Blob dynamics in TORPEX null point configurations

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Introduction

Filaments, or blobs, are field aligned plasma structures which have been observed in the scrape of layer of magnetically confined plasmas. These filaments carry particles into the SOL and therefore play a role in determining the profiles during L-mode and inter-ELM H-mode scenarios. While there have been many investigations into the dynamics of such filaments [1, 2], few have concentrated on the explicit behavior near X-points. Magnetic tori such as the TORPEX device [3] replicate tokamak scrape off layer (SOL) scenarios while allowing straightforward diagnostic access. While filaments have been studied extensively experimentally within Torpex [4, 5, 6], no theoretical studies have yet explored the dynamics in X-point configurations [7]. The results presented here are a natural progression from previous studies in linear configurations [8], towards an ultimate aim of full tokamak edge simulations.

The dynamics of propogating filaments depends on the mechanism for charge dissipation within the blob and can be explained by considering the system as a circuit, Figure 1 [2]. If the charge separation caused by diamagnetic drifts is resolved primarily via the parallel current through the sheath, the filament is considered to be sheath-connected. If the connection length to the sheath is too high, or likewise the resistivity too large, charge is dissipated via the polarization current and the blob is considered to enter the inertially limited regime. The dependence of regime characterization can be detected in the perpendicular motion of the filament.

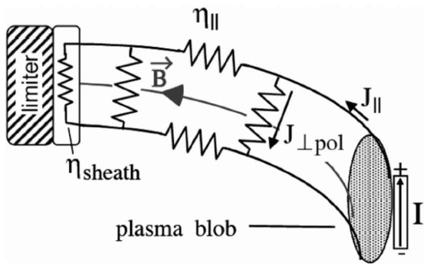

Figure 1: Circuit diagram indicating the mehanisms to resolve charge separation within a blob [2]

Torpex null point scenarios

The aim of this work is to explore blob dynamics in the TORPEX device in X-point geometries [7]. The experimental magnetic geometry to be simulated is shown in Figure 2.

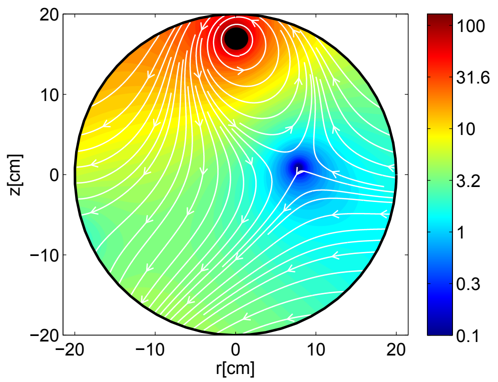

Figure 2: Magnetic geometry of Torpex X-point scenarios [7]

The TORPEX device has a major radius of 1m, minor radius of 20cm, and a toroidal magnetic field at about 75mT [7].

Isothermal Model

An isothermal cold-ion fluid model initially constructed for plasma blob studies [1, 9] has been extended for use in X-point scenarios [8]. The model is electrostatic, and inviscid; while the isothermal electron temperature T_{e0} is 5eV. While this model includes several simplifications, it still captures relevant physics such as Kelvin-Helmholtz, interchange and driftwave turbulence, an important class of instabilities in tokamak edge plasmas [10], as it is a ubiquitous instability. The equations which are solved are given as follows in SI units:

$$\frac{dn}{dt} = 2c_s\rho_s\xi\cdot(\nabla n - n_0\nabla\phi) + \nabla_\parallel\frac{J_\parallel}{e} - n_0\nabla_\parallel u_\parallel \tag{1}$$

$$\rho_s^2 n_0\frac{d\Omega}{dt} = 2c_s\rho_s\xi\cdot\nabla n + \nabla_\parallel\frac{J_\parallel}{e} \tag{2}$$

$$\frac{du_\parallel}{dt} = -\frac{c_s^2}{n_0}\nabla_\parallel n \tag{3}$$

$$J_\parallel = \frac{\sigma_\parallel T_e}{en_0}(\nabla_\parallel n - n_0\nabla_\parallel\phi) \tag{4}$$

Where $\Omega \equiv \nabla_\perp^2\phi$ is vorticity, total derivatives are split via $\frac{d}{dt} = \frac{\partial}{\partial t} + \mathbf{u_E}\cdot\nabla + \mathbf{u}_\parallel\cdot\nabla$, and parallel derivatives are evaluated using $\nabla_\parallel = \mathbf{b}\cdot\nabla$. Curvature effects are included via the polarization vector $\xi \equiv \nabla\times\frac{\mathbf{b}}{B}$. In the above equations, $\rho_s = \frac{c_s}{\Omega_i}$ is the Bohm gyroradius. These equations are normalized such that density (n) is normalized to typical TORPEX values, $n_0 = 5\times10^{16}m^{-3}$, speeds are normalized to the sound speed, and $\phi = \frac{e\Phi}{T_{e0}}$ is the normalized electrostatic plasma potential. Boundary conditions for the vessel walls were set as the presheath boundary conditions for oblique magnetic fields [11]. Finally, the magnetic geometry shown in Figure 2 is implemented by specifying a function for the vector potential, A_{ext}, and modifying the parallel gradient operator such that: $\mathbf{b}\cdot\nabla f = \nabla_\parallel f - \left[\frac{A_{ext}}{B}, f\right]$.

This model differs from that used in reference [1] in that it incorporates parallel ion free streaming, $u_\parallel$, as parallel flows are vital when determining the effects of X-points. Additionally, energy conservation required the restriction that n is considered constant (n_0) in terms where it is not differentiated, which is simply a limit of the imposed Boussinesque approximation which assumes that density fluctuations are small: $\nabla\times\left(n\frac{d\nabla_\perp\phi}{dt}\right) \approx n\frac{d}{dt}\nabla_\perp^2\phi$

Simulation results

Simulations were performed to validate the extension to toroidal geometries of the model described previously and to determine the nature of blob propagation within the TORPEX device.

As mentioned previously, we can determine the blob regime by examining the relative contributions of the given currents in a system. For the baseline TORPEX scenario($T_{e0} = 5eV, n_0 = 5 \times 10^{16} m^{-3}$), we found a peak parallel current density of $J_{||} \sim 15A$ and a peak polarization current density of $J_{pol} \sim 800A$. This indicates that the filaments are inertially limited, as described in Figure 1. Previous studies on TORPEX filaments have also determined that blobs in Hydrogen plasmas to be inertially-limited [6].

To further analyze the filament dynamics, simulations were performed in various electron temperatures, as shown on the left in Figure 3. The center of mass velocity increases with increasing isothermal electron temperature. This result is expected as $E \times B$ velocity is proportional to electron temperature.

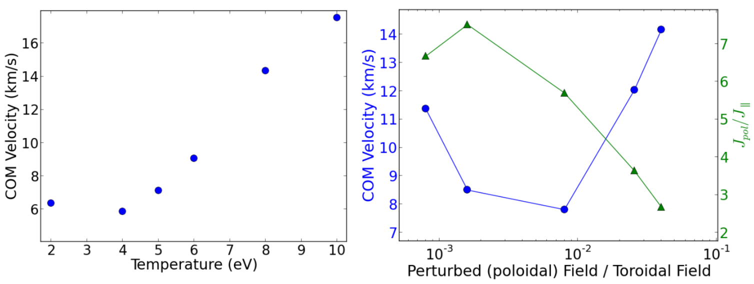

Figure 3: Parameter scans for blob propogation. Left: Center of mass velocity as a function of electron temperature. Right: COM velocity (blue) and Polarization current over parallel current (green) vs poloidal vector potential strength.

In addition, a scan of the poloidal magnetic field strength was conducted, as shown on the right in Figure 3.

The plot on the right in Figure 3 indicates somewhat unexpected results, in that there is a turnover in blob behavior at higher poloidal magnetic field strengths. One possible cause for this behavior is that as the poloidal field is increased, the parallel component of the poloidal blob propagation becomes more prominent, and therefore the blob is able to propagate faster.

Experimental Comparison

To further characterize the model and simulation methods, we have begun preliminary comparison to experimental measurements. Primarily, we have looked at time-averaged potential, as this is a straightforward and reliable

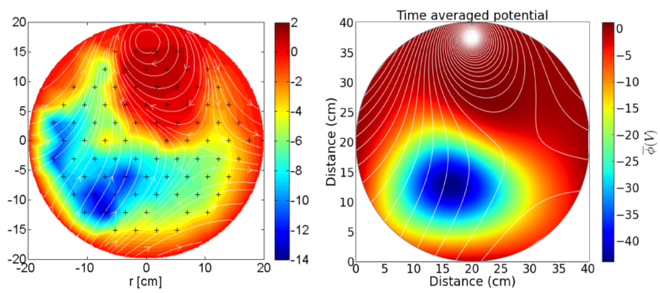

Figure 4: Measured time averaged floating potential from experiment (left), and simulations (right)

measurement within the TORPEX de-
vice. The results of this comparison are shown in Figure 4.

The discrepancy in the scales in Figure 4 are potentially due to the dependence of potential on temperature and density, and that our isothermal temperature assumption of 5eV should be reconsidered. While these are preliminary results, the experimental profiles share qualitative similarities to the results from simulation and merit further investigation.

Conclusions and future work

We have successfully been able to model blob propagation in the TORPEX device. We have characterized the filament propagation regimes and established a promising correspondence with experimental measurements. The characteristics of the system can be explored further by varying the size of the initial seeding and implementing a realistic source within the system. We are also working toward extending our methods to full tokamak edge simulations in order to explore the mechanisms of blob propagation across the separatrix and null regions.

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