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Investigations of coupling MHD duct flows under inclined magnetic fields

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Motivation and background

- The interaction between a flowing electrically conducting fluid and an external applied magnetic field in a liquid metal blanket will modify the heat transfer and velocity distribution significantly and cause an extraordinary pressure drop .
- In real fusion reactor blanket configurations, the ducts which liquid metal flows through are usually electrically conducting coupled , and there is a certain angle between the confinement magnetic field and the side walls of the fluid channels.
- The electromagnetic coupling effect in inclined transversal magnetic fields will dramatically modify the velocity and pressure distributions in the flow field, causing reversed flows and an increased pressure loss.
- In addition, 3D effect induced by the gradient magnetic fields has a noteworthy impact on the velocity distribution and pressure drop in the flow channels.
- Therefore, it is important to investigate liquid metal coupling ducts MHD flows under inclined magnetic fields in order to guide the future design of the liquid metal blanket.

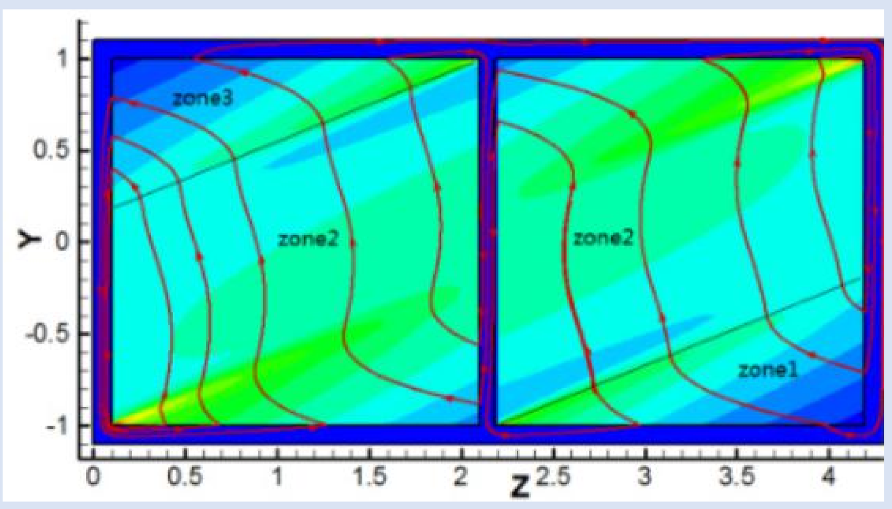
Mathematical model

$$\upsilon\left(\frac{\partial^2 u}{\partial z^2}+\frac{\partial^2 u}{\partial y^2}\right)-\frac{1}{\rho}\frac{dp}{dx}+\frac{1}{\rho}\frac{1}{\mu_0}\left(B_0\sin\alpha\frac{\partial B_x}{\partial y}+B_0\cos\alpha\frac{\partial B_x}{\partial z}\right)=0 \quad (1)$$

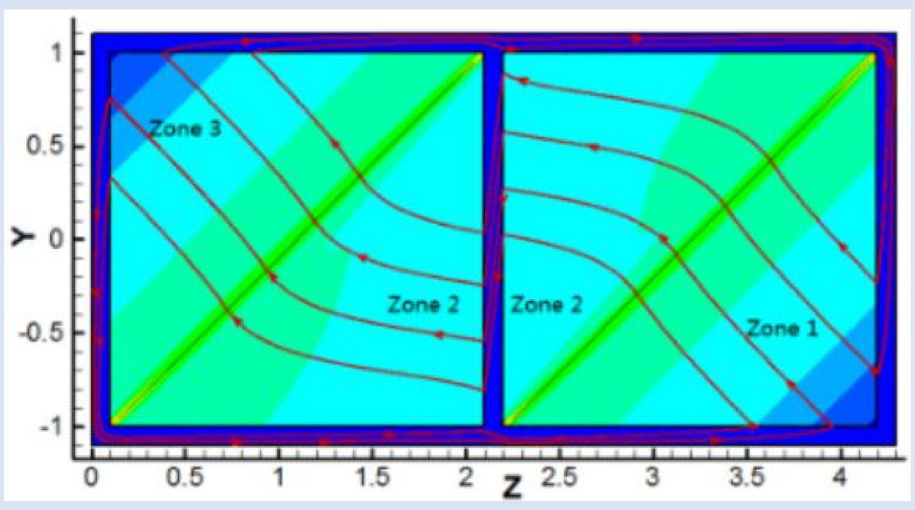
$$\frac{1}{\mu_0}\frac{\partial}{\partial z}\left(\frac{1}{\sigma}\frac{\partial B_x}{\partial z}\right)+\frac{1}{\mu_0}\frac{\partial}{\partial y}\left(\frac{1}{\sigma}\frac{\partial B_x}{\partial y}\right)+B_0\sin\alpha\frac{\partial u}{\partial y}+B_0\cos\alpha\frac{\partial u}{\partial z}=0 \quad (2)$$

$$j_y=\frac{1}{\mu_0}\frac{\partial B_x}{\partial z},\qquad j_z=-\frac{1}{\mu_0}\frac{\partial B_x}{\partial y} \quad (3)$$

Velocity distributions in co-flow cases



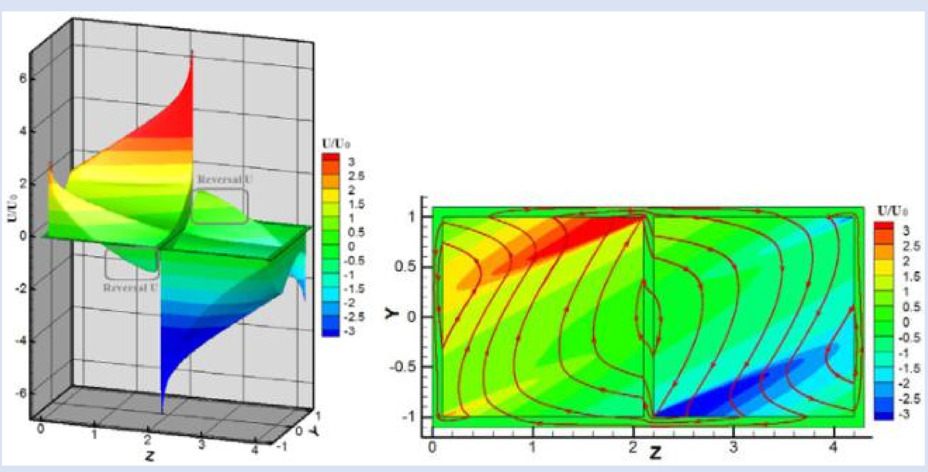
$\alpha = 22.5^\circ$



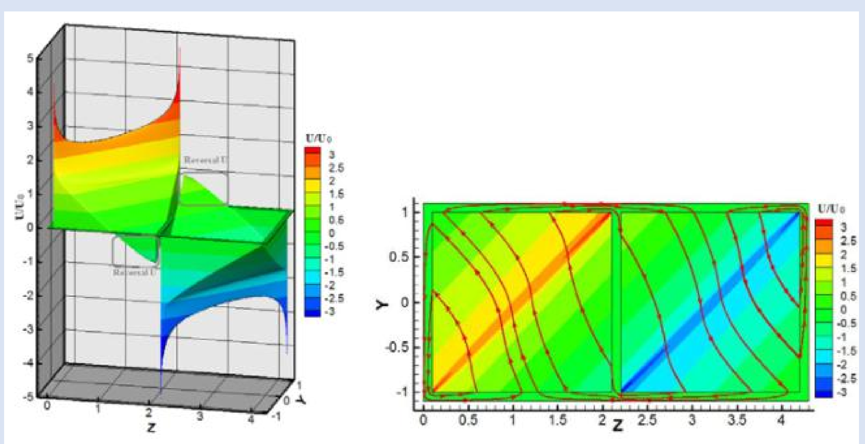
$\alpha = 45^\circ$

- Velocity jets along the direction of the external magnetic field.
- Electric currents leaking from one channel to the adjacent one

Velocity distributions in counter-flow cases



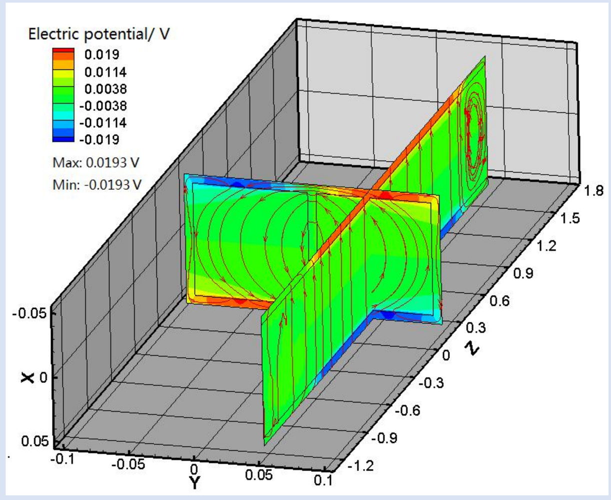
$\alpha = 22.5^\circ$



$\alpha = 45^\circ$

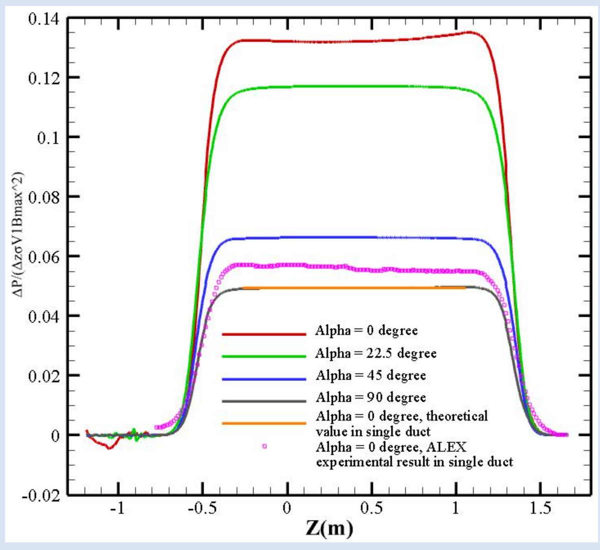
- Velocity jets along the direction of the external magnetic field.
- Defomed short circuit currents flowing across the middle coupling wall directly.
- The existence of a large reversal velocity region.

Electromagnetic coupling effect suppresses 3D MHD effect

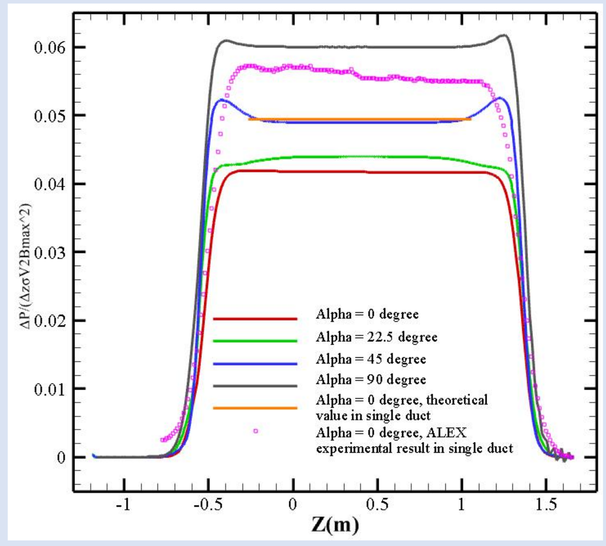


- The presence of the electromagnetic coupling effect between the two coupling ducts will lead the 3D currents flowing to the adjacent channel. As a result, the strength of the transversal Lorentz forces will decrease in the counter-flow case when $\alpha=0^\circ$.

Effect on the streamwise pressure gradient



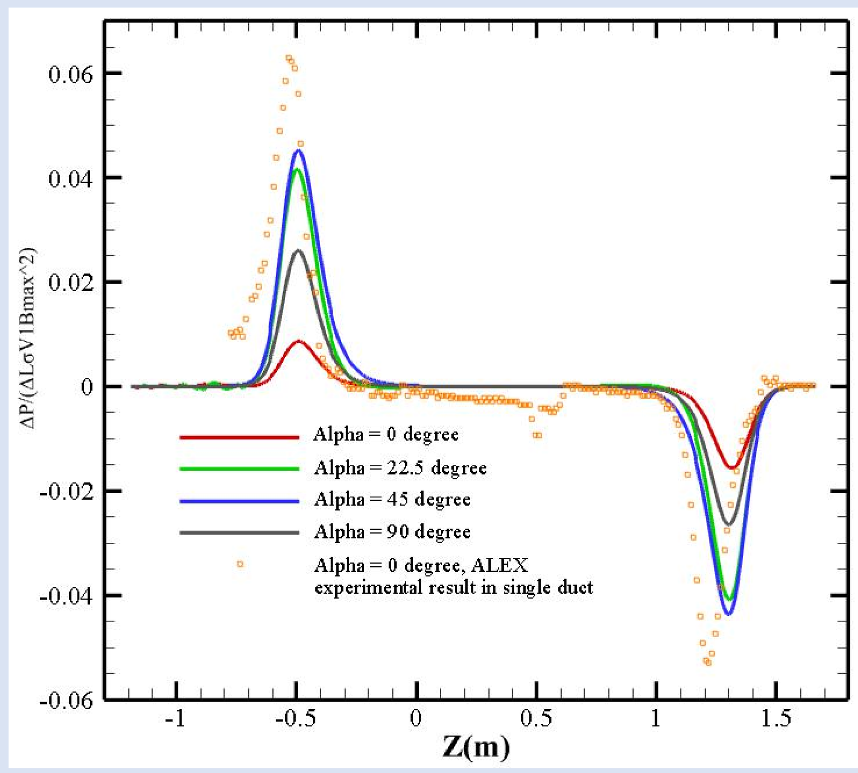
counter-flow case



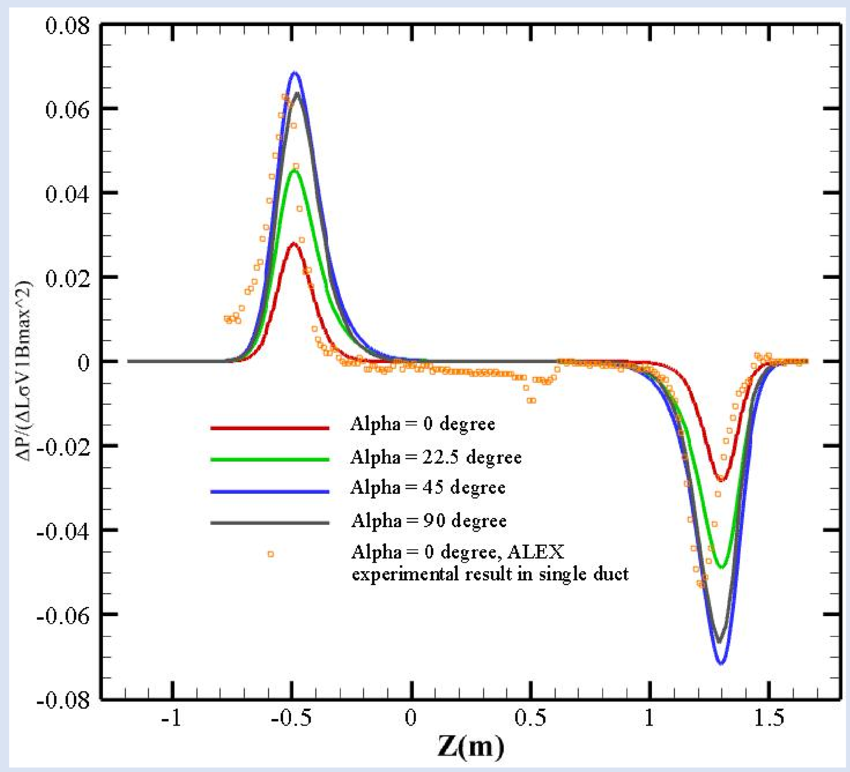
co-flow case

- The electromagnetic coupling effect enhances the streamwise pressure gradient in the counter-flow case when $\alpha=0^\circ$.

Effect on the transversal pressure difference



counter-flow case



co-flow case

- The electromagnetic coupling effect can suppress the transversal pressure difference in the counter-flow case.

CONCLUSION

- The MHD coupling effect in the co-flow case is much weaker than that in the counter-flow case.
- The inclined transversal magnetic fields have an obvious influence on the velocity distributions in the coupling MHD duct flows.
- The electromagnetic coupling effect between the coupling channels will suppress the 3D MHD effect in the counter-flow case when the inclined angle is zero.