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LARGE EDDY SIMULATION OF MAGNETIC DAMPING OF JET

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Summary In the present study, we perform large eddy simulations to investigate the effect of magnetic field on the flow characteristics of a round jet at Re=10000. We consider two different directions of magnetic field. With the axial magnetic field, the shear layer becomes thinner and the potential core becomes longer than those without magnetic field. In case of the transverse magnetic field, the jet progressively spreads along the direction of the magnetic field applied, and the negative axial velocity appears along the direction perpendicular to the magnetic field line.

It has been known that a static magnetic field is able to suppress the turbulent motion of liquid metal. This phenomenon is called magnetic damping. This magnetic damping is useful for metallurgical processes which commonly take the form of submerged jet. Generally, the current induced by the motion of liquid across the magnetic field leads to Joule dissipation and the rise of thermal energy due to Joule dissipation decreases the kinetic energy. As a result, the turbulent motion of liquid metal is suppressed. Sajben & Fay [1] performed an experiment for a turbulent mercury jet in a coaxial magnetic field. They observed that the rate of spreading of the jet and the turbulent intensity decreased with increasing magnetic-field strength. Davidson [2] analytically investigated the evolution of the inviscid jet under the magnetic damping by a transverse magnetic field.

However, the previous studies have not investigated the effect of the magnetic field on the vortical structures of a turbulent jet in detail. In early seventies, Crow & Champagne [3] observed that the turbulence field is made up of the large-scale coherent structure and fine-scale turbulence motion. Since that time, it has been well known that the dynamics in a round jet significantly depends on the coherent structures. Therefore, the change in the coherent structures by the magnetic damping is important to understanding the magnetic damping phenomenon, which is the objective of the present study.

The computation of a round jet is conducted using large eddy simulation (LES) with a dynamic subgrid-scale model (Germano *et al.* [4], Lilly [5]). In the present study, we consider MHD flow at a low magnetic Reynolds number. The governing equations for an electrically conducting and incompressible flow considered in the present study are as follows;

$$\frac{\partial u}{\partial t} + (u \cdot \nabla)u = -\nabla p + \frac{1}{Re}\nabla^2 u + N(-\nabla\phi + u \times B) \times B, \quad (1)$$

$$\nabla^2\phi = \nabla \cdot (u \times B) = B \cdot \omega, \quad (2)$$

$$\nabla \cdot u = 0, \quad (3)$$

where u is the velocity, p is pressure, $\omega = \nabla \times u$ is the vorticity, B is magnetic field, Re and N are the Reynolds and Stuart numbers, respectively. The Suart number N is the ratio of the electromagnetic force to the inertial force. The numerical method used to solve these equations in a cylindrical coordinate is based on a semi-implicit fractional-step method (Akselvoll & Moin [6]). In the present computation, the Reynolds number based on the jet velocity (U_J) and jet diameter (D) is 10,000. At the jet exit, we imposed a top-hat velocity profile with a laminar blasius profile near the wall. In MHD turbulent flow, the direction of the magnetic field is one of the important parameters of determining the effect of magnetic field on the flow characteristics (Lee & Choi [7]). In the present study, a uniform magnetic field is applied in the axial or transverse direction to a turbulent jet. The Stuart numbers are $N_x = 0.5$ and $N_y = 0.05$ in the cases of axial and transverse magnetic fields, respectively. The computational domain size used is $-3.6 \le x/D \le 30$, $0 \le r/D < 7$ and $0 \le \theta < 2\pi$.

Figure 1 shows the contours of the instantaneous axial velocity in the cross-sectional plane with and without magnetic fields. With the axial magnetic field, the thickness of shear layer is thinner and the length of potential core is longer than those without magnetic field. In case of the transverse magnetic field, the jet progressively spreads along the magnetic field line with increasing x/D. Also, the negative axial velocity is observed along the direction perpendicular to the magnetic field line, which qualitatively agrees with the results by Davidson [2].

Figure 2 shows the vortical structures with and without magnetic fields. The iso-pressure surface is used to identify the vortical structures. Without magnetic field (Fig. 2a), the shear layer becomes unstable due to the shear layer instability (Kelvin-Helmholtz instability) and large coherent structures are observed due to the vortex pairing at a downstream location. As shown in Fig. 2, the changes in the vortical structures by the magnetic field depend on the direction of magnetic field. With the axial magnetic field, the vortical structures become weak because the magnetic field decreased the turbulence intensity as observed by Sajben & Fay [1]). On the other hand, with the transverse magnetic field, the vortical structures are weakened at a further downstream location because the Stuart number in this case is small as compared to the case of axial magnetic field. Currently, we are conducting LES at larger Stuart numbers. The detailed vortical structures and turbulence statistics with respect to the Stuart number will be shown in final presentation.

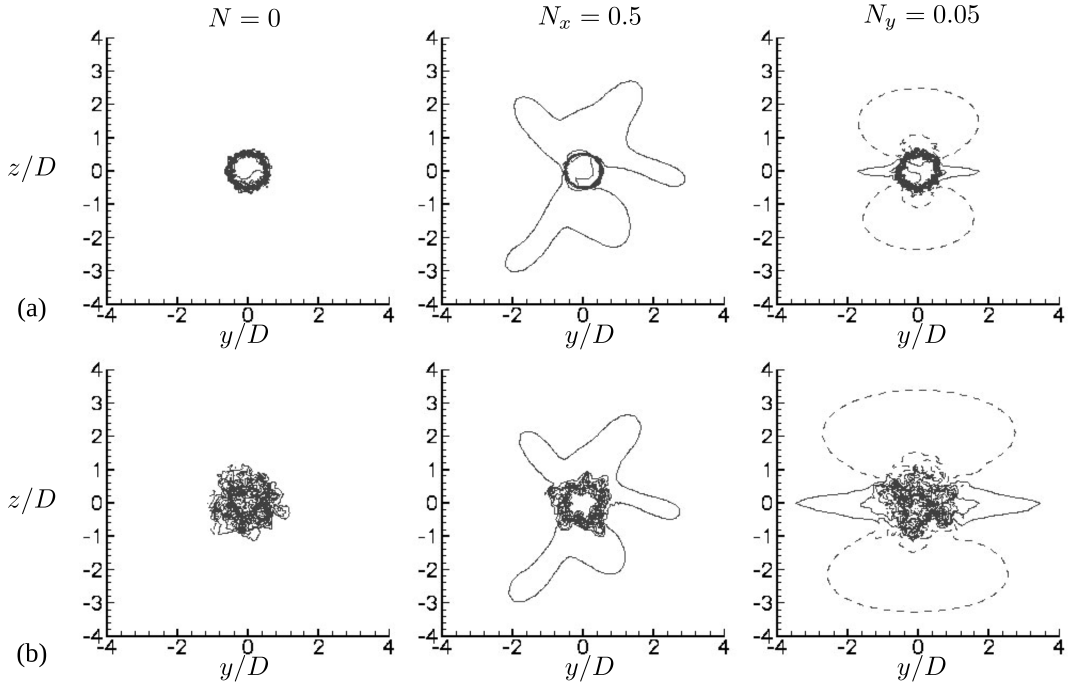

Figure 1. Contours of the instantaneous axial velocity in the cross-sectional plane: (a) $x/D = 1$; (b) $x/D = 5$. Dashed line represents the negative value.

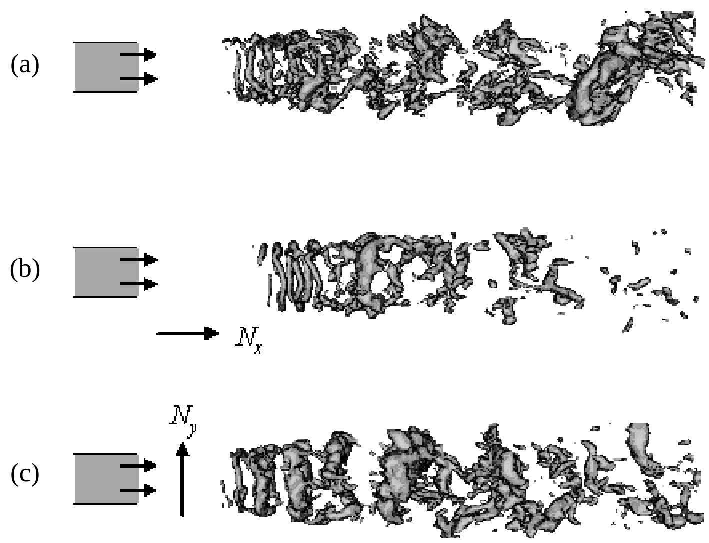

Figure 2. Instantaneous vortical structures: (a) without magnetic field; (b) $N_x = 0.5$; (c) $N_y = 0.05$.

References

[1] Sajben, M., Fay, J.A.: Measurement of the growth of a turbulent mercury jet in a coaxial magnetic field. *J. Fluid Mech* **27**:81–96, 1967.
[2] Davidson, P.A.: Magnetic damping of jets and vortices. *J. Fluid Mech* **299**:153–186, 1995.
[3] Crow, S.C., Champagne, F. H.: Orderly structure in jet turbulence. *J. Fluid Mech* **77**:397–413, 1971.
[4] Germano, M., Piomelli, U., Moin, P., Cabot, W.H.: A dynamic subgrid-scale eddy viscosity model. *Phys. Fluids A* **3**:1760–1765, 1991.
[5] Lilly, D.K.: A proposed modification of the Germano subgrid-scale closure method. *Phys. Fluids A* **4**:633–635, 1992.
[6] Akselvoll, K., Moin, P.: Large eddy simulation of turbulent confined coannular jets and turbulent flow over a backward facing step. *Report No. TF-63*, Thermoscience Division, Department of Mechanical Engineering, Stanford University, Stanford, CA.
[7] Lee, D., Choi, H.: Magnetohydrodynamic turbulent flow in a channel at low magnetic Reynolds number. *J. Fluid Mech* **439**:367–394, 2001.