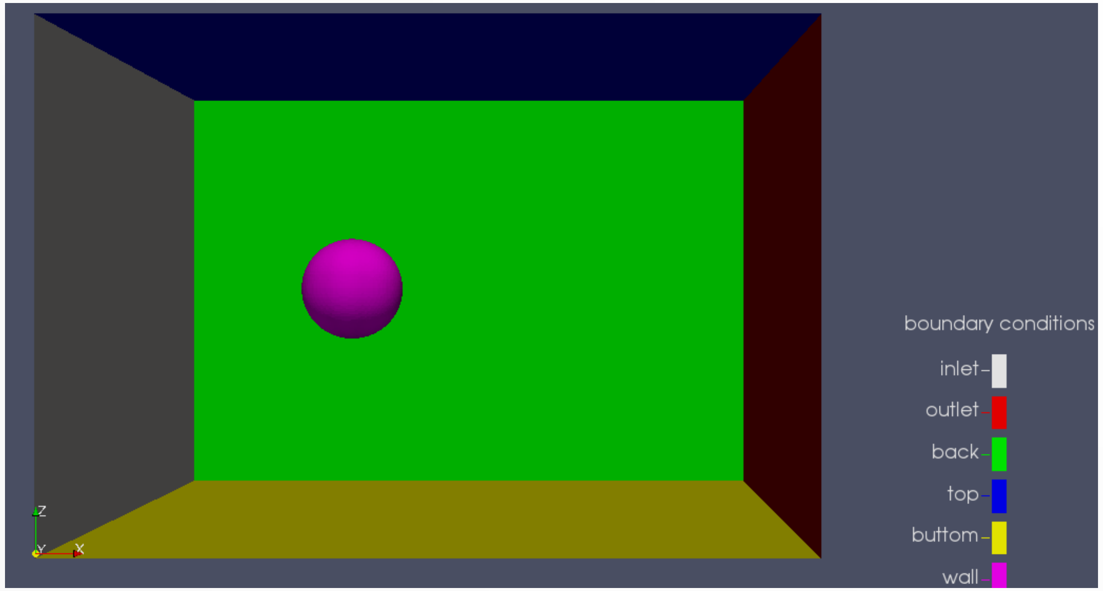
$i - turbulent\ intensity\ (chosen\ value\ 0.01\ for\ low\ turbulent\ intensity)$

$l_{char} - characteristic\ length\ (monkey\ head\ height)$

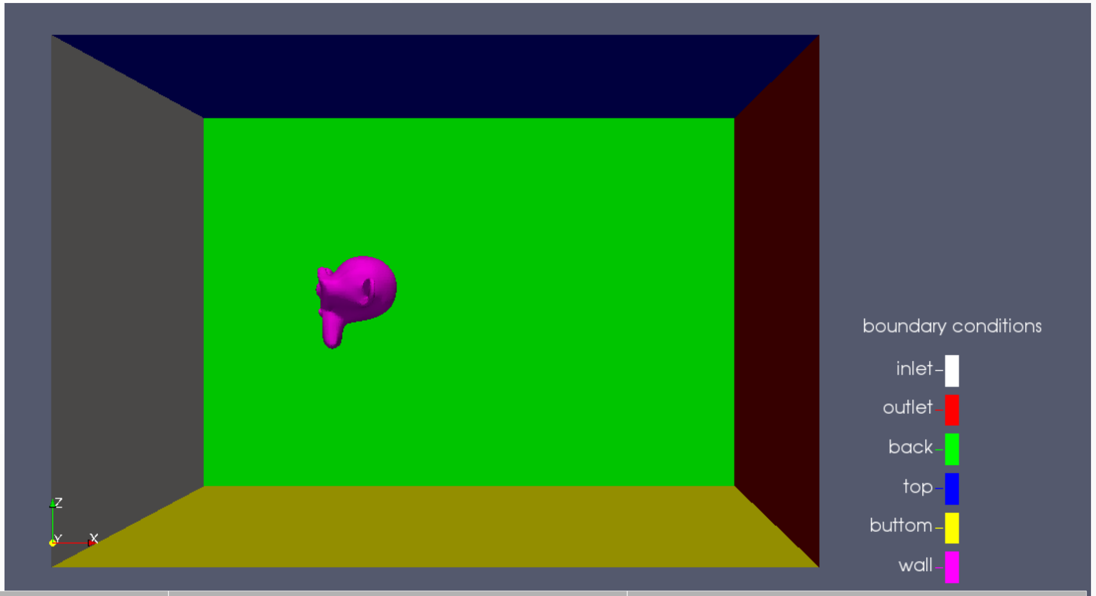
$C_\mu - model\ constant\ (chosen\ value\ 0.09\ for\ \omega\ model)$

Boundary conditions

validation case



monkey case



boundary	k	ω	p	u	ν_t
Inlet	type fixedValue value uniform 0.06;	type fixedValue; value uniform 0.22;	type zeroGradient;	type fixedValue; value uniform (20 0 0);	value uniform 0;
outlet	type inletOutlet; InletValue uniform 0.06; Value uniform 0.06;	type inletOutlet; InletValue uniform 0.22; value uniform 0.22;	type fixedValue; value uniform 0,	type inletOutlet; InletValue; uniform (0 0 0); valueuniform (20 0 0);	value uniform 0;
back/top/ buttom/ from	type slip	type slip;	type slip;	type slip;	value uniform 0;
wall	type kqRWallFunction; Value uniform 0.06;	type omegaWallFunction;	type noSlip,	type noSlip;	type nutkWallFunction; value uniform 0;

Mesh generation

- A convergence analysis has been conducted, using a parameter variation of the base mesh via blockMesh at a Reynolds number of 300
- Every mesh has been generated using snappyHexMesh using a castellatedMesh with a maximum refinement level of 4 around the wall (monkey head) and two surface layers
- Convergence can been achieved after about 250 000 cells in the base mesh
- At base mesh size of about 300 000 cells in the base mesh (using blockMesh) has been used for the calculations, since it is a good balance between computation time and accuracy of the results
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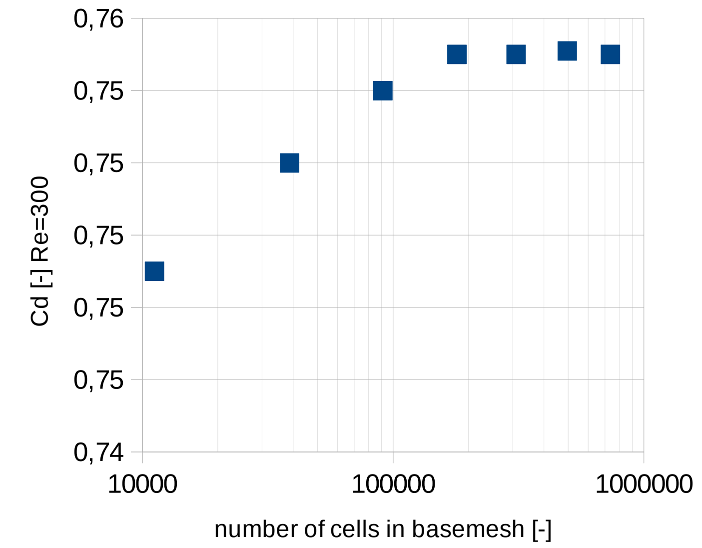
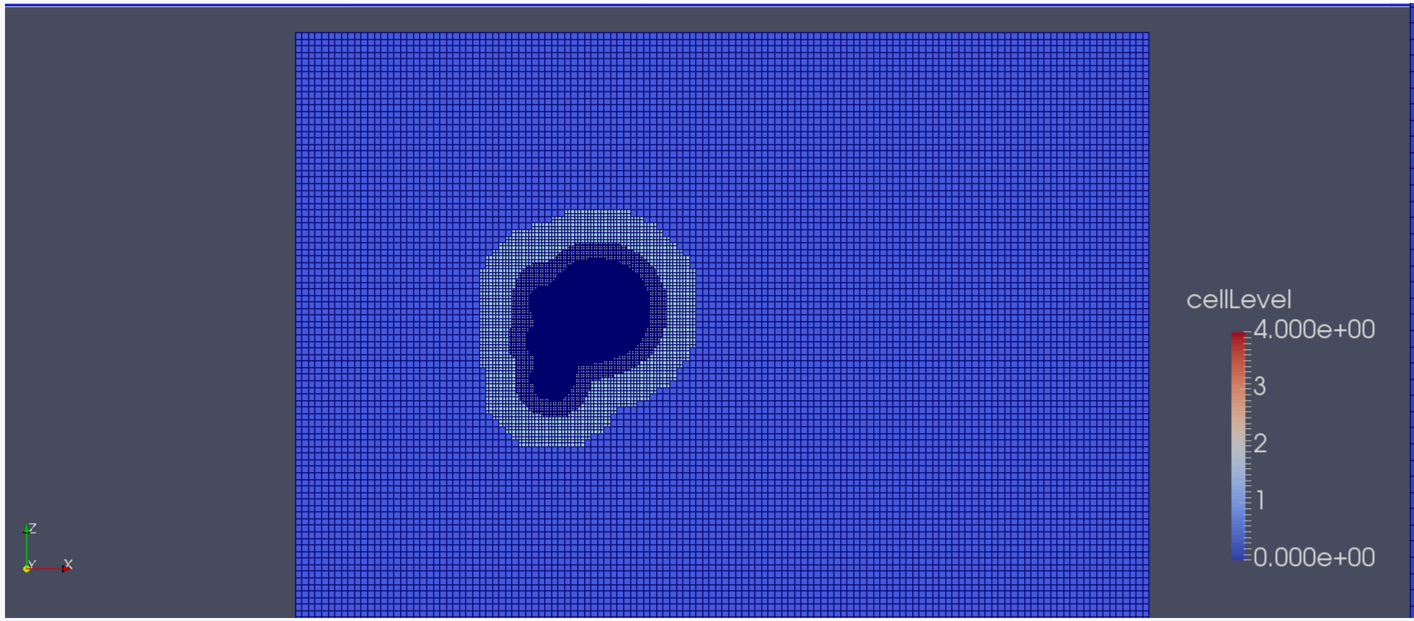
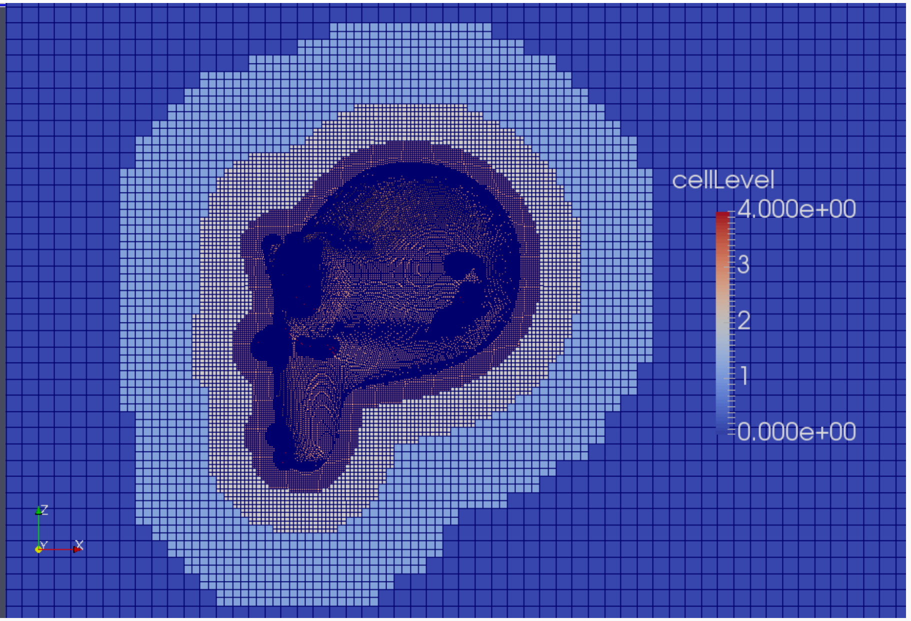






General definitions

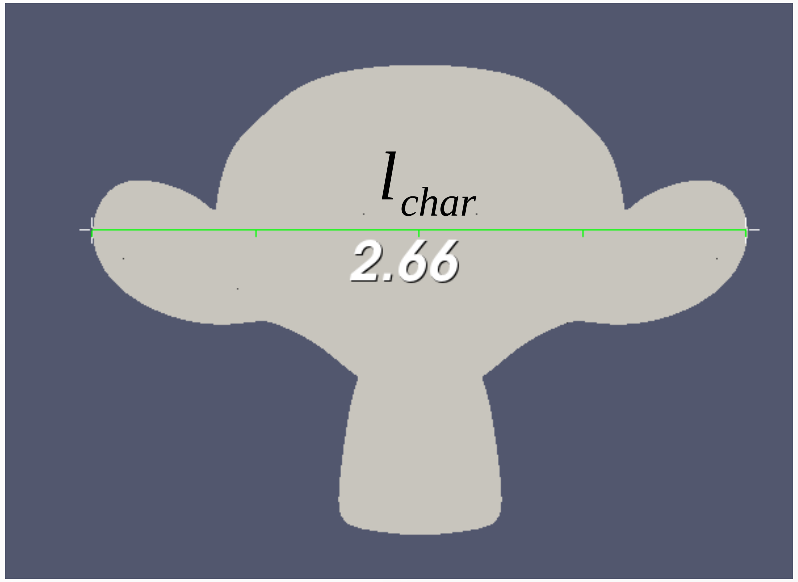
- Reynolds number

$$Re = \frac{u_{inlet} \cdot l_{char}}{\nu}$$

$u_{inlet} - inlet\ velocity$

$l_{char} - characteristic\ length\ (width\ of\ the\ monkey\ head = 2.66\ m)$

$\nu - kinematic\ viscosity$



- Drag coefficient

$$C_d = \frac{2 \cdot F_x}{u_{inlet}^2 \cdot \rho \cdot A}$$

$u_{inlet} - inlet\ velocity$

$F_x - Force\ x\ direction$

$\rho - density\ (default\ value: 1)$

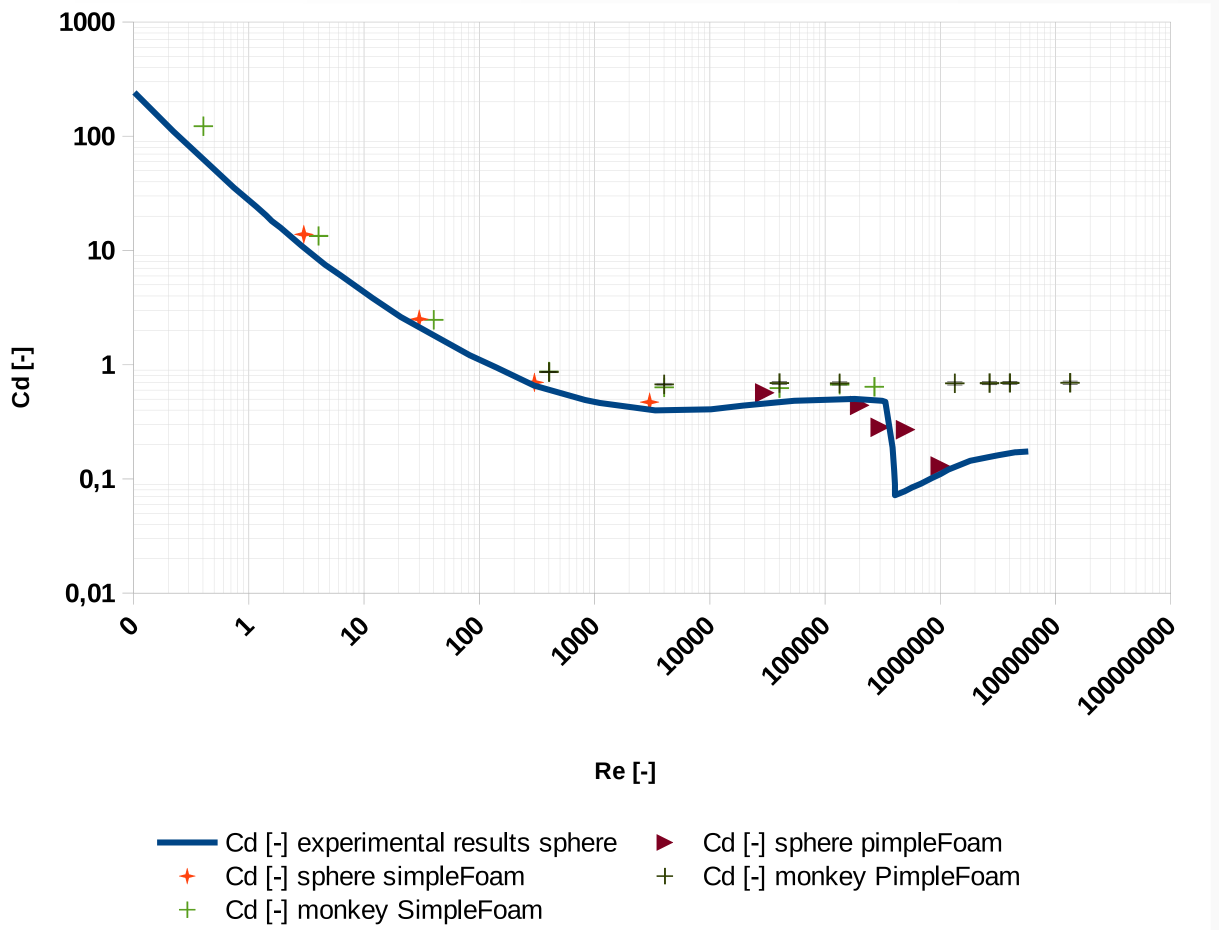
$A - reference\ plane\ Area\ (2.72\ m^2)$

Results drag determination

- Drag results out of skin friction and form drag

  $C_d = C_{skin\,friction} + C_{form\,drag}$

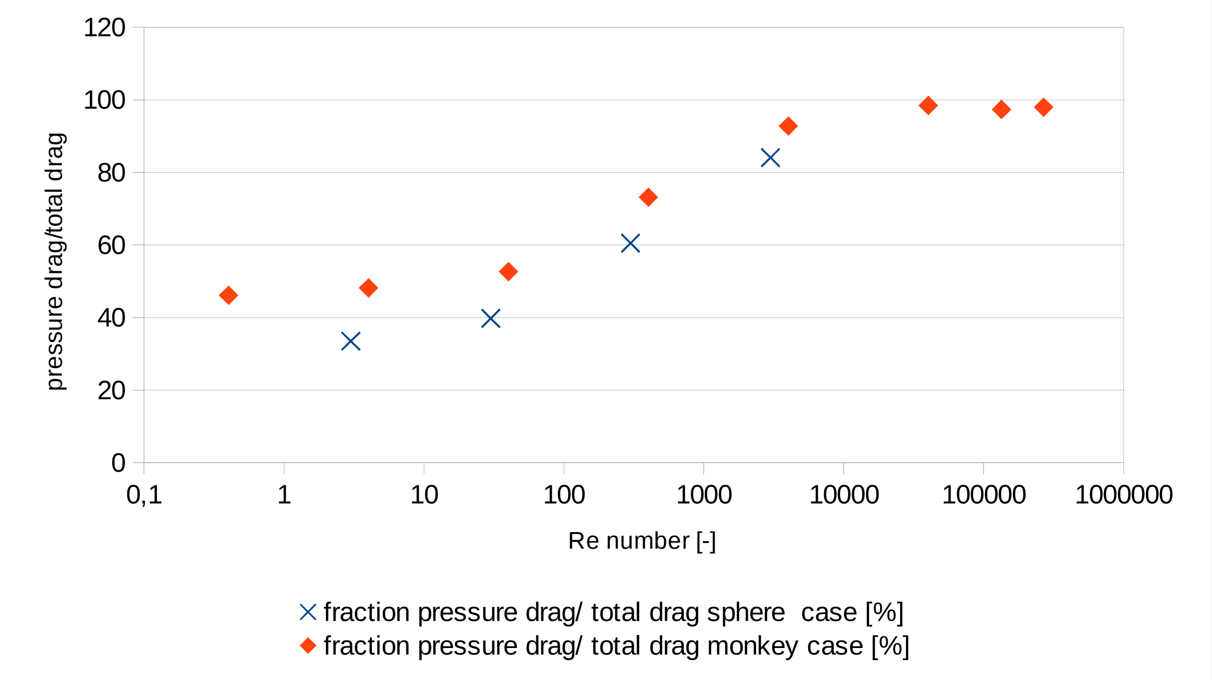
- verifikation sphere case shows good correlation with experimental results
- monkey case has no rapid drag coefficient drop in contrast to sphere case (sphere case Re~400 000) (validation case and experimental results)
- Due to the high fluctuations due to votex shedding, transient pimpleFoam Solver has been used at Re_{monkey}>3000 instead of static simpleFoam solver
- In order to achieve a better convergence of the transient results, approx. 1200 SimpleFoam iterations have used before pimpleFoam run



Experimental results for the sphere drag were obtained from: “Schlichting, Aerodynamik des Flugzeugs, Erster Band: Grundlagen der Strömungstechnik Aerodynamik des Tragflügels, 3. Auflage, 1967”

Drag distribution

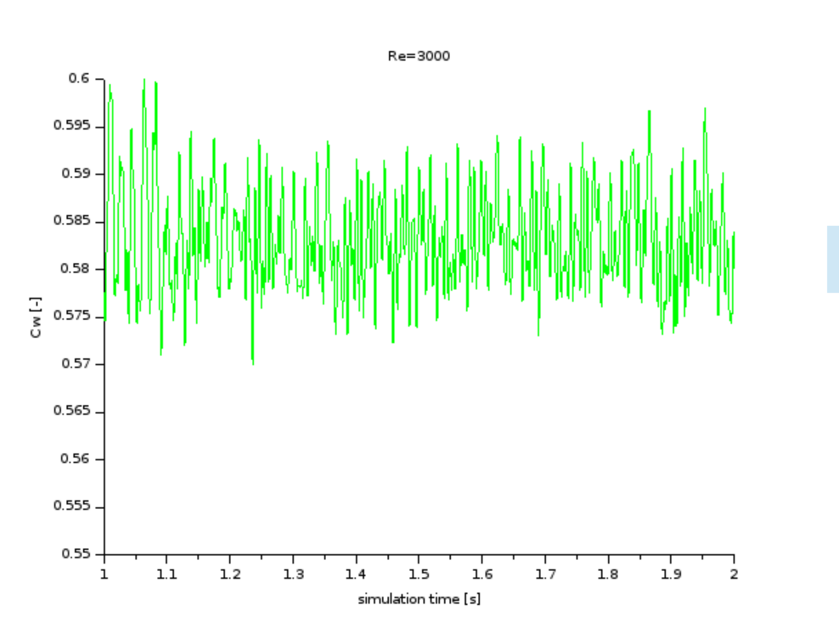
- It can been shown, that at low Re numbers, the viscous drag is dominant for the sphere and the monkey case. At higher reynolds numbers (Re>300), the form drag is dominant.
- At lower Re numbers the drag results predominantly from the viscous drag.



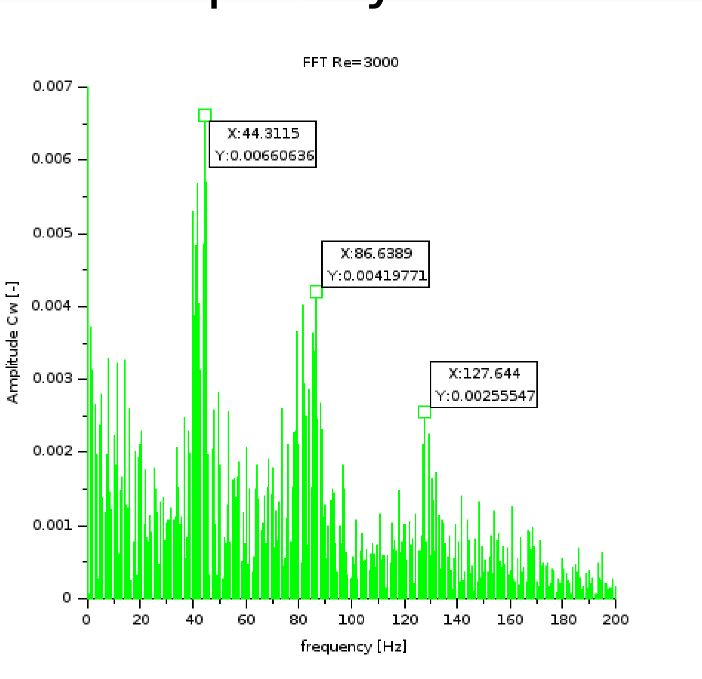
Transient effects

- At Re higher than 300, votex shedding leads to high oscillations of the drag coefficient.
- In order to investigate these effects (see Strouhal number), a FFT has been used in order to determine the frequency of the oscillation
- For a Reynolds number of 3000, the first frequency can be determined at ~44 Hz for example
- Therefore Suzanne gets her head shaken with a frequency of 44 Hz @ Re=3000

Time domain

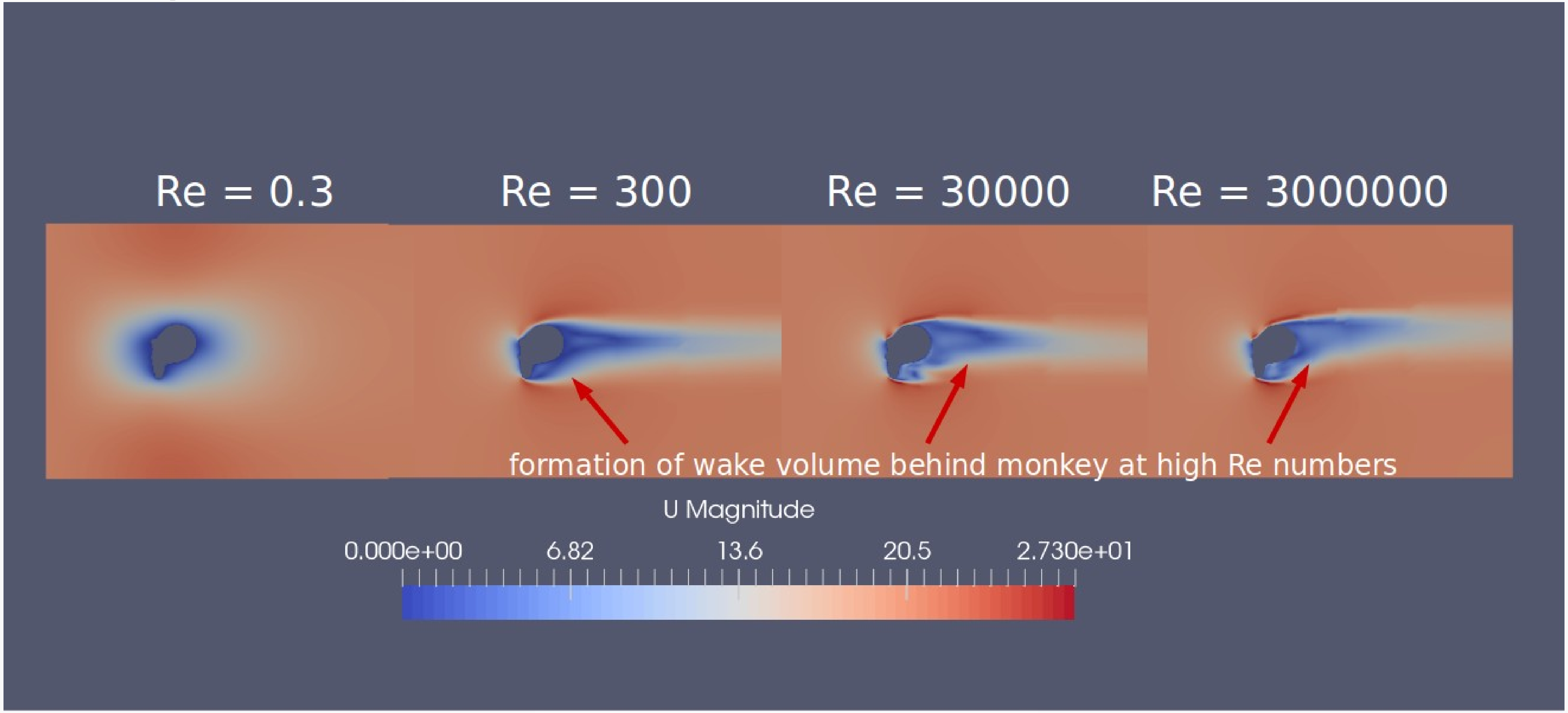


Frequency domain



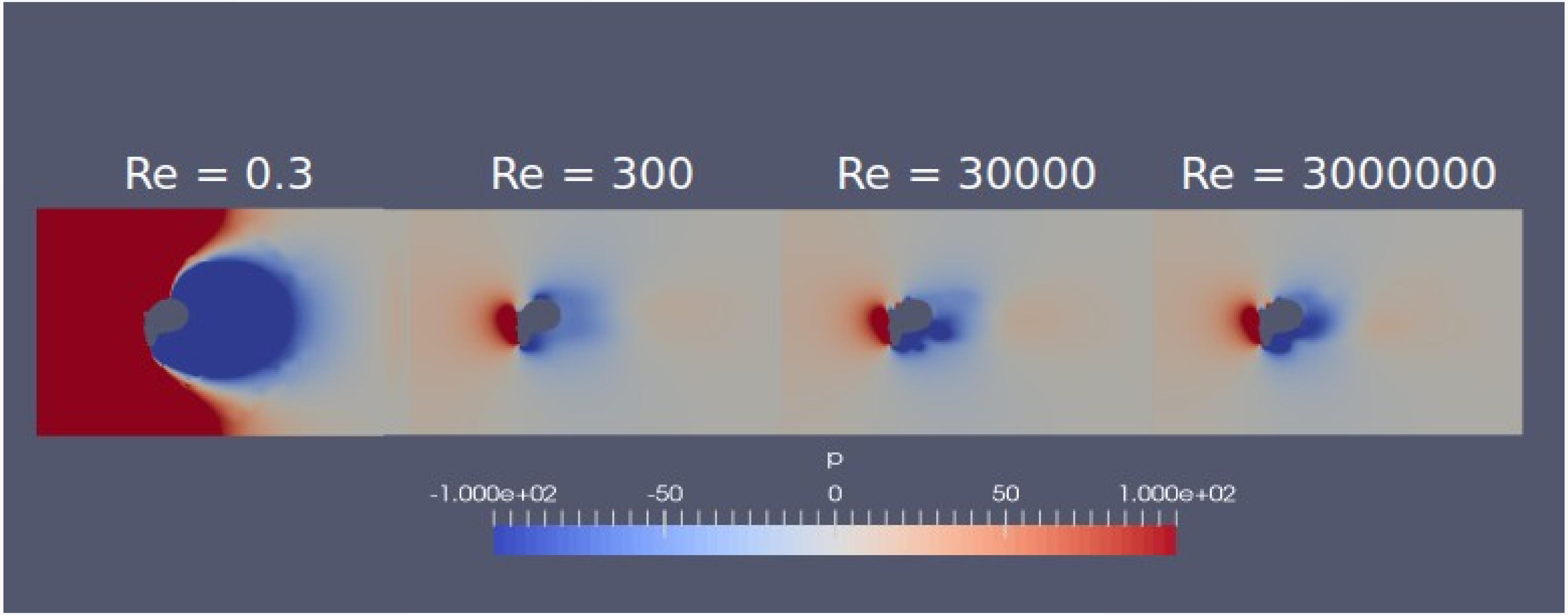
Colourful Fluid Dynamics

Velocity Field



Colourful Fluid Dynamics

Pressure Field



Colourful Fluid Dynamics

nut Field