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Investigation of Compressible Electromagnetic Flute Mode Instability in Finite Beta Plasma in Support of Z-pinch and Laboratory Astrophysics Experiments

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Abstract. Flute mode turbulence plays an important role in numerous applications, such as tokamak, Z-pinch, space and astrophysical plasmas. In a low beta plasma flute oscillations are electrostatic and in the nonlinear stage they produce large scale density structures co-mingling with short scale oscillations. Large scale structures are responsible for the enhanced transport across the magnetic field and appearance of short scales leads to ion heating, associated with the ion viscosity. In the present paper nonlinear equations which describe the nonlinear evolution of the flute modes treated as compressible electromagnetic oscillations in a finite beta inhomogeneous plasma with nonuniform magnetic field are derived and solved numerically. For this purpose the 2D numerical code FLUTE was developed. Numerical results show that even in a finite beta plasma flute mode instability can develop along with formation of large scale structures co-existing with short scale perturbations in the nonlinear stage.

AMS subject classifications: 70K75, 82D10, 76F35

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1 Introduction

In the flute or interchange instability the perturbations are uniform parallel to the magnetic field. In cylindrical geometry, the structure resembles a fluted column. In the

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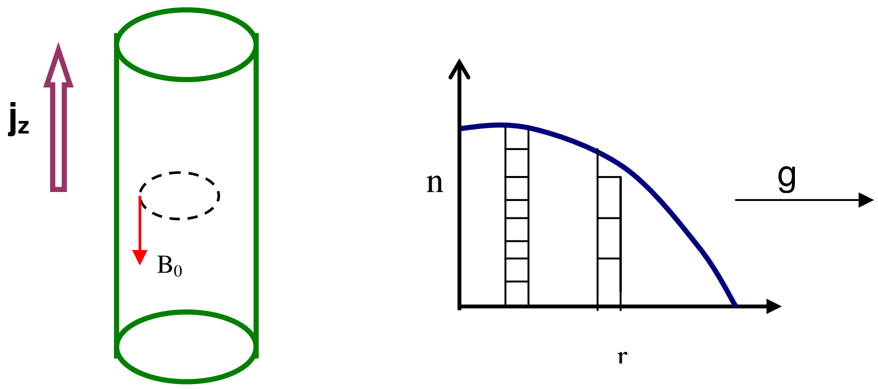

Figure 1: In the left plot the current-carrying plasma in the center of a cylindrical wire array is displayed. In the right plot the radial density dependence inside the plasma cylinder and artificial gravity constant g, associated with the magnetic field lines curvature are presented. A high-density plasma is on top of a low-density plasma in the gravitational field.

current-carrying cylindrical plasma of the precursor (Fig. 1) particles moving along the azimuthal magnetic field lines experience centrifugal acceleration due to the curvature of the magnetic field lines. This acceleration can be explained by introduction of the fictitious gravity force with gravitational constant g, directed outward along the plasma cylinder radius. This configuration creates a situation typical of Rayleigh-Taylor or interchange type instabilities, when a high-density fluid is placed on top of a low-density fluid in a gravitational field. Any perturbation in density at the fluid interface allows gravity to pull the high-density fluid downwards so that the low-density fluid ends up on top. As a result the two fluids interchange places. In plasmas with magnetic fields, both the plasma and the field have pressure and therefore the plasma may interchange position with the magnetic field.

Flute mode turbulence in laboratory and space plasmas can be responsible for formation of large scale structures associated with the anomalous plasma transport across a magnetic field and for appearance of short scales in the turbulent wave spectrum, resulting in enhanced ion heating due to ion viscosity. Analysis of the data obtained during laboratory experiments on imploding wire arrays [1,2] has demonstrated that flute-like perturbations of density appear in the finite beta z-pinch plasma of the precursor. The difference in the electron and ion drifts due to the curvature of magnetic field lines is the source of the flute type instability in the axially current-carrying precursor plasma of cylindrical geometry.

Moreover, density perturbations were observed simultaneously with magnetic field perturbations which were directed along the direction of the ambient magnetic field in the pinch. It was also observed that with time the excited perturbations evolved into large scale structures while the excited wave spectrum migrated into the region of shorter wavelengths.

Laboratory experiments on the interaction of a plasma flow produced by laser ab-