A new plasmon solution with centrifugal pressure

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Abstract

The ‘plasmon’ solution of De Young & Axford describes the interaction between a high-velocity clump and the surrounding medium. Even though this solution is probably too simplistic, it has proven to be most useful in the study of diverse astrophysical flows. In the present paper, we discuss a more detailed solution of the plasmon problem, which includes the centrifugal effects of the environmental material flowing around the plasmon. We derive both numerical and approximate analytic solutions of this problem, and compare them with the analytic solution of De Young & Axford.

Key words: hydrodynamics – shock waves – ISM: general.

1 Introduction

De Young & Axford (1967) derived the well-known analytic ‘plasmon’ solution for the problem of a clump of gas propagating through a uniform environment. This solution is based on the direct consideration of the balance between the ram pressure of the environment and the internal, stratified pressure of the decelerating clump.

There are important questions as to whether this analytic solution actually represents the real flow. Numerical simulations of a gaseous clump streaming past a uniform environment have been carried out many times (see e.g. Nittmann, Falle & Gaskell 1982), and consistently find that the clump tends to break up into smaller fragments. This kind of phenomenon clearly lies outside the simple, analytic description of De Young & Axford (1967, hereafter DA).

Through the years the analytic plasmon solution has played a very important role in attempts to model different kinds of astrophysical flows. For example, the plasmon solution has been used for models of the confinement of radio lobes propagating through the intergalactic medium (Ubachukwu, Okoye & Onuora 1991; Daly 1994), models of radio-loud quasars (Daly 1995) and models of the optical narrow-line regions of Seyfert galaxies (Taylor, Dyson & Axon 1992; Veilleux, Brent & Bland-Hawthorn 1993). The plasmon solution has also been used to compute the trajectory of a cloud ejected from a galactic nuclear region as it interacts with the surrounding medium (Pišmiš & Moreno 1993). On interstellar scales, the cometary shape of some molecular clouds (Odenwald et al. 1992) and also the head–tail morphologies observed in the fine structure of H\(_2\) (galactic) high-velocity clouds (Giovanelli & Haynes 1977) suggest that the mechanism of ram pressure sweeping (plasmon model) can also be applied. This ram pressure confinement model is also relevant in modelling the strings of knots observed in some planetary nebulae which propagate supersonically through the ambient gas, forming a bow shock (Palmer et al. 1996).

Because of the importance of the plasmon model, we have re-analized this problem, and derived a new solution along the same lines as the work of DA, but now including the centrifugal effects of the environmental gas as it streams around the clump.

In the following section (Section 2), we rederive in detail the plasmon solution of DA. The equations for the plasmon including the centrifugal pressure, and a numerical solution of these equations are presented in Section 3. Approximate, analytic solutions to the problem with centrifugal pressure are presented in Section 4.

2 The Plasmon of De Young & Axford

Let us consider a clump of mass \(M\), moving supersonically with a velocity \(v_0\) in the \(x\)-direction through a uniform medium of density \(\rho_0\) (see Fig. 1). The clump feels a deceleration \(a\), and adopts a pressure and density stratification given by the hydrostatic condition:

\[
\frac{dP}{dx} = -\rho a, \tag{1}
\]

which has a solution of the form

\[
P(x) = \rho(x) c^2 = P_0 e^{-x/h}, \tag{2}
\]

where \(P_0\) is the pressure at the tip of the clump and \(h\) is the scaleheight of the pressure distribution, which is given by

\[
h = \frac{c^2}{a}. \tag{3}
\]

DA found the shape of the clump by assuming a balance between the pressure in the clump and the ram pressure of the impinging external medium. This condition can be expressed as

\[
\rho_0 v_0^2 \cos^2 \theta = P(x), \tag{4}
\]