Critical Velocity and Vortex Nucleation for Superfluid Flow Past a Finite Obstacle

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When a superfluid flows about a cylindrical obstacle, vortex pairs will be shed by the obstacle when the critical velocity is exceeded. This phenomenon was observed and characterised in a theoretical study using the Gross-Pitaevskii equation by Frisch *et al.* in 1992 [1]. They investigated this behaviour for an infinite obstacle (zero superfluid density inside) and found that vortex pairs would arise at the lateral edges of the obstacle above the critical velocity. More recently, a study by Stockdale *et al*. in 2021 [2] looked at vortex pinning in a superfluid flow about a finite cylindrical obstacle (non-zero superfluid density inside). They found that at some velocity a pair of vortices would nucleate inside the obstacle. Increasing the velocity would cause the vortices to move outwards, and at the critical velocity, the obstacle would shed the vortices.

This study aims to characterise vortex nucleation and subsequent shedding for a finite cylindrical potential obstacle within a superfluid flow in two dimensions. This was done both analytically and numerically, building on the insights of Stockdale *et al.* [2]. We have developed an analytical model for stationary states of the system for a given superfluid velocity using hydrodynamics and the point vortex model, using an analogy to Maxwell's equations of electromagnetism. The model can be used to predict the velocity at which vortices nucleate, as well as the critical velocity.

The analytic results for the emergence of single vortex pairs have been compared to numerical stationary solutions of the Gross-Pitaevskii equation. We have found good agreement for large radius obstacles and larger obstacle heights. This limitation is likely due to the reduced validity of the hydrodynamic approximation and point vortex model for smaller and weaker obstacles.

Numerically, we have found that solutions exist with two and three vortex pairs arising in the obstacle for a given superfluid velocity. We will present a map of the full excitation spectrum of vortex pairs for a particular flow velocity, and extend the analytical model for multi-vortex pair solutions. We will present results for the dynamics and stability of the solutions.

[1] T. Frisch, Y. Pomeau, S. Rica, *Phys. Rev. Lett.* **69**(11), 1644 (1992).

[2] O. R. Stockdale, M. T. Reeves, M. J. Davis, *Phys. Rev. Lett.* **127**(5), 255302 (2021).