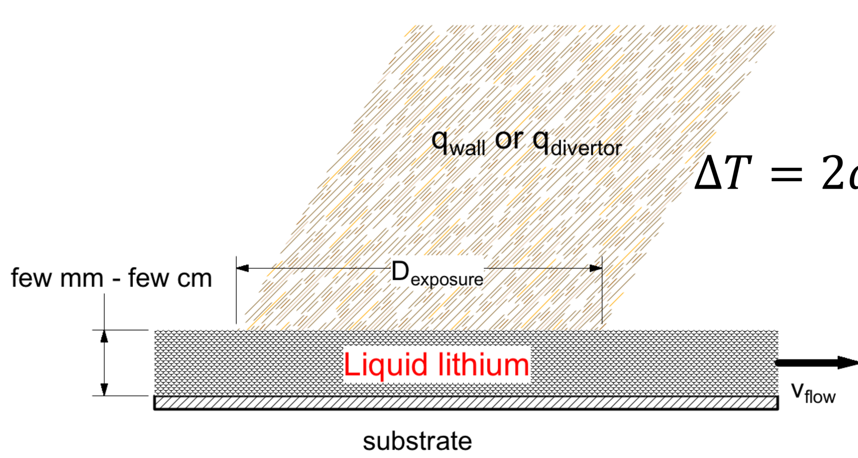
Effects of Externally Applied Lorentz Force on Liquid Metal Flow

Adam Fisher, Egemen Kolemen, Mike Hvasta,
Dick Majeski, Hantao Ji
Department of Mechanical and Aerospace Engineering, Princeton University
Princeton Plasma Physics Laboratory

Motivation

There are many reasons why nuclear fusion has not hit commercial viability yet; one of these reasons is the inability to effectively remove heat from the reactor. Current plasma facing components (PFCs) can't withstand the intense heat and radiation created by a high-power reactor, especially in the divertor region. Fast flowing liquid lithium PFCs have the ability to actively remove this heat as shown in figure 1. As also shown in past work, liquid lithium PFCs improve confinement and enhance plasma performance by reducing particle-recycling.

The results presented here were obtained using a eutectic alloy galinstan (GaInSn) rather than lithium. This is done both for lab safety reasons, and that galinstan is far easier to work with as it is liquid at room temperature.



$$\Delta T = 2q_{wall}\left[\frac{W}{cm^2}\right]\sqrt{\frac{t}{\pi\kappa\rho_m C_p}} = 0.92 q_w \sqrt{\frac{D_{ex}}{v_{flow}}}$$

κ = thermal conductivity, lithium = 85 W /m°C
ρ_m =mass density=0.5 g/cm^3,
C_p= specific heat capacity=3.56 J/g°C

Figure 1. Reactor heat flux on flowing liquid metal surface.

Introduction to Liquid Metal Walls

Lorentz (jxB) force can keep flowing liquid metal attached to the wall of a reactor. This force may be far greater than that of gravity, and may be done using a configuration such as the one shown in figure 2. The Kolemen group is currently focused on how jxB force may be used for a liquid metal divertor; specifically, how jxB force affects flow phenomena.

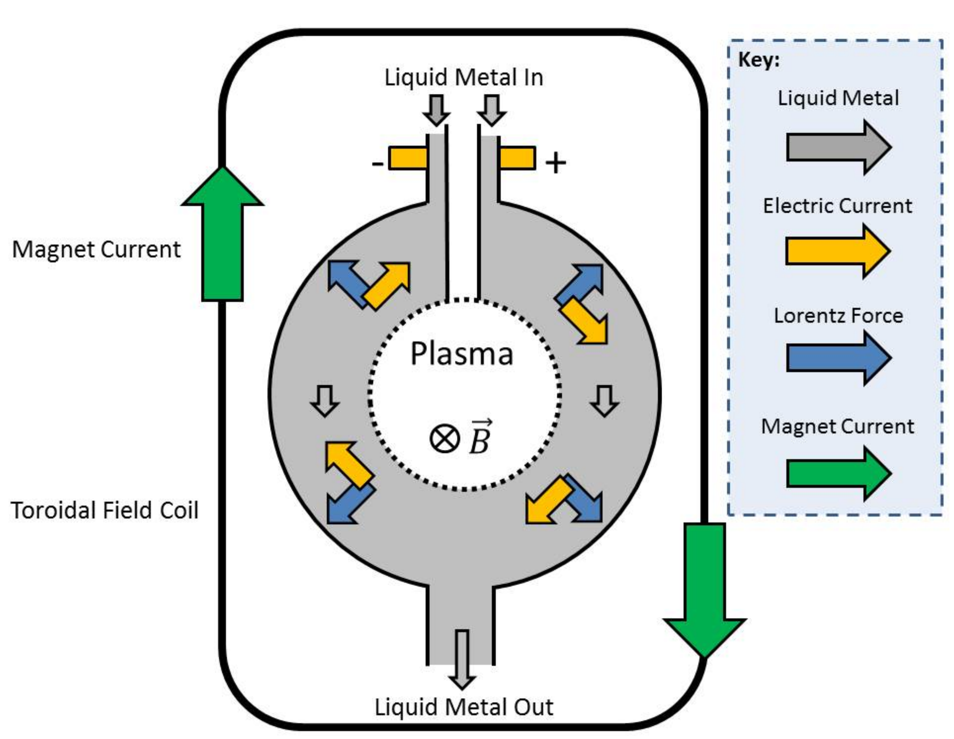


Figure 2. Layout of an electromagnetically confined flowing liquid metal wall within a circular cross-section.

Liquid Metal eXperiment (LMX)

LMX is an open channel flow of galinstan immersed in a magnetic field directed in the horizontal-transverse direction. Using electrodes located at the inlet and outlet of the channel, electric currents may be injected into the system and generate a force due to the interaction of the currents with the magnet field.

Upgrades have been recently installed on LMX. The previously used laser diagnostic shown in figure 8 has been upgraded to slide along half the channel length so that multiple locations in the channel can be observed.

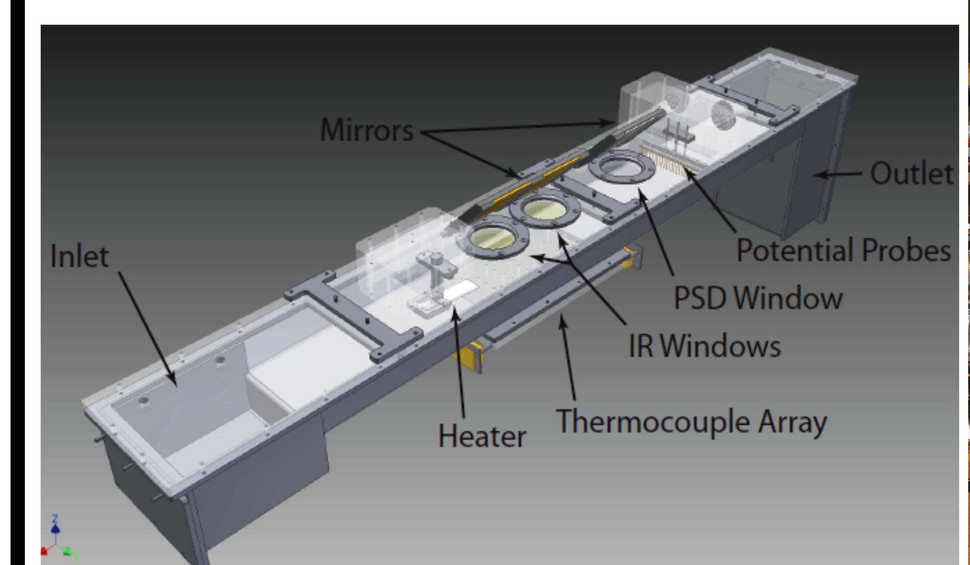


Figure 3. Graphical depiction of the LMX channel.

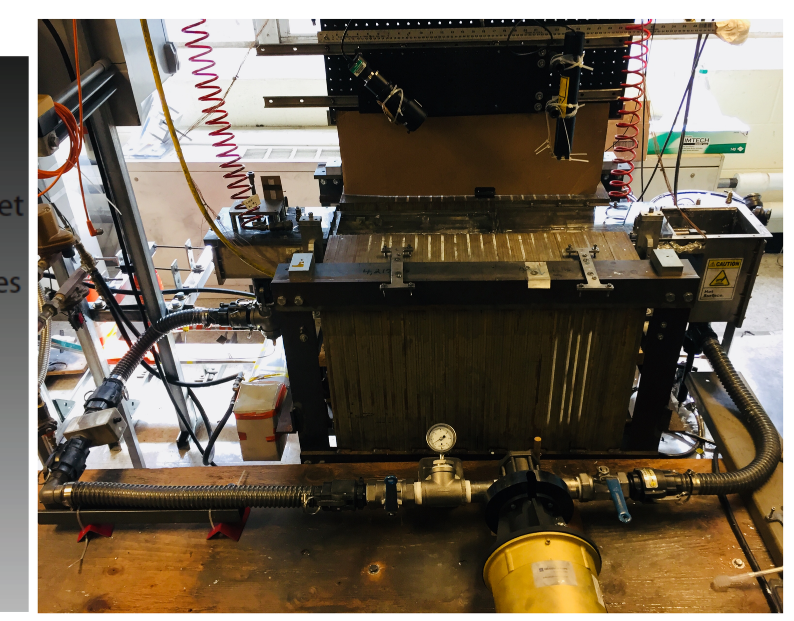


Figure 4. Actual image of LMX Upgrade.

jxB Force Depth Control

Mass and momentum conservation equations including vertical Lorentz force as an added gravity-like term leads to:

$$\rho v_0^2 h_0 + \frac{\rho g h_0^2}{2} = \rho v_1^2 h_1 + \frac{\rho g h_1^2}{2} + \frac{j_y B_x h_1^2}{2} \ , \qquad j_y = \frac{I_y}{w h_1}$$

Depth changes due to jxB force were measured in experiments and showed close agreement to theory across multiple tests. The setup and results are shown in figure 5 and figure 6.

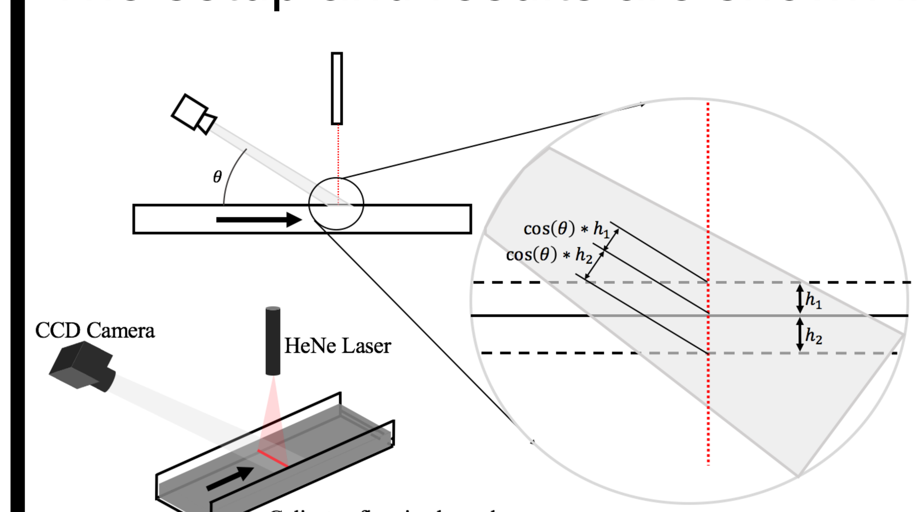


Figure 5. Schematic of the laser sheet diagnostic used to measure the liquid metal height.

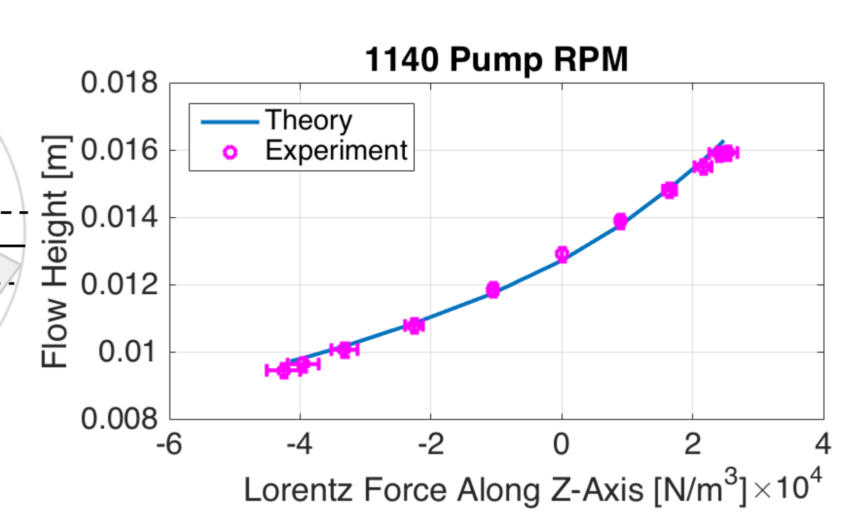


Figure 6. Experimental results versus theoretical predictions.

Hydraulic Jump

Hydraulic jump is a phenomenon where thin, fast-flowing liquid metal transitions into slower, thicker flow. We've shown jxB force effects both the jump position and height change across a hydraulic jump.

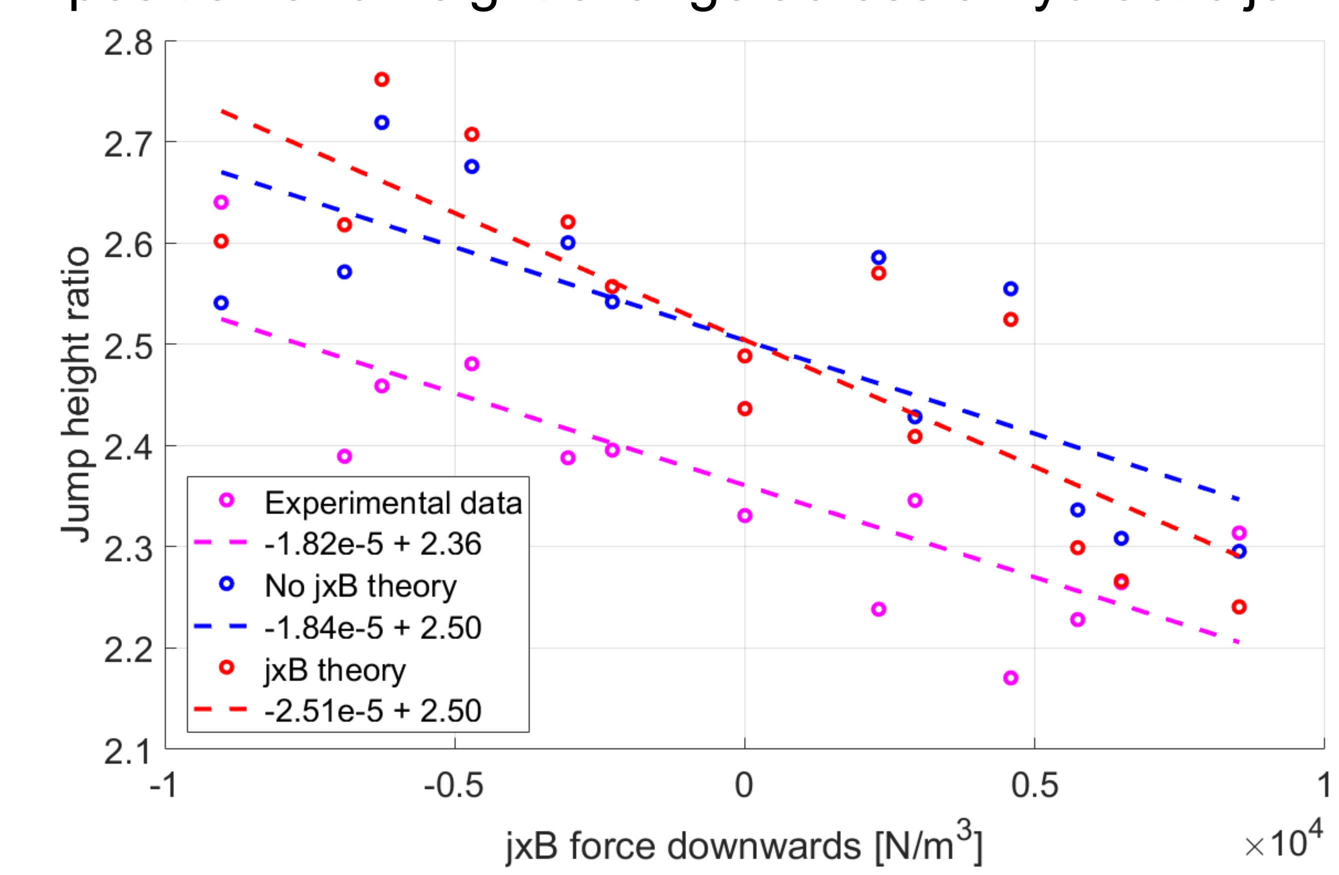


Figure 7. Hydraulic jump height change ratio change with added jxB force

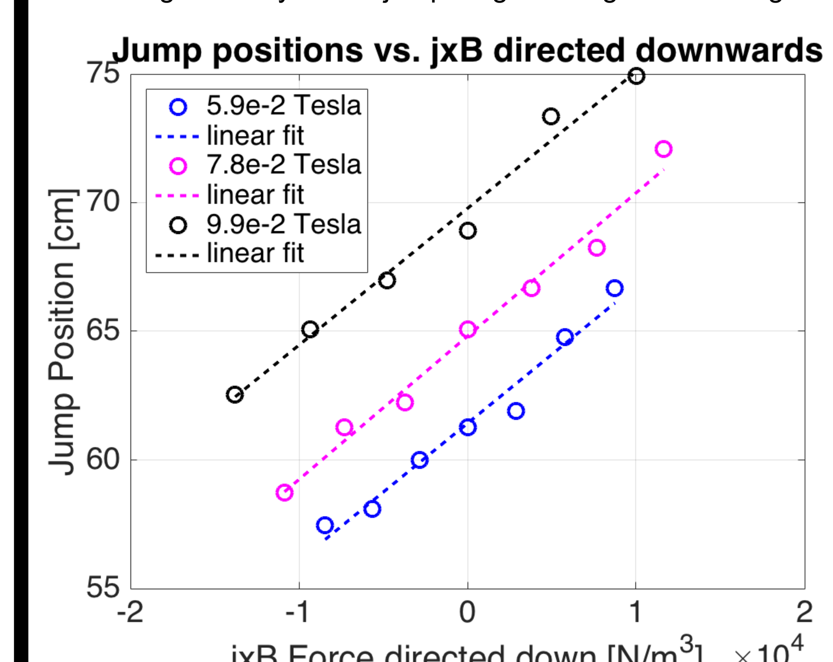


Figure 8. Hydraulic jump position change with added jxB force

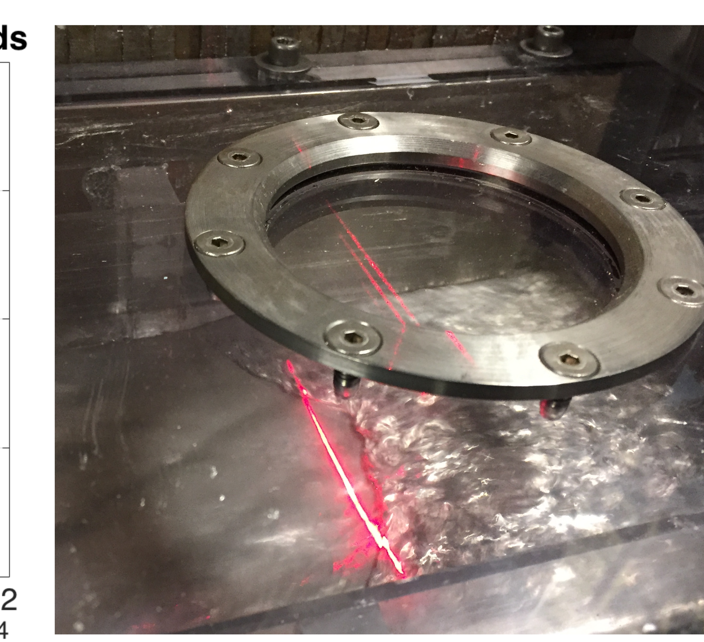


Figure 9. Example of a hydraulic jump and laser sheet diagnostic in use

Future Work

Additional hydraulic jump studies are planned, as the experiment has just recently come online following upgrades. Surface wave work has also been started using current diagnostics, and new methods are in development.

An experiment called FLIT is being designed to study a fully axisymmetric poloidal flow in a 1/r toroidal magnetic field to mimic reactor-like conditions. Work on LMX will add insight to these future experiments.