Three Dimensional Numerical Study of the Flow Past a Magnetic Obstacle

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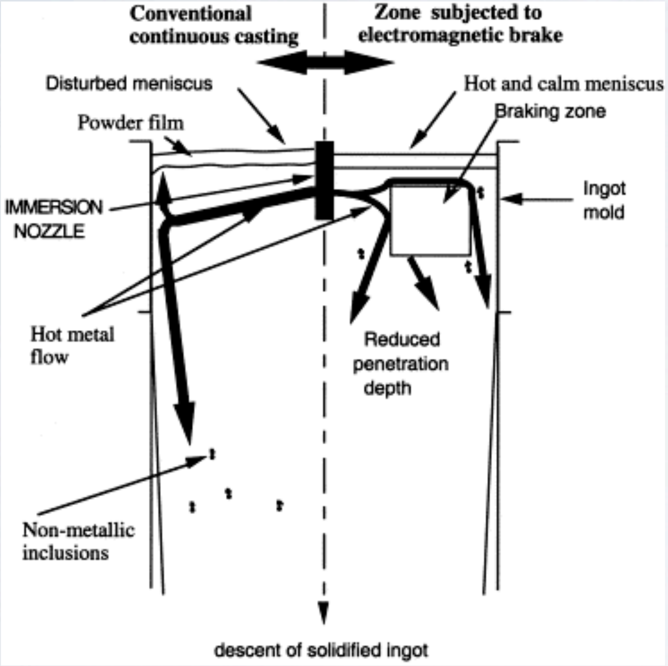
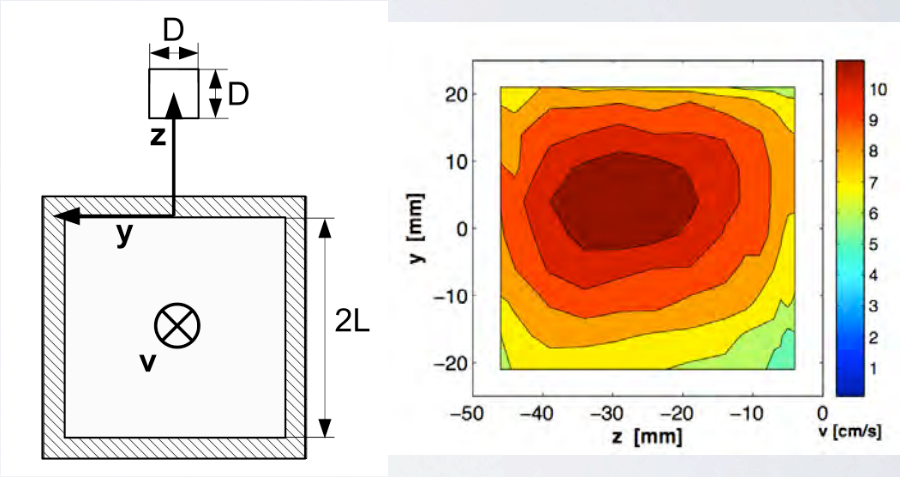
MOTIVATION

The influence of inhomogeneous magnetic fields in MHD flows has been barely studied despite the fact that these fields are widely used to manipulate, brake, stir or characterize show flows.



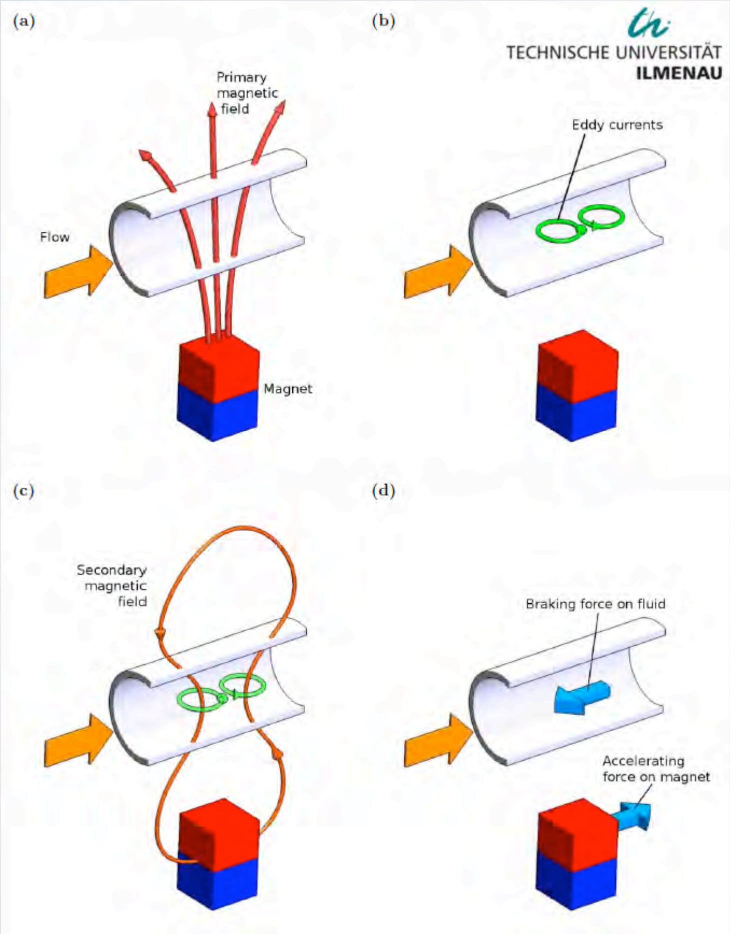
Effects of electromagnetic brake in continuous casting. P. Guillon, Materials Science and Engineering A 287, 2 (2000)

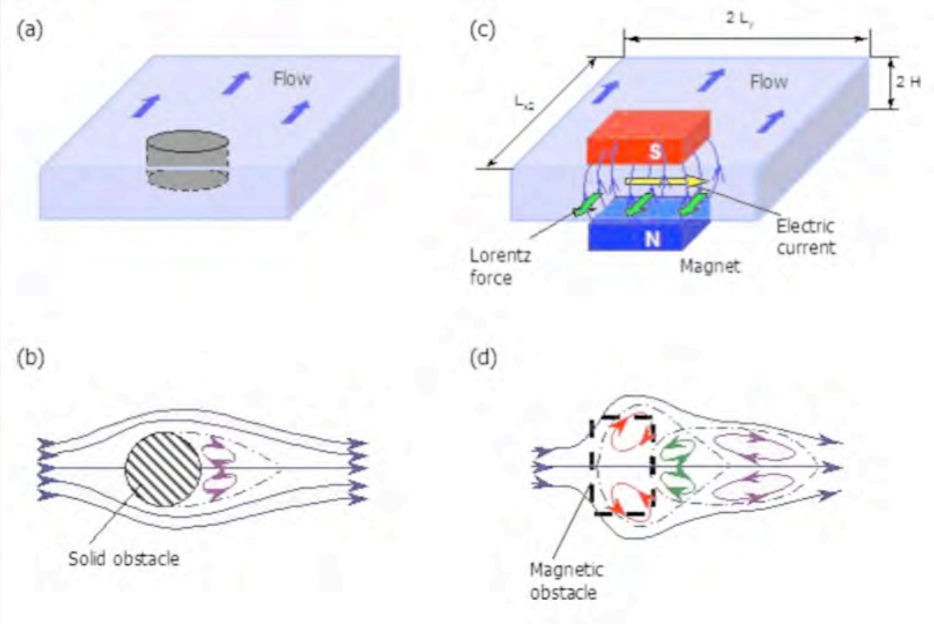


Local Lorentz Force Velocimetry for liquid metal duct flows, Christiane Heinicke PhD Thesis (2013)

MAGNETIC OBSTACLE

The interaction of the fluid flow and the externally applied magnetic field induces a force that brakes the flow.





On the analogy between streamlined magnetic and solid obstacles. E. Votyakov et al., Physics of Fluids (2007)

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MAGNETOHYDRODYNAMIC EQUATIONS

Navier-Stokes Eqs. (CFD) ⟺ **Maxwell‘s Eqs. (AC/DC)**

$$\rho(\boldsymbol{u}\cdot\boldsymbol{\nabla}) = \boldsymbol{\nabla}\cdot\left[-p\boldsymbol{I} + \eta(\boldsymbol{\nabla}\boldsymbol{u} + (\boldsymbol{\nabla}\boldsymbol{u})^T) - \frac{3}{2}\eta(\boldsymbol{\nabla}\cdot\boldsymbol{u})\boldsymbol{I}\right] + \boldsymbol{j}\times\boldsymbol{B}$$

$$\boldsymbol{\nabla}\cdot(\rho\,\boldsymbol{u}) = 0$$

$$\boldsymbol{\nabla}\cdot\boldsymbol{j} = \boldsymbol{\nabla}\cdot(\sigma\boldsymbol{u}\times(\boldsymbol{\nabla}\times\boldsymbol{A}) - \boldsymbol{\nabla}V) = 0$$

$$\boldsymbol{\nabla}\times\left(\frac{\boldsymbol{\nabla}\times\boldsymbol{A}}{\mu_r\mu_0}\right) = \sigma(\boldsymbol{u}\times(\boldsymbol{\nabla}\times\boldsymbol{A}) - \nabla\boldsymbol{V}) \qquad \boldsymbol{B} = \boldsymbol{\nabla}\times\boldsymbol{A}$$

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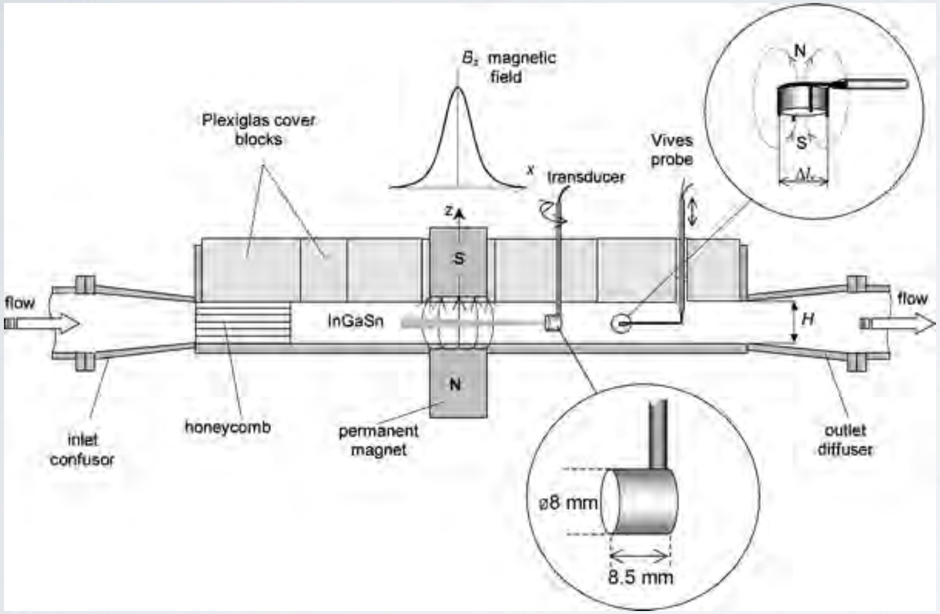
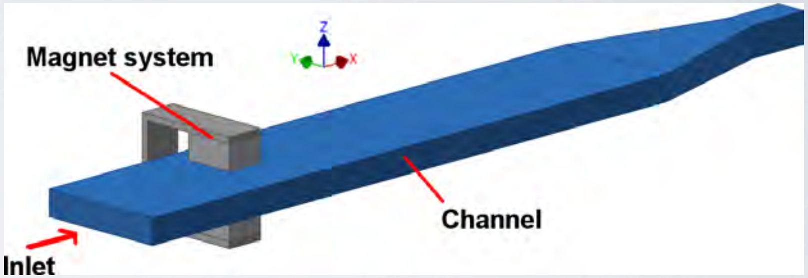
PROBLEM DESCRIPTION



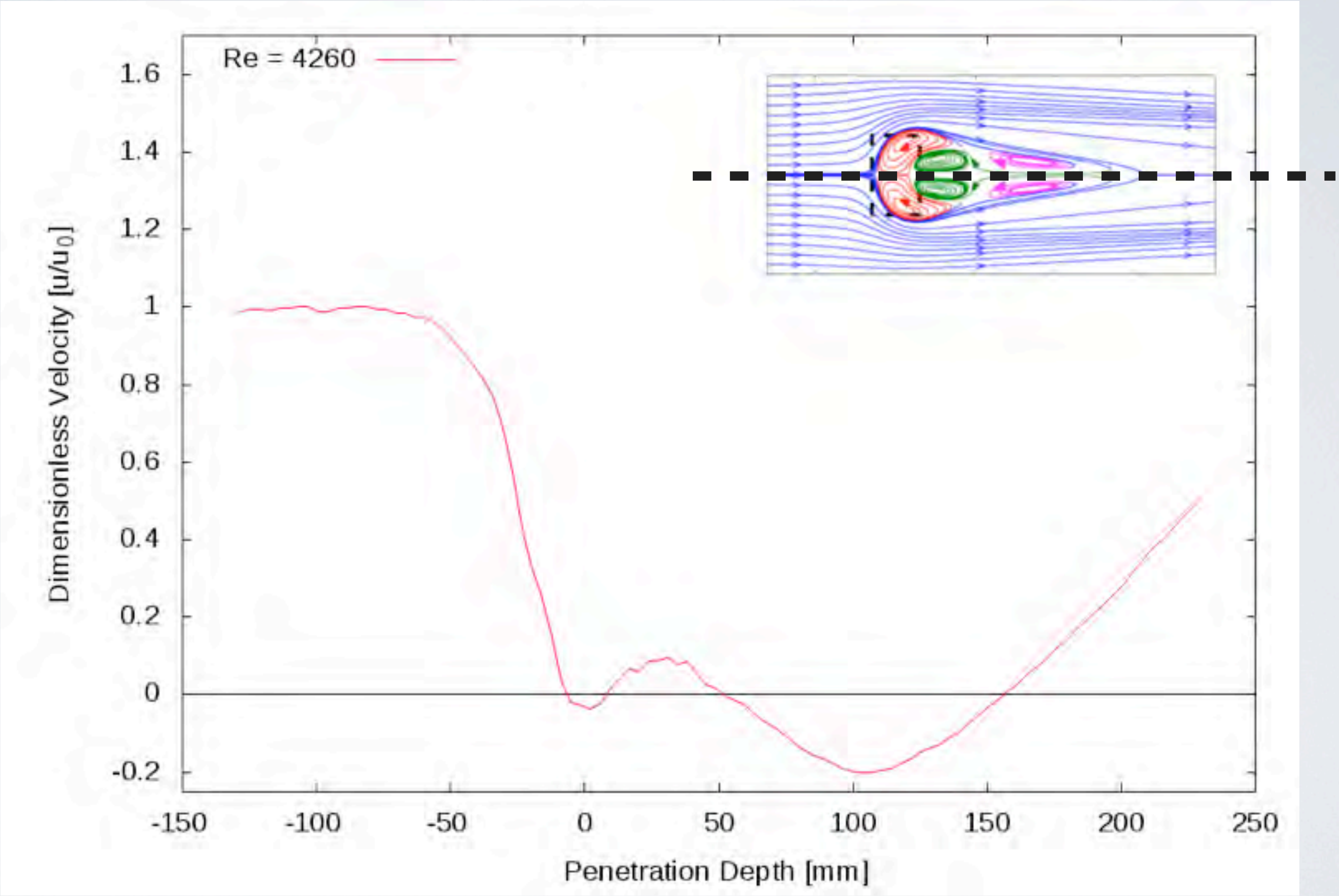
Experimental setup.



Simulated geometry.

Channel : 20x100x500 mm^3
Magnets : 20x40x30 mm^3
Neodymium-Iron-Boron
Bmax ~ 0.4 T
Fluid : GaInSn
Melting temperature ~10 ºC
Electrical conductivity ~ $3.46*10^6$ S/m
Density = 6360 kg/m^3

UDV MEASUREMENT



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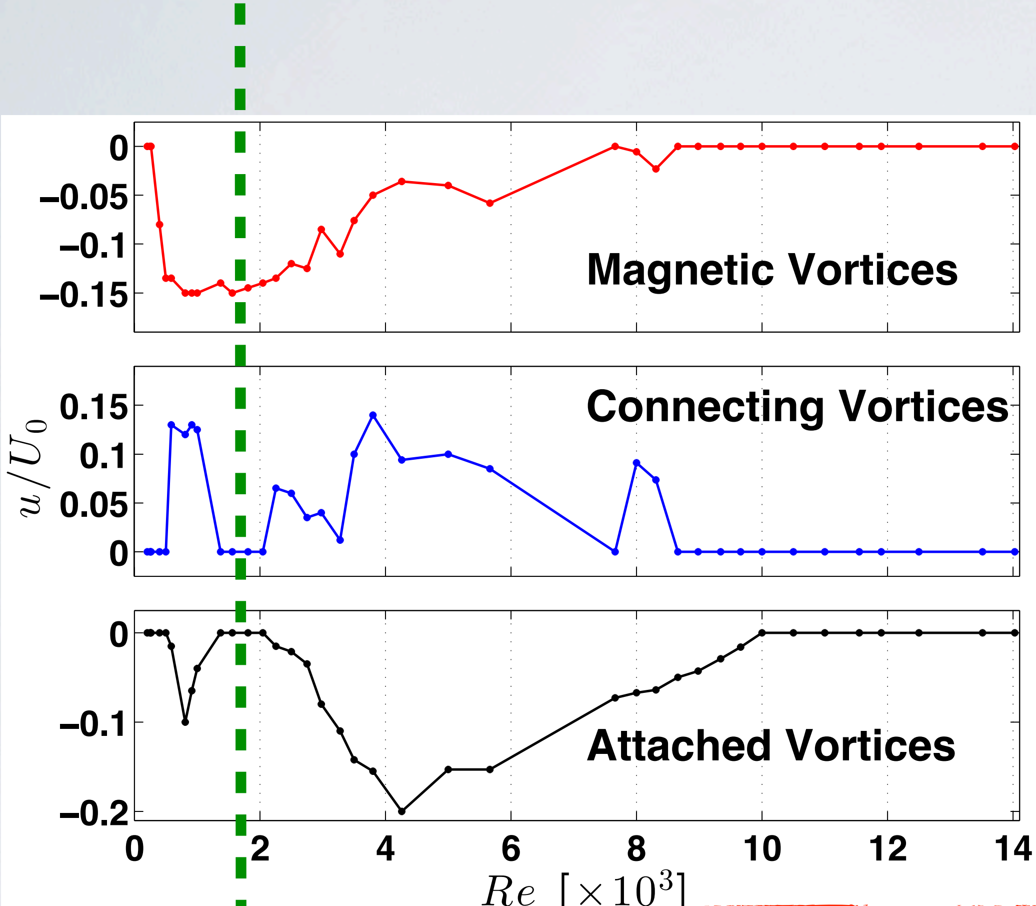
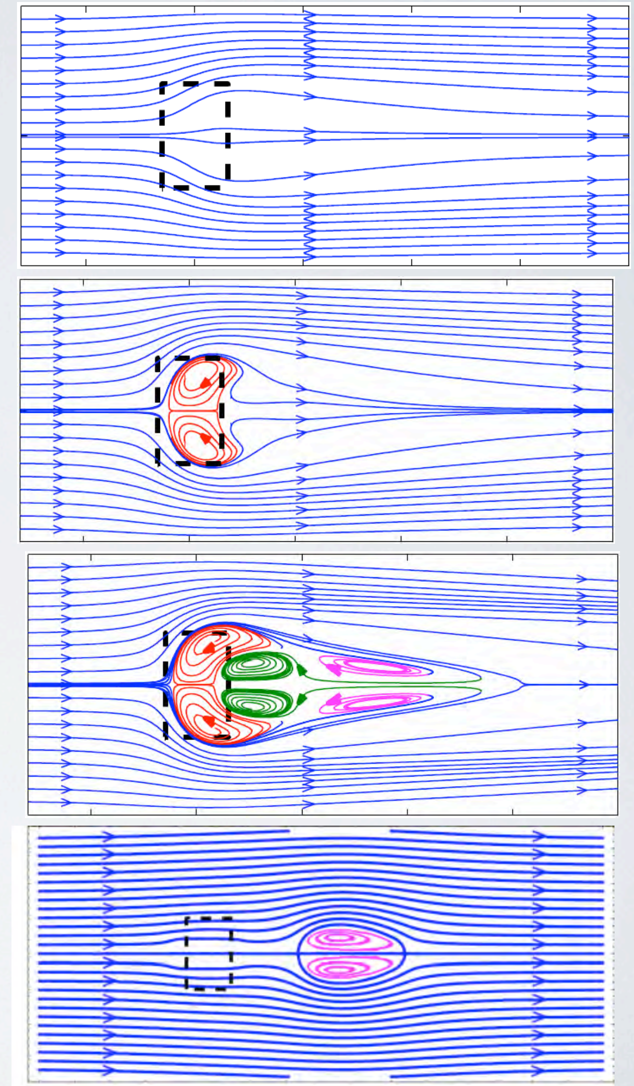
STEADY VORTEX PATTERNS





$$Re = \frac{U_0\,\ell}{\nu}$$

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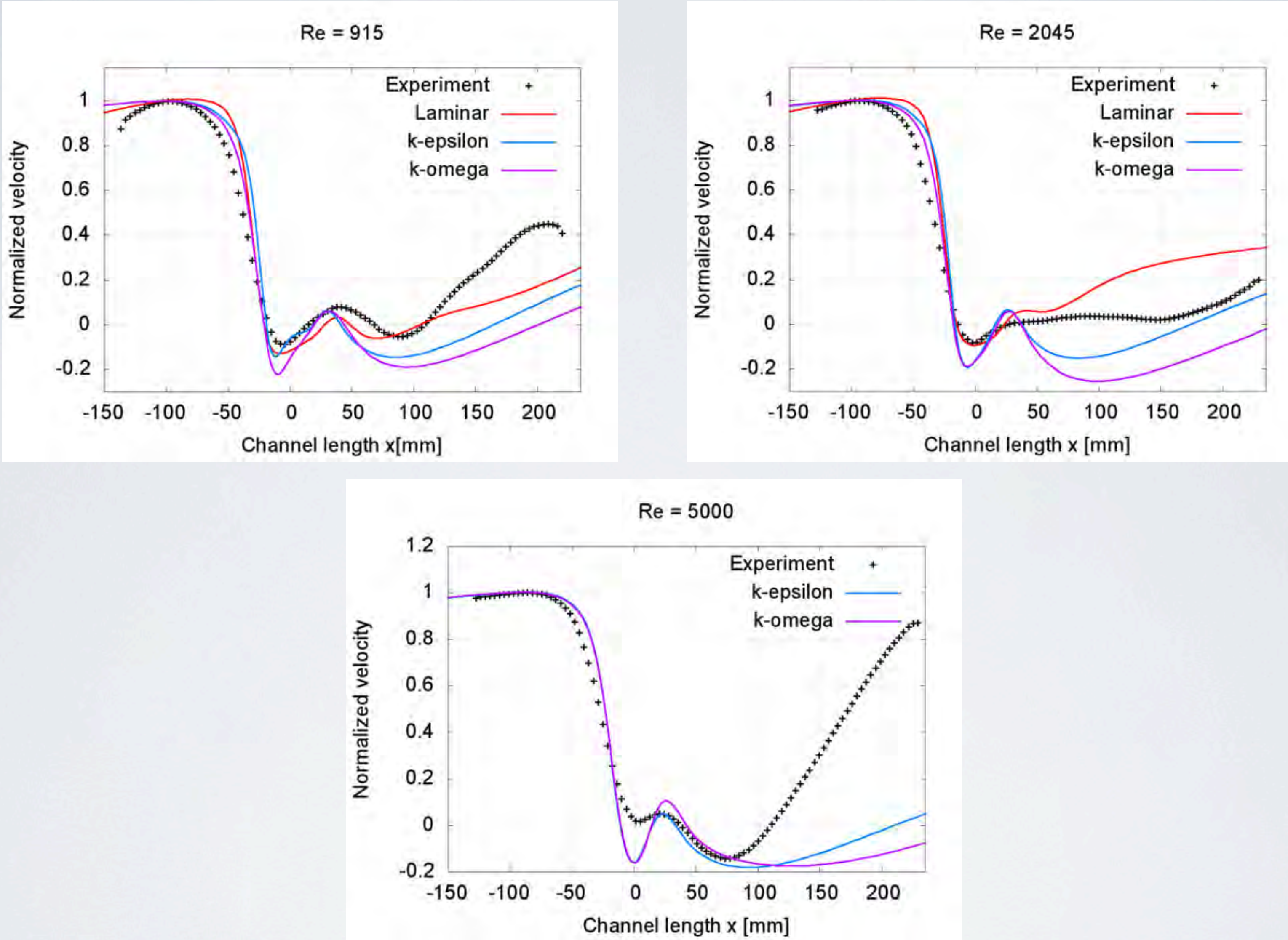

Comparison of numerical results for the axial velocity and experimental data.

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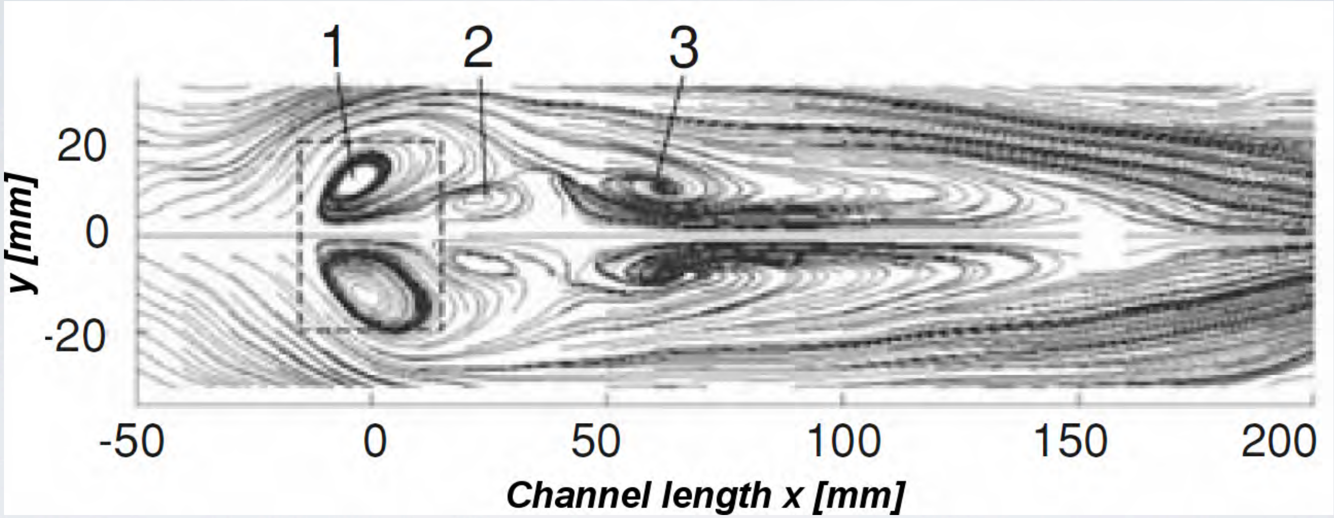
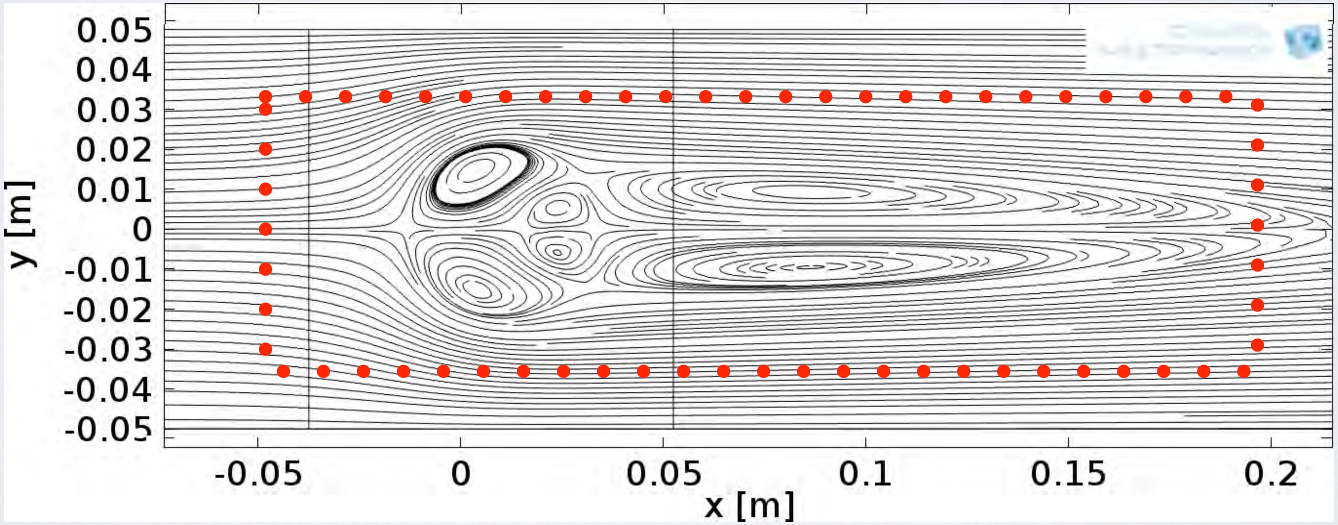
COMPARISON





Streamlines for the time averaged flow over a magnetic obstacle

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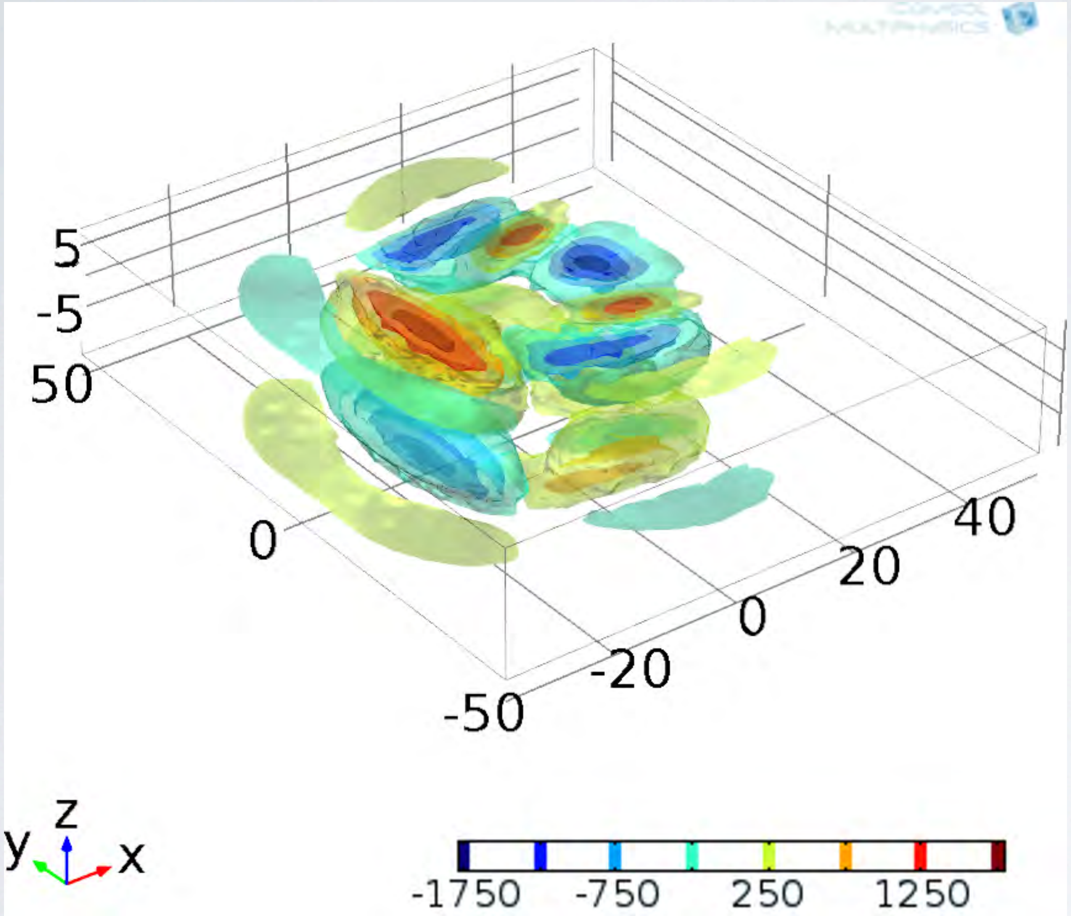
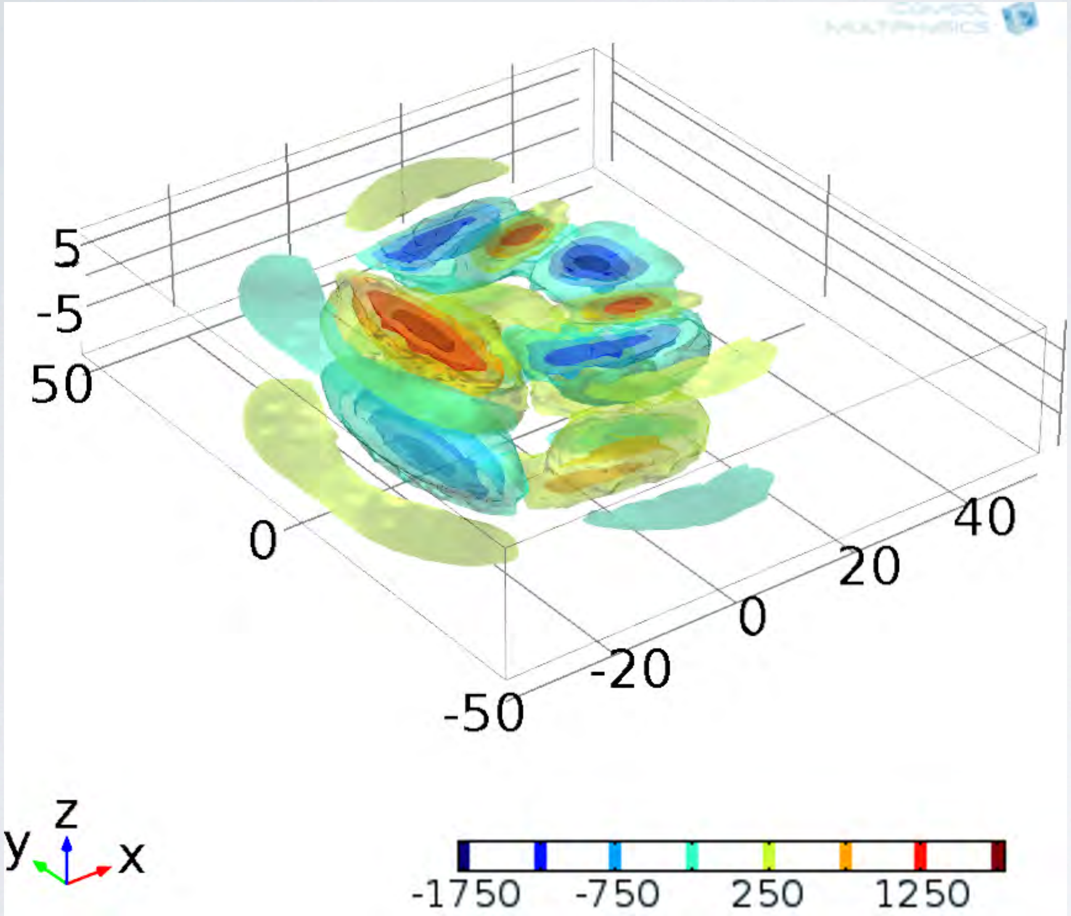
LORENTZ FORCE DISTRIBUTION



Vertical component of the Lorentz force

LORENTZ FORCE DISTRIBUTION



Vertical component of the Lorentz force

BL thickness

Flow over a flat plate

+

$$\delta_{Re} \sim \frac{\ell}{Re^{1/5}} \sim 0.016\ m$$

$$\delta_{Ha} \sim \frac{\ell}{Ha} \sim 0.07\ mm$$

$$Ha = B_0\,\ell\,\sqrt{\frac{\sigma}{\nu\rho}}$$

⇩

Instability of the Hartmann layer

CONCLUSIONS AND FURTHER WORK

Simulations capture the essential physics of the flow.

- For Re < 2050, the laminar model fits better to the experimental data than turbulent models,
- Re > 2050 the turbulent models present a better agreement but still do not reproduce the behavior accurately in the whole region.

- Results suggest that the dynamics of vortex patterns as Re is increased may be due to the *transition from a laminar to turbulent regime*.

★ Implementation of wall functions suited for MHD problems.
★ Transient flow.
★ Multiphase flow (Gallium oxides).

*Also in poster session

Thanks for your attention !

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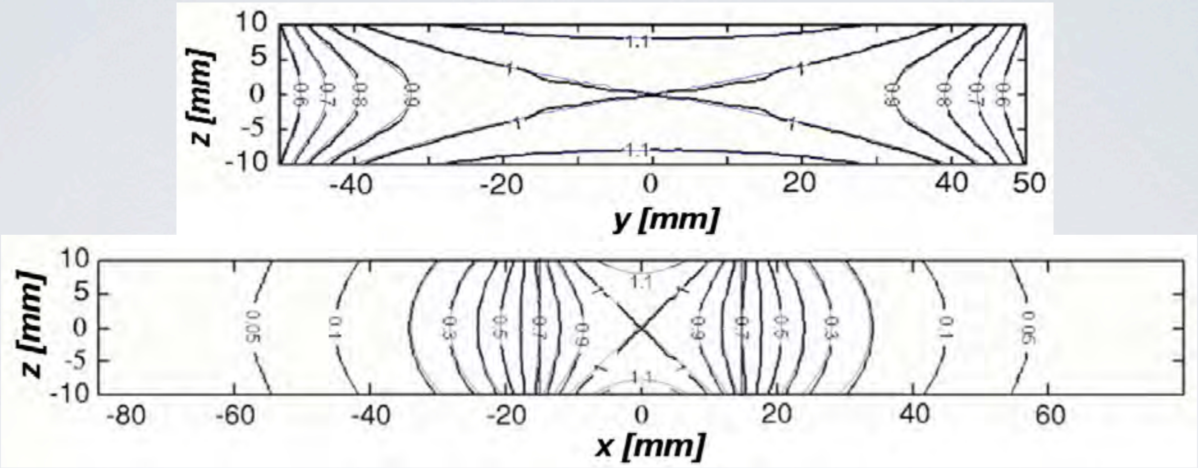
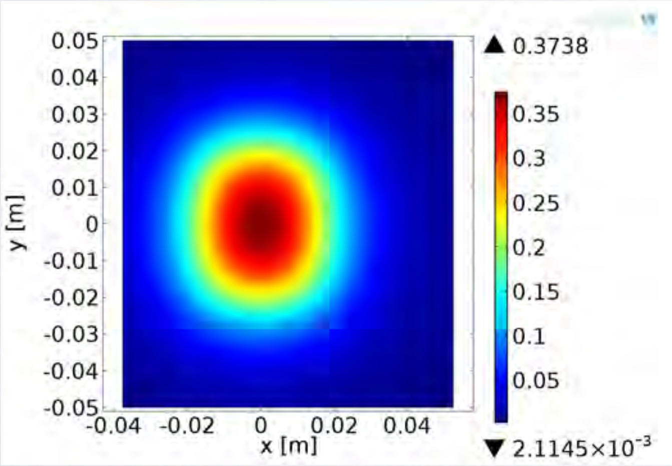
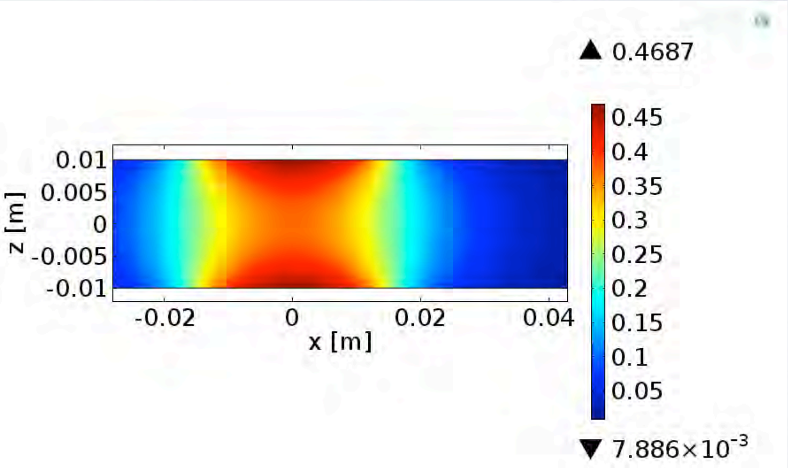
MAGNETIC FIELD VALIDATION



O. Andreev et al.,Experimental study of liquid metal channel flow under the influence of a nonuniform magnetic field, Phys. Fluids 19





Vertical magnetic field at the midplanes of the channel.