Progress on the liquid metal "divertorlets" concept: Experiments and Simulations

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Summary

Among the development of liquid metal concepts for divertor applications, the "divertorlets" concept is a potential non-evaporative liquid metal solution for heat removal at low recycling regime [1]. A toroidal divertorlets prototype was built and tested at LMX-U at PPPL for performance evaluation. Flow speed was measured during experimental tests, and results were compared to COMSOL simulations. Finally, both results from experiments and simulations were analytically reviewed.

Motivation

Plasma facing components (PFCs) can experience extreme heat flux. Particularly, the divertor region has reached over 10 MW/m^2, and may increase in a commercial reactor [2]. Solid PFCs are limited in handling heat flux and experience irreversible damage, requiring maintenance shutdowns. Liquid metals (LM) have been proposed to address these challenges as they can carry away heat and self-heal through replenishment. However, no consensus has been reached about the most advantageous LM PFC configuration [3–5]. Particularly, flow speed of the liquid metal is one of the most important as it contributes to MHD drag [2–4]. Fast-flowing encounter severe MHD drag for the system with risk of piling and splashing [10]. On the other hand, slow-flowing LM-PFCs achieve reduced MHD drag but may not avoid evaporation [1].

The Divertorlets Concept

The divertorlets concept combines advantages of fast and slow flowing regimes: large flow rates with relatively small velocities and reduced exposure time of the LM to the plasma through the minimization of the flow path length. This leads to lower LM temperatures, allowing the achievement of low recycling surface (for lithium), reduced evaporation and impurity diffusion [10].
The toroidal divertorlets consists of directionally alternating flow paths that are connected by a layer of liquid metal at either end. The flow paths are separated by toroidally oriented "slats" (see Fig. 1 (a)). These slats generate channels for each of the flow paths. A unidirectional external current generates a current distribution j_0 that is modified by strategically placed conductors. In combination with an external magnetic field B_0, $j_0 \times B_0$ drives the body force, and the j_0-difference between consecutive channels drives the flow due to the designed slat geometry.

Experimental setup & simulations

- Tests performed at LMX-U of PPPL. Background magnetic field strength up to 0. 33 T and externally applied currents up to 900 A.
- Galinstan alloy (67% Ga, 20.5 In, 12.5% Sn) as LM for experiments.
- Slats made of copper and inserted in a polycarbonate box.
- Straight and L-shaped plastic tubes were used for velocity measurements.
- COMSOL Multiphysics simulations, with same conditions as experiments.

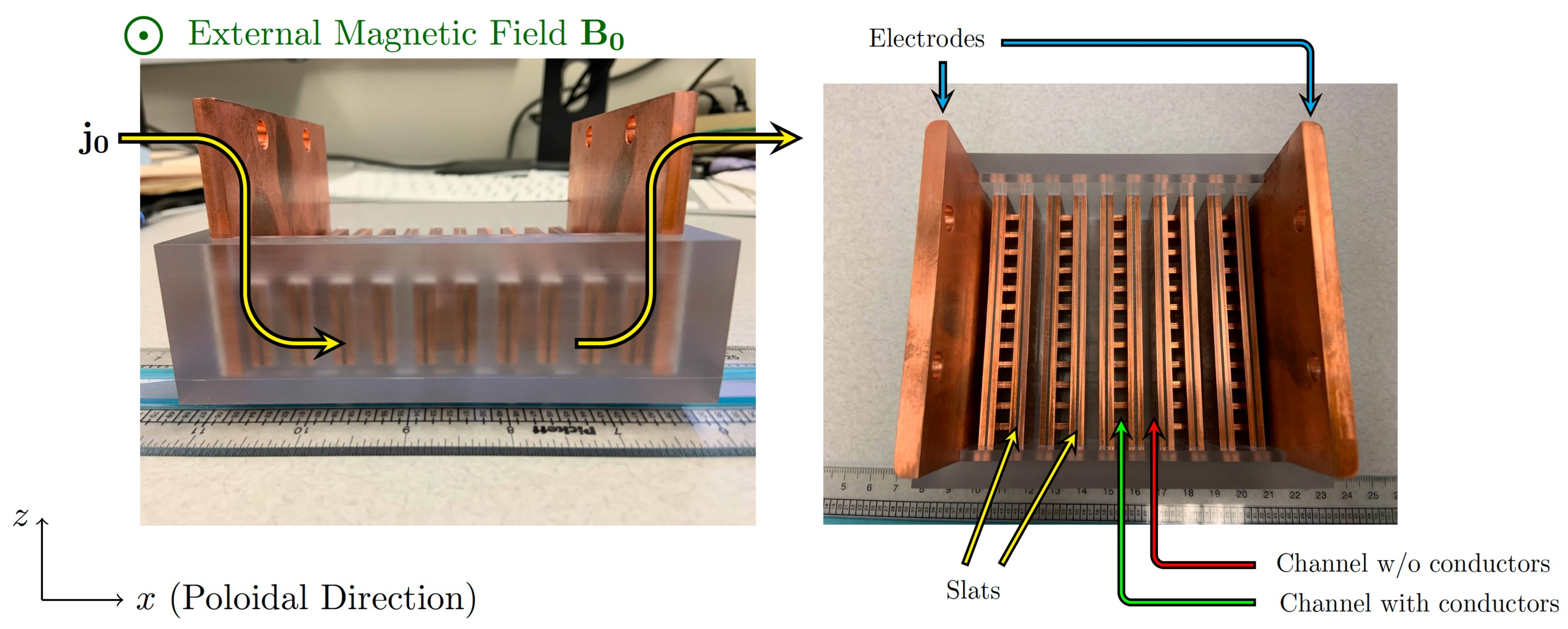
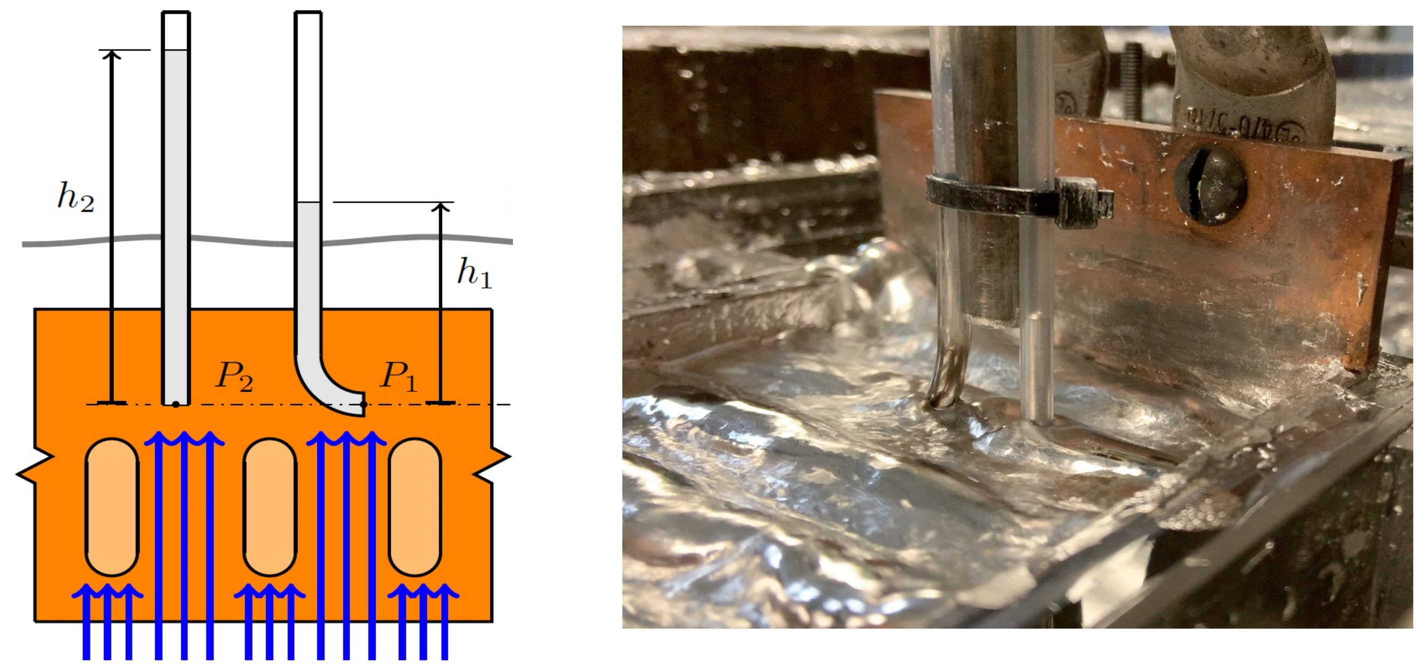


Figure 1. Toroidal divertorlets prototype used for experiments.



$$\|\mathbf{U}\| \approx \sqrt{2g\Delta h}$$

Figure 2. Experimental setup for velocity measurements.

Results

- Experiments confirmed the flow around the slats and continuous operation.
- Results indicate increasing flow speeds with increasing external current.
- Analytical model consists of a balance between $j_0 \times B_0$ force, MHD drag and viscous drag. See Fig, 5 for a comparison between simulations, experiments and analytical model at 0.3 T.

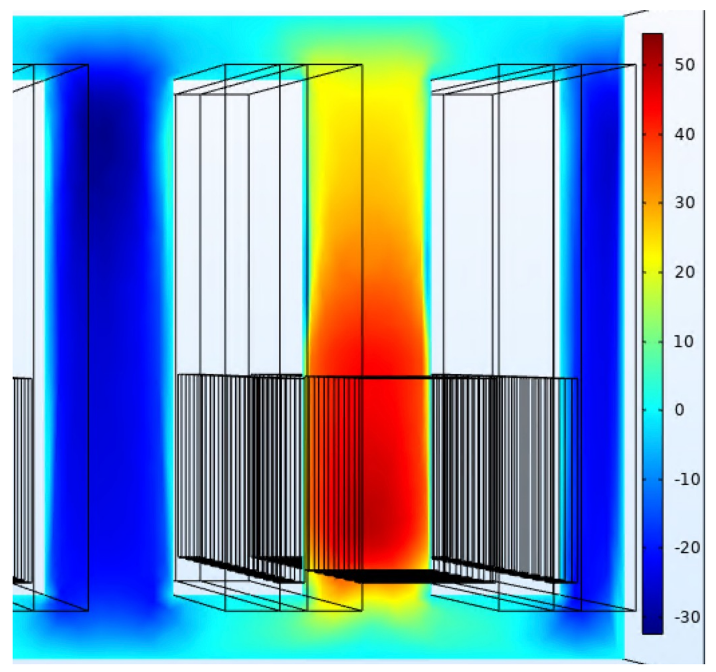


Figure 3. Simulation at 0.3 T, 900 A.

$$\Delta P_{j\times B} - \Delta P_{\text{visc}} \approx 0$$

$$\mathbf{j} = \mathbf{j_0} + \sigma(\mathbf{E_i} + \mathbf{U} \times \mathbf{B})$$

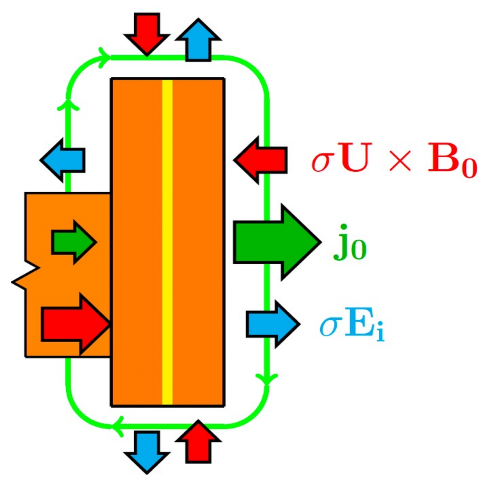


Figure 4. Diagram of electric currents around a slat.

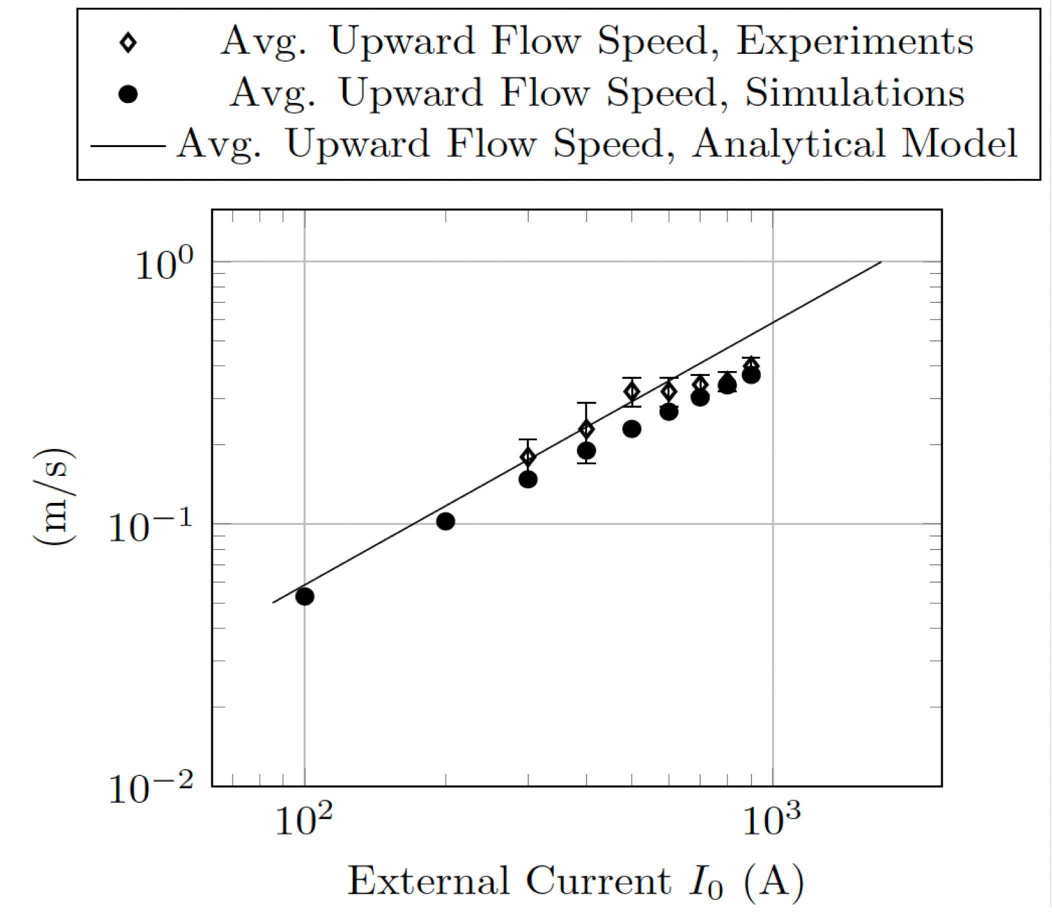


Figure 5. Comparison between experiments, simulation and analytical model.

Conclusions and future work

- Simulations agreed with experimental measurements at magnetic field strengths up to 0.33 T.
- An analytical model to describe flow speeds on a toroidal divertorlets device was derived and compared with simulation results.
- Studies about surface oscillations (amplitude/frequency) will be performed, including heat transfer on the system.

Acknowledgements

This work was supported by the US DOE through Field Work Proposal No. 1019, Domestic Liquid Metal Plasma Facing Component Development. The research was conducted under the LDRD Program at Princeton Plasma Physics Laboratory.

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