Liquid Metal Divertorlets Concept: Experiments, Simulations, and Projections

F. Saenz[1], Z. Sun[2], B. Wynne[1], E. Kolemen[1,2]

[1]Princeton University, Princeton, NJ 08540 USA

[2]Princeton Plasma Physics Laboratory, Princeton, NJ 08540 USA

Motivation

Plasma facing components (PFCs) can experience extreme heat flux in the divertor region. Solid PFCs may be limited in handling high heat loads. Liquid metals (LM) can carry away heat and self-heal through replenishment.

However, there is no consensus about the most advantageous LM PFC. Flow speed of the liquid metal contributes to MHD drag. Fast-flowing concepts encounter severe MHD drag with risk of piling. On the other hand, slow-flowing configurations achieve reduced MHD drag but may not avoid evaporation [1-2].

The Divertorlets Concept

The divertorlets is a liquid lithium PFC that combines advantages of fast and slow flow regimes: small speeds (low MHD drag) and reduced exposure time of the LM to the plasma. It is designed to mix the bulk liquid metal to handle greater heat loads and keep the temperature of the plasma facing surface (PFS) below 450˚C. Moreover, the continual flow mixing ensures a constantly fresh PFS, leading to low hydrogen recycling.

The divertorlets consists of directionally alternating flow paths in channels, separated by toroidally oriented "slats" (Fig. 1). An external current generates a current distribution **j** that is modified by strategically placed conductors in every other channel. With a tiroidal field **B**, **j**×**B** drives the body force, and the **j**-difference between channels drives the flow due to the designed slat geometry.

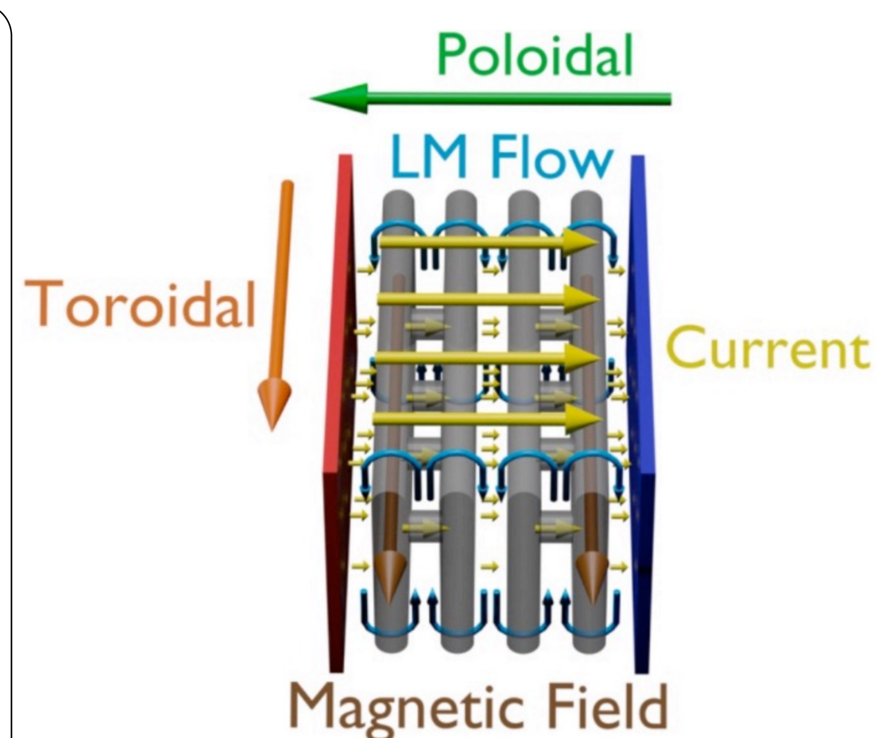

Figure 1. Diagram of electric currents around a slat [1].

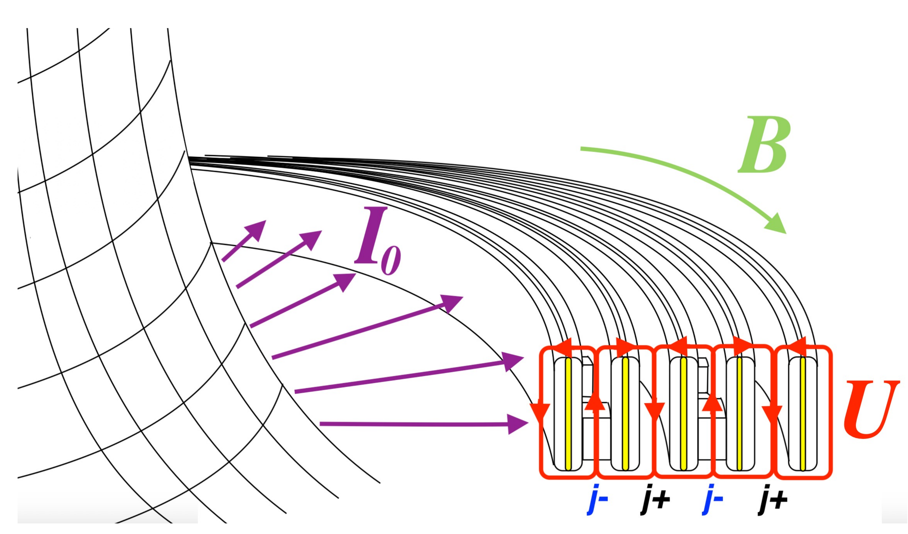

Figure 2. Toroidal divertorlets in a reactor.

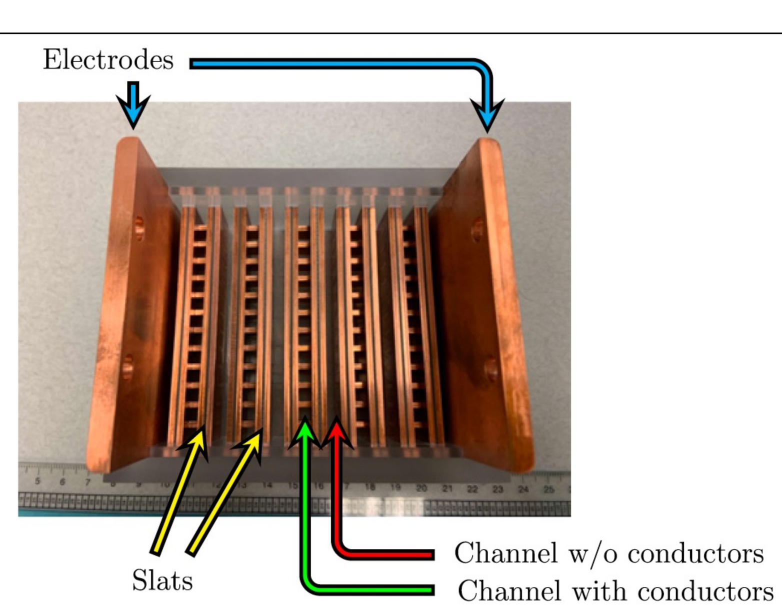

Figure 3. Top-view of divertorlets [2].

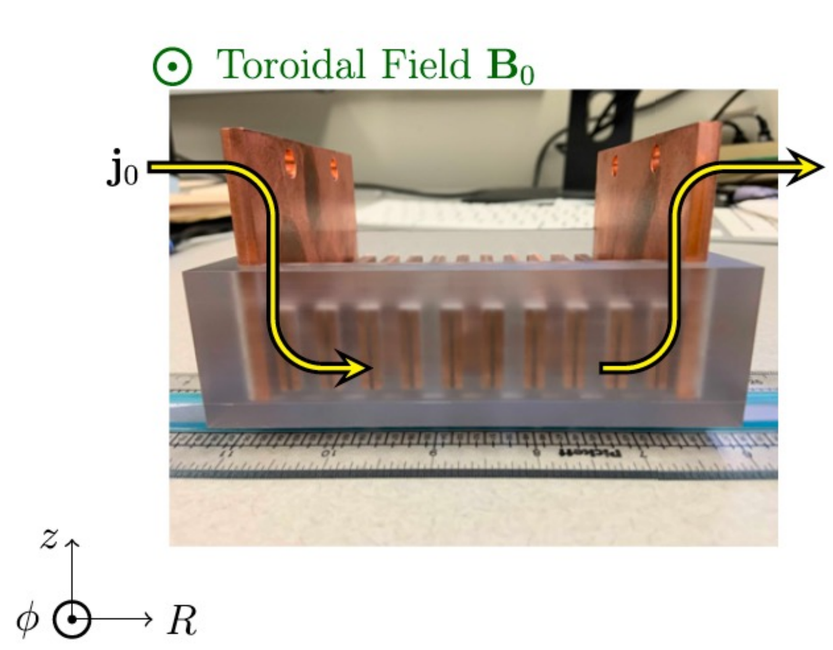

Figure 4. Side-view of divertorlets [2].

Experiments and simulations

- Tests performed in LMX-U, PPPL. **B**: 0.1 T - 0.33 T. External electric currents: 100 A - 900 A.
- Surrogate liquid metal: galinstan (67% Ga, 20.5 In, 12.5% Sn).
- Slats made of copper and inserted in a polycarbonate box.
- Plastic tubes were used for velocity measurements.
- COMSOL Multiphysics used for simulations.

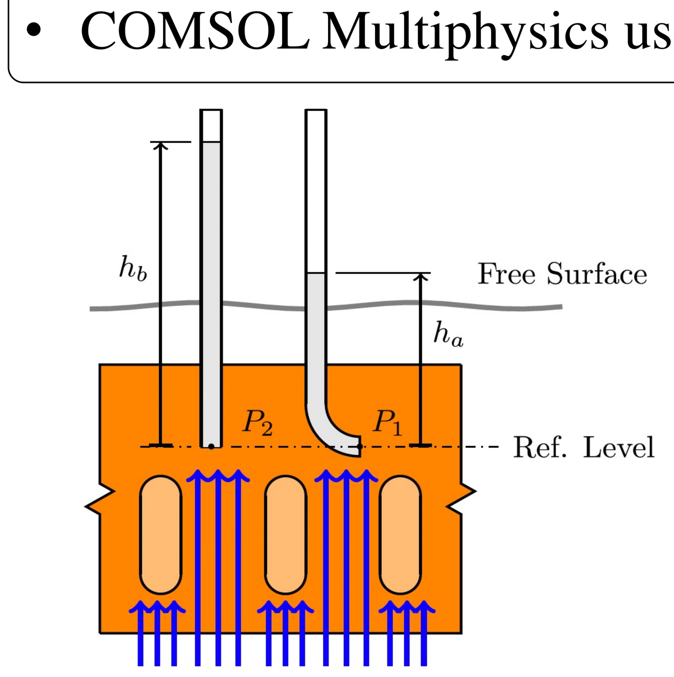

Figure 5. Speed measurements [2].

Figure 6. Free surface of divertorlets.

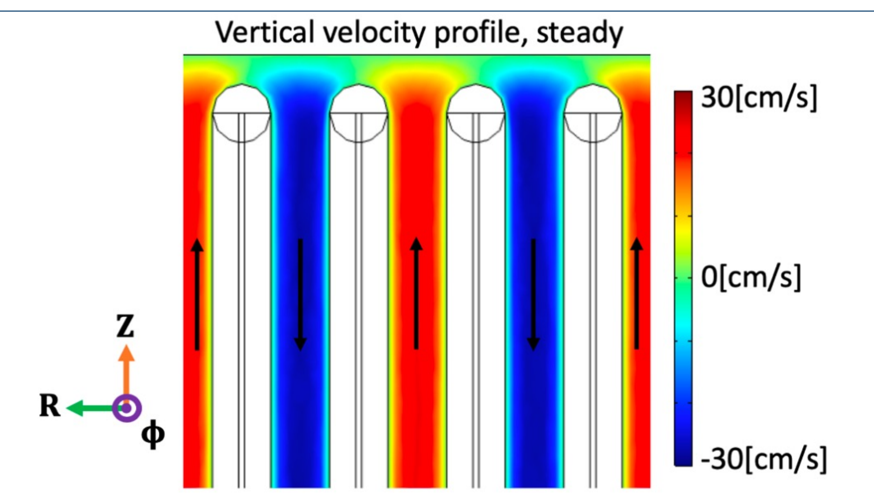

Figure 7. Velocity field from simulations [1]

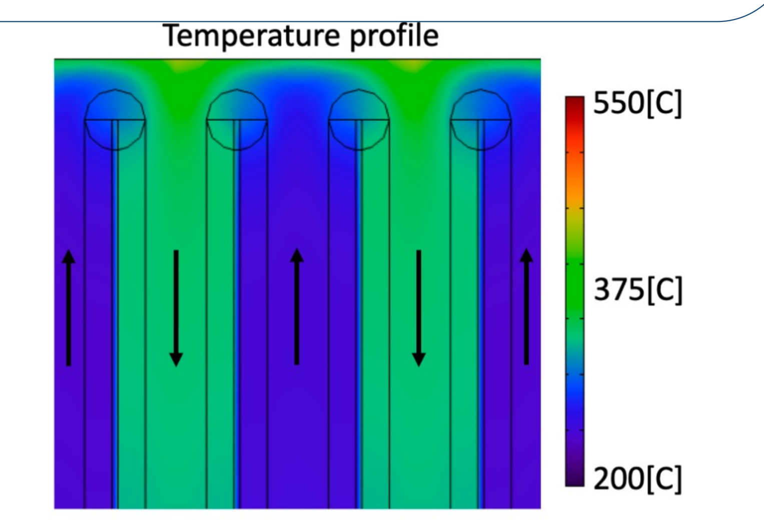

Figure 8. Temperature with 10 MW/m² [1].

Results

- Experiments confirmed cyclical flow around the slats (Fig. 6).
- Increasing flow speeds with increasing external current (Fig. 9).
- Balance between $\mathbf{j_0}\times\mathbf{B_0}$ force, MHD drag and viscous drag (Fig. 5).

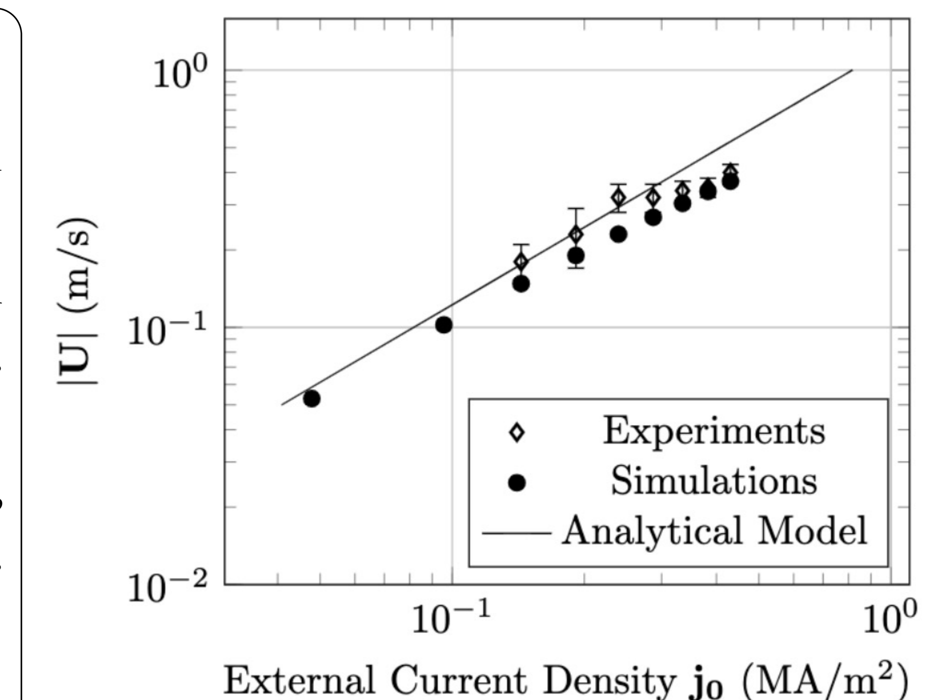

Figure 9. Comparison results.

Reactor-scale projections

- Simplified heat transfer analysis with a semi-infinite slab of liquid metal.
- **Liquid lithium as the operating LM** and tungsten for the slats/substrate.
- **Operation at 6 T, heat load of 10 MW/m², critical temperature increase of 425 K**.
- Exposure time t of the liquid metal to the plasma: $t = \frac{L}{|\mathbf{U}|}$
- q_{crit} is the maximum permissible heat load for a divertorlets system in a reactor scenario.

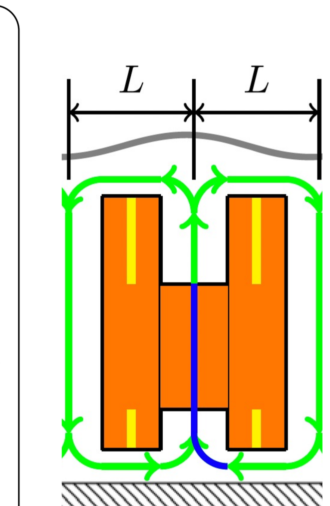

Figure 10. Diagram of a slat [2].

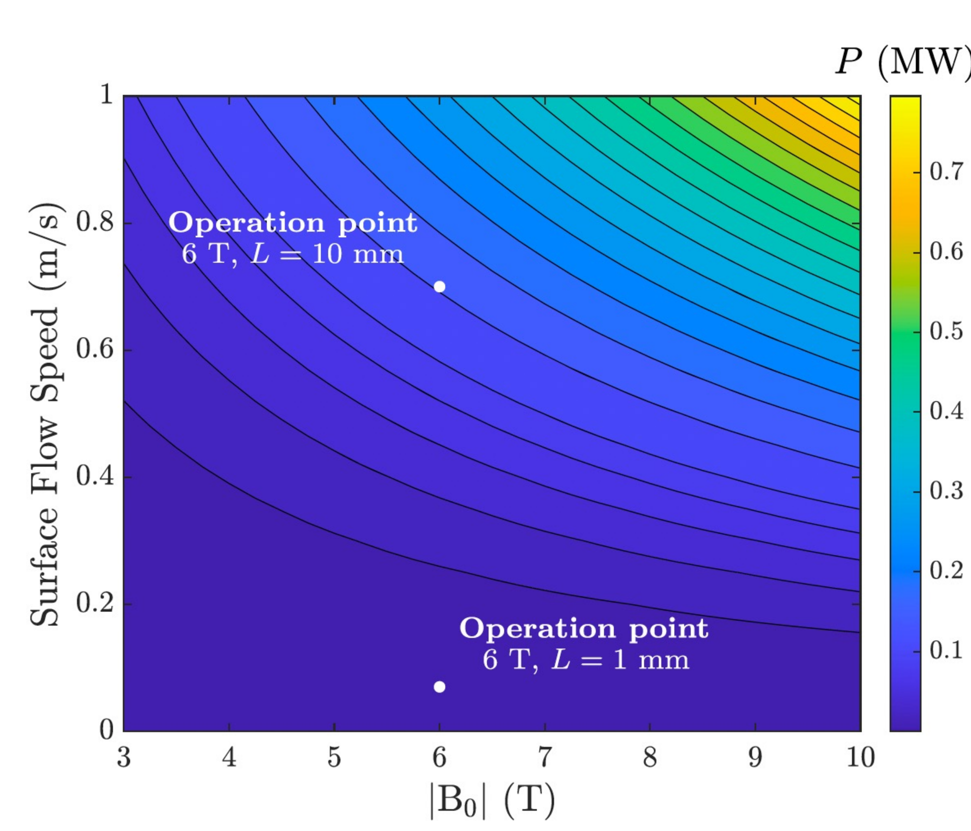

Figure 11. Power requirements at the reactor scale [2].

$$q_{\mathrm{crit}} = \frac{k\Delta T_{\mathrm{crit}}}{2}\sqrt{\frac{\pi|\mathbf{U}|}{\alpha L}}$$

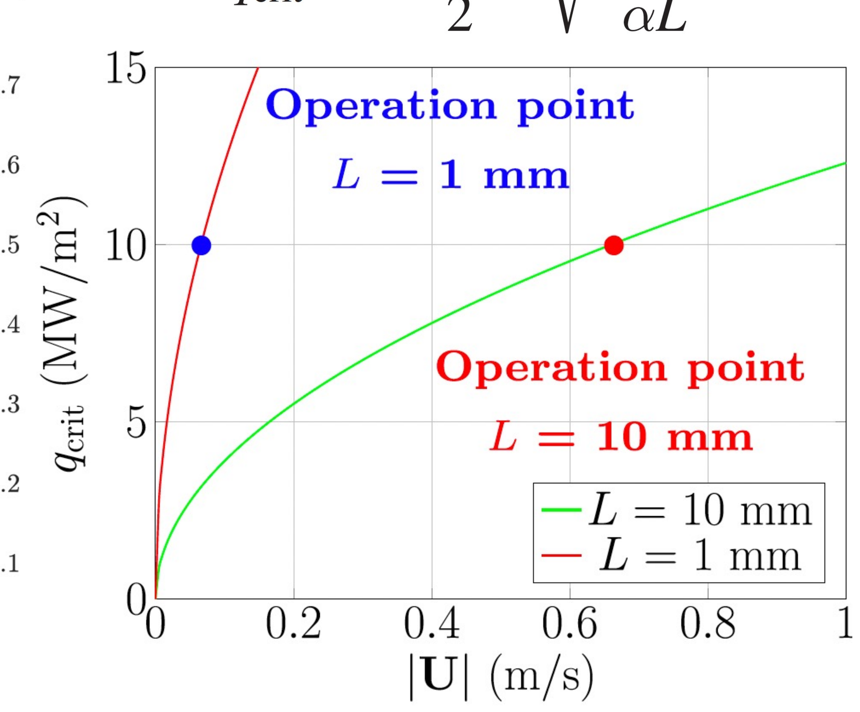

Figure 12. Critical heat flux [2].

Conclusions and future work

- Experiments agreed with simulations and MHD theory at **B** ≤ 0.33 T.
- Projections indicate divertorlets can exhaust heat 10 MW/m².
- Ripples at the free surface must be minimized, *L*-reduction will help to generate flat free surfaces.
- A cooling system must be integrated to divertorlets for a final design, including TEMHD analysis.

Acknowledgements

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References

[1] A. Fisher, et al, "Liquid metal "divertorlets" concept for fusion reactors", Nuclear Materials and Energy, vol. 25, p. 100855, 2020.

[2] Saenz, F et al, E. Divertorlets concept for low-recycling fusion reactor divertor: experimental, analytical and numerical verification. United States: N. p., 2022. Web. doi:10.1088/1741-4326/ac6682.