Numerical Simulations of an Electromagnetic Braking System

Magnetohydrodynamics (MHD) of an Impinging Jet

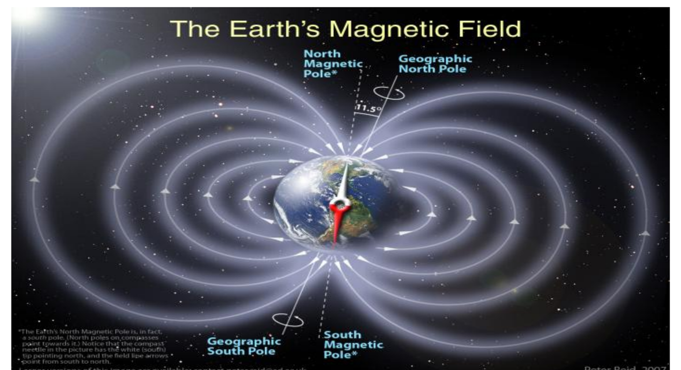
Alan McCausland, Abhilash J. Chandy, Dept. of Mechanical Engineering: Computational Fluid Dynamics.

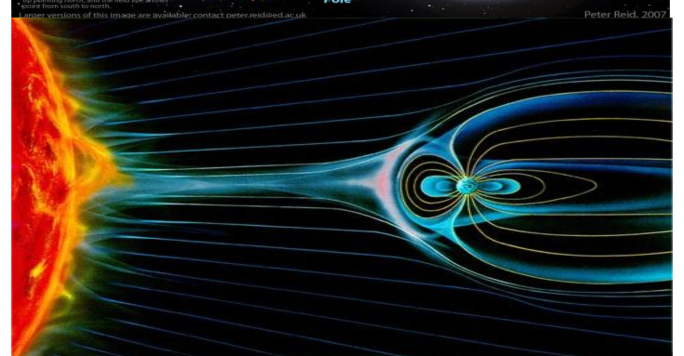
Sponsored by: Choose Ohio First

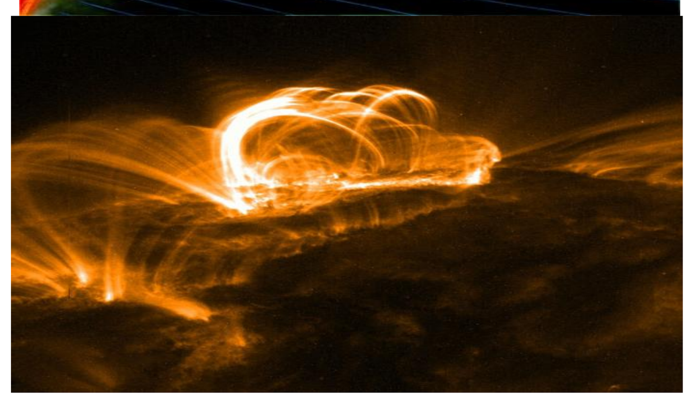
The University of Akron

MHD Background

- **MHD: Magnetohydrodynamics is the interaction of electrically conducting fluid flows with a magnetic field.**
- **Scientific areas of interest:**
  - **Geophysical**
    - **The earth's terrestrial magnetic field, and its interaction with the liquid metal core of the earth.**
  - **Astrophysical**
    - **solar flares, solar wind, formation of stars, and galactic magnetic fields.**
  - **Engineering**
    - **Steel casting, electromagnetic stirring, energy generation i.e. nuclear reactors integrated with MHD generators.**







MHD in Steel Casting

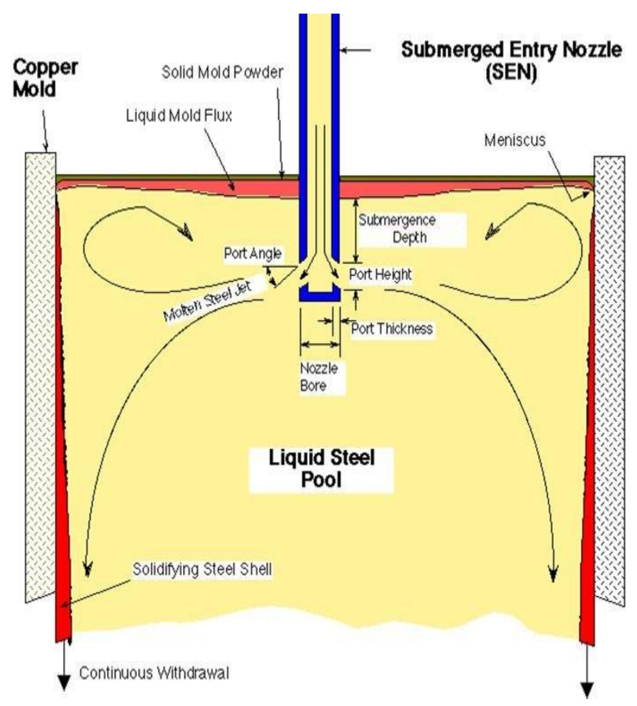
MHD has applications in industrial processes involving fluid flow control.

- An electromagnetic brake (EMBR) is a promising electromagnetic technology in the field of steel manufacturing.

- Involves applying a DC magnetic field to a casting or foundry to induce the flow.

- When melt rotates in a magnetic field, the *Lorentz force*, resulting from the interaction of fluid motion and the magnetic field, leads to electromagnetic stirring (EMS), which greatly influences solidification features of materials by retarding the flow.

- Retardation of the flow is seen an impinging jet



Why an Impinging Jet?

The impinging jet is a fundamental physical phenomena in which a fluid is ejected or exited out from a source (the jet) and then is "impinged" on the surface interaction of a boundary.

Industrial engineering applications of an impinging jet:

1. **electronic component cooling to enhance the rate of heat transfer**
2. **drying of papers, films, glass, and metal, freezing of foods and tissues**
3. **cooling gas turbine and combustor components**

Tasks of the Simulation

Modeling of a two-dimensional (2D) impinging jet with ANSYS FLUENT

Employing a high (Re) Reynolds number: Re = 7,500

Used a turbulent, k-epsilon, Reynolds Average Navier Stokes (RANS) modeling scheme

Flow assumptions:
(1) steady state
(2) negligible molecular viscosity
(3) incompressible

An applied magnetic field was used to exhibit MHD effects.

The magnetic field was varied in strength to investigate the damping effect of the *Lorentz force*.

Compared *velocity vectors, Nusselt numbers, mean temperature and radial velocity profiles* to show this damping effect of the Lorentz force due to the presence of a magnetic field.

Non-Dimensional Parameters

Reynolds Number:

$$\frac{inertial\_forces}{viscous\_forces} = \mathrm{Re} = \frac{V_j D}{\nu} = \frac{\rho V_j (2W)}{\mu}$$

Prandtl Number:

$$\Pr = \frac{\nu}{\alpha} = \frac{\text{viscous diffusion rate}}{\text{thermal diffusion rate}} = \frac{c_p \mu}{k}$$

Nusselt Number:

$$\mathrm{Nu}_L = \frac{hL}{k_f} = \frac{\text{Convective heat transfer coefficient}}{\text{Conductive heat transfer coefficient}}$$

Stuart Number:

[N] magnetic interaction parameter that defines the strength of the magnetic field

$$N = \frac{\sigma B_o^2 D}{\rho U_o}$$

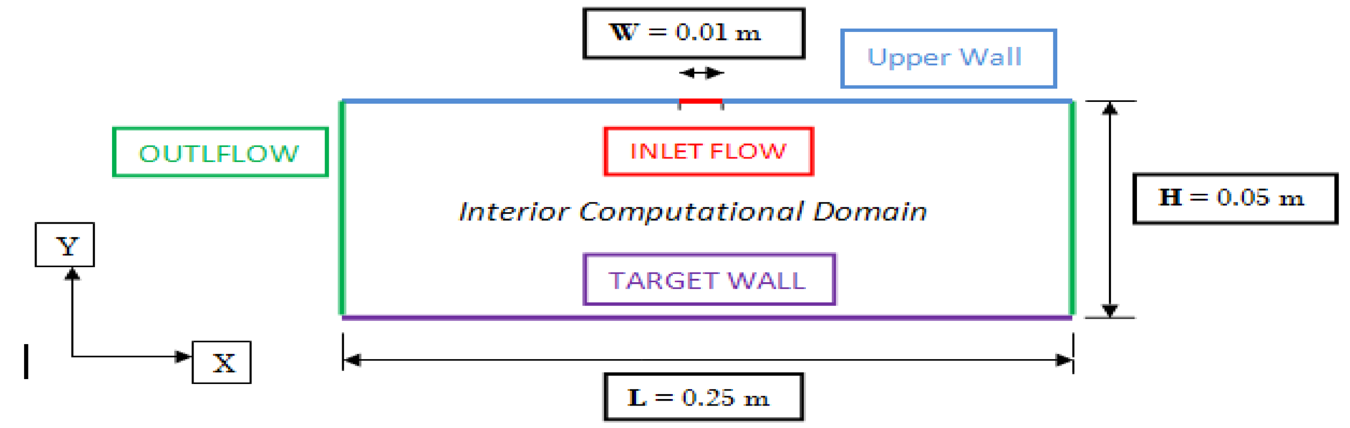
σ: electric conductivity

B_o: external magnetic field

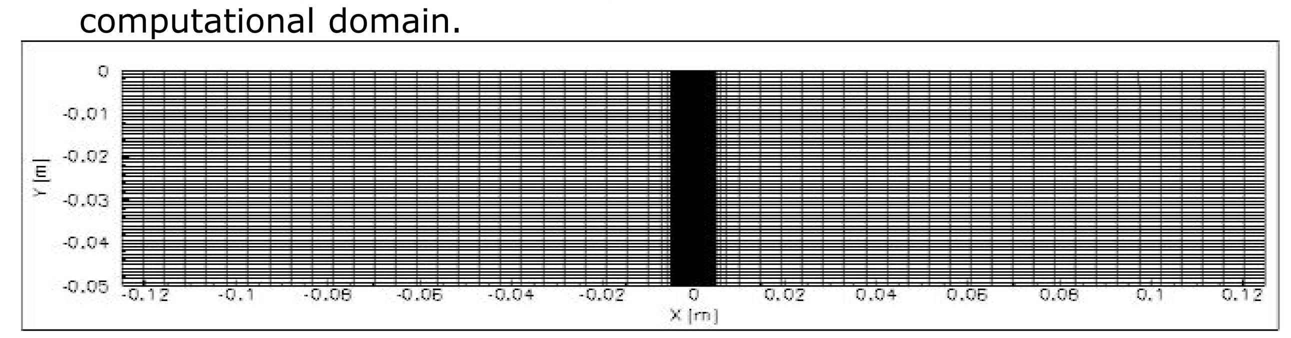
What are the Fluid Properties?

- **Liquid Metal, i.e. mercury (Hg) or molten steel**
- **Electrically Conductive**
- **Non-magnetic**
- **Pr = 0.02**

Boundary Conditions & Geometry

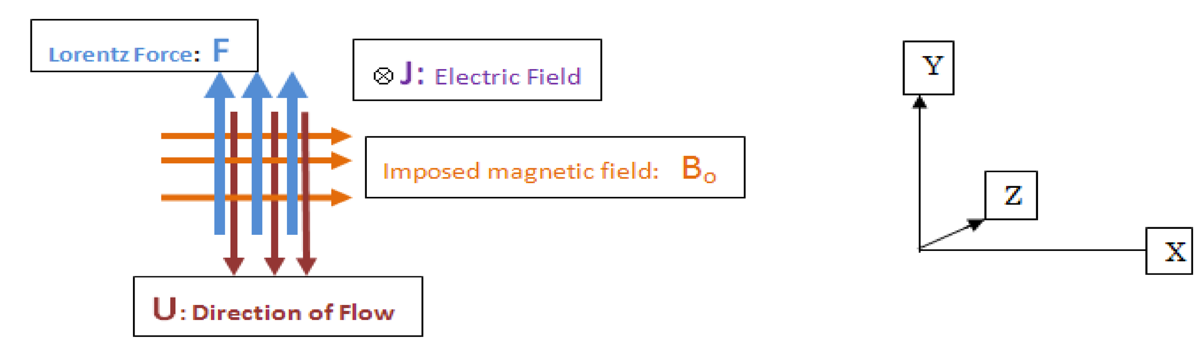


- **pressure outflow**: Outflow side boundaries
- **target wall**: Impingement wall or target wall
- **inlet velocity**: Inlet flow
- **upper-wall**: wall that surrounds the inlet flow boundary for the fluid entry into the computational domain.



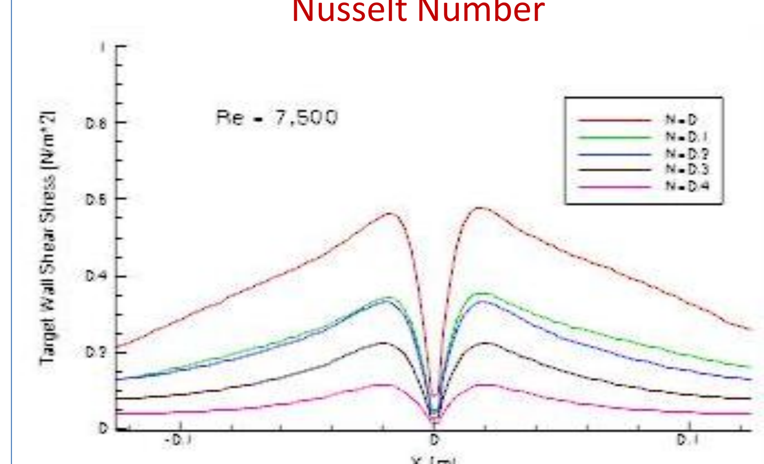
2D impinging jet geometrical mesh (84 x 62 grid)

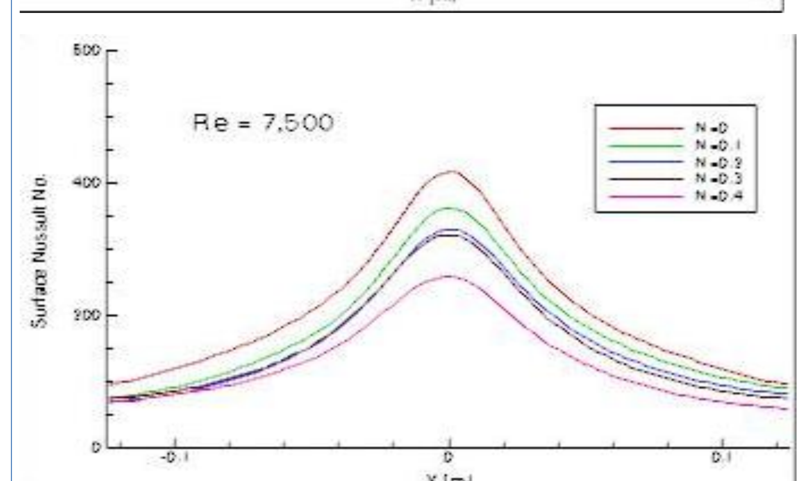
The Damping Effect due to the Lorentz Force



$$\vec{F} = (\vec{J} \times \vec{B}) \longrightarrow \mathbf{F} = -N\left(\frac{\rho U_o}{L_o}\right)(v)j$$

Wall Shear Stress & Surface Nusselt Number

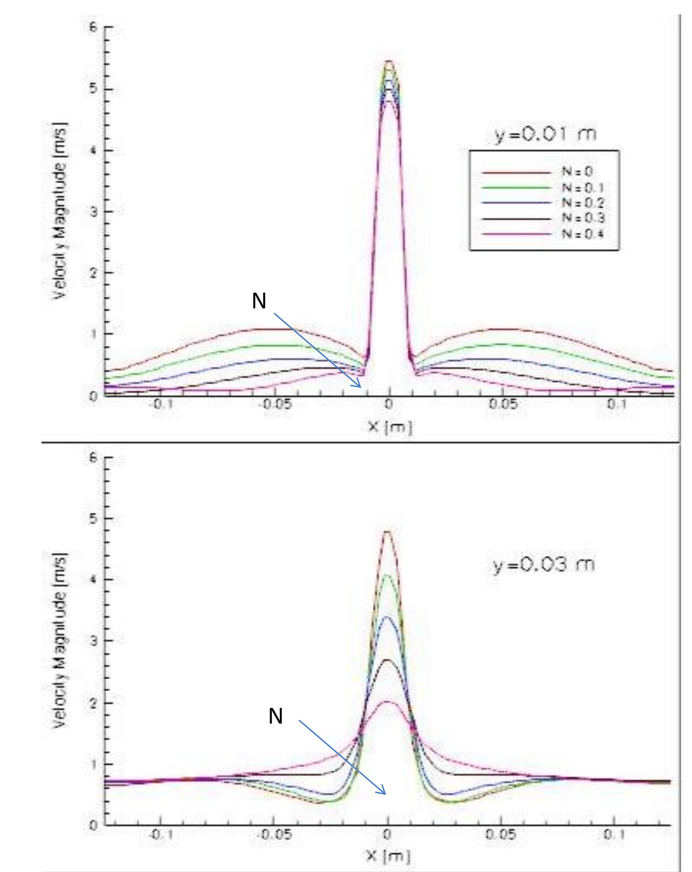




The wall shear stress & Nusselt number plots both supported the damping effect of the Lorentz force due to the presence of a magnetic field.

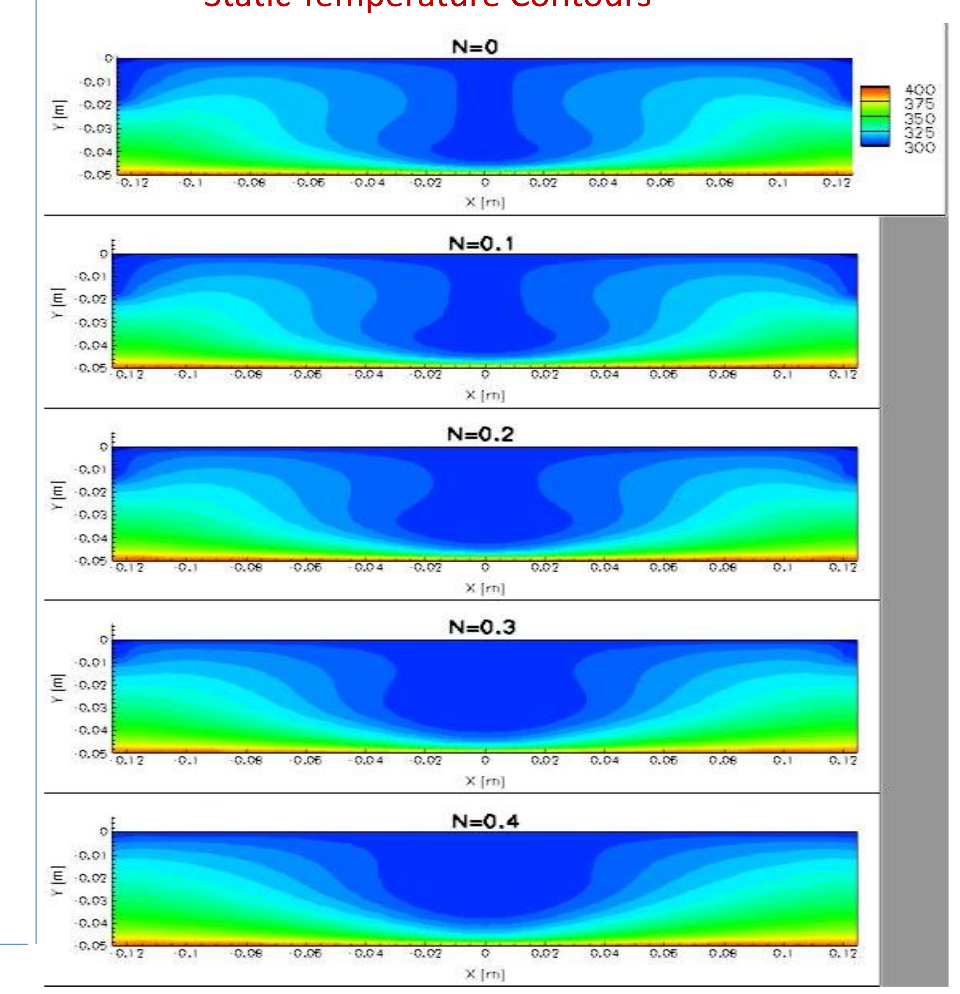
Results

Radial Velocity Magnitude Profiles

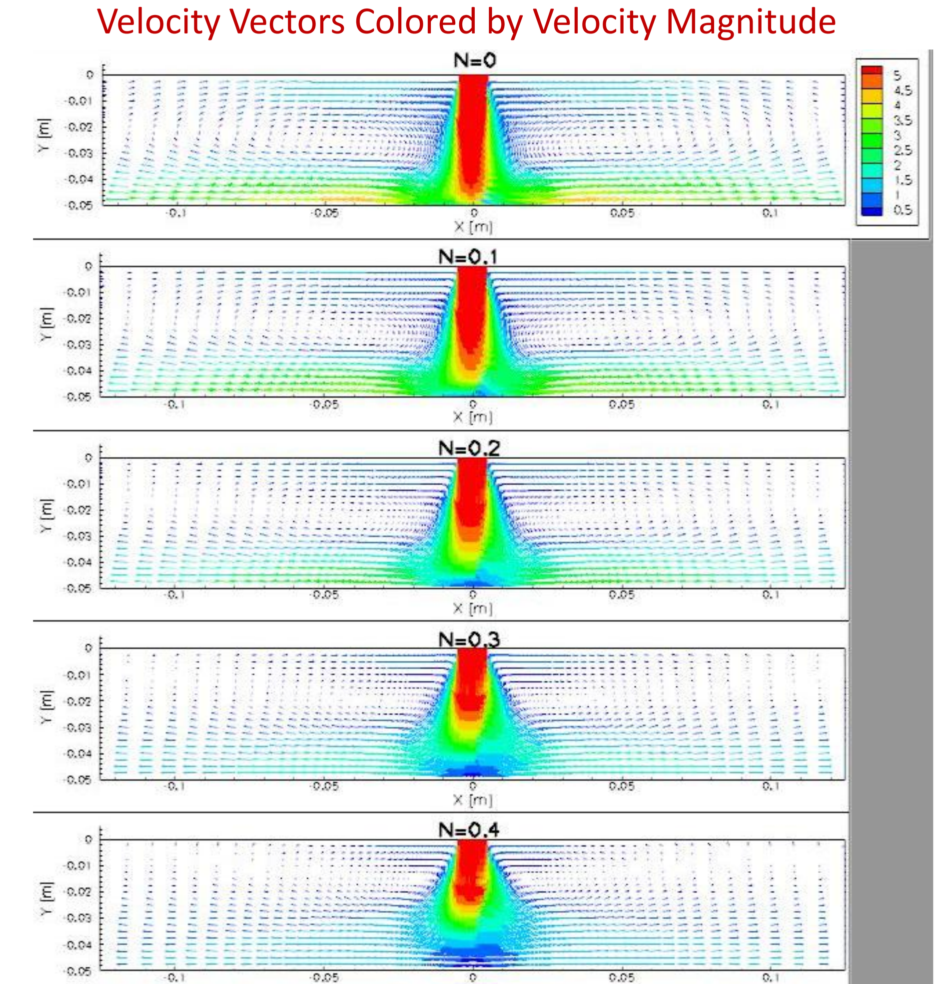


The radial velocity profiles displayed, confirmed the results of the velocity Vectors by showing that with two horizontal locations within the computational domain), with increasing N, the Velocity was decreasing, or retarded, due the interaction of the liquid metal and the magnetic field.

Static Temperature Contours



Velocity Vectors Colored by Velocity Magnitude



The velocity vectors showed that as the magnitude, or intensity, of the magnetic field was increased, the jet was impinged consistently to a point at which the jet no longer reached the target wall.

The static temperature contours showed that the temperature distribution, or temperature gradient, increased with increasing N values, or magnetic field intensity.

This was due to the decreasing of the Impingement effect of the jet on the target wall.