Gravitational instability and shear stabilization in a dusty plasma layer

David A. Kessler, Russell B. Dahlburg, and Gurudas Ganguli
Naval Research Laboratory, Washington, DC 20375

We examine the behavior of a diffuse layer of metallic dust particles under the combined influence of gravity and magnetic fields. Such a configuration has recently been proposed as a means of promoting passive removal of orbital space debris by artificially enhancing the drag on the debris, thereby decelerating it and hastening its reentry into the thermosphere. We assume that the metallic dust particles become charged in the earth's ionosphere so that the particles in the layer can be treated collectively as a plasma continuum. Using two- and three-dimensional magnetohydrodynamic simulations, we consider the long-time nonlinear evolution of several such ideal dusty plasma layers. Simulations confirm that the well-known Rayleigh-Taylor instability that arises when a heavy fluid is placed on top of a lighter fluid is present in these systems. We show that a quiescent, uniform layer is unstable to very small perturbations and rapidly breaks up. Layer breakup is complete within 15 minutes after particle deposition, which is much too short a time to provide any meaningful reduction in debris velocity. We consider a possible method for stabilizing the layer by imposing a tailored shear flow, a technique that has shown promise for stabilizing plasmas in magnetic fusion applications. We discuss the long-time evolution of dusty plasma layers subjected to this shearing motion and show how layer stability is affected for a range of flow conditions. We also highlight other practical aspects of layer initialization, orientation, and morphology and discuss how these properties impact layer stability. The results of the full nonlinear numerical simulations are compared to results obtained using a linear theory.