Time-dependent Nonlinear Cosmic Ray Shocks
Confirming Abstract

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1 Introduction

Numerical studies of time dependent cosmic ray shock structures in planar geometry are interesting because analytical time-independent solutions are available which include the non-linear reactions on the plasma flow (1). A feature of these time asymptotic solutions is that for higher Mach numbers ($M \geq 5$) and for a low cosmic ray upstream pressure the solution is not uniquely determined by the usual conservation laws of mass, momentum and energy.

2 Basic physics, initial conditions and method of solution

We start with the time-dependent Euler-equations of hydrodynamics and use an additional equation desribing the cosmic rays in the two-fluid approximation. The mean diffusion coefficient $\bar{\kappa}$ and the adiabatic index γ_C are fixed and we refer for further details to the literature (2,3,4). A shock wave is created by reflection of the flow on a rigid wall ($x = 0$). The gas comes from the left with specified density $\rho = 1$, velocity $u = -1$ and gas and particle pressure P_G and P_C, respectively. A shock wave starts travelling to the right leaving the heated gas at rest behind. The basic parameters characterizing this situation are the diffusion time scale $t_d = \bar{\kappa}/u^2$, the Mach number of the incoming flow $M^2 = \rho u^2/(\gamma_C P_C + \gamma_G P_G)$ and the ratio of the particle pressure to the total pressure in the upstream region, $N = P_C/(P_C+P_G)$, respectively. The system of equations is solved on a fully adaptive grid (5).

3 Results

For low Mach numbers we get weakly modified gas shocks, as expected. The flow in the upstream region is slightly decelerated by the cosmic ray precursor and the main portion of the kinetic energy of the incoming flow is transfered to the gas. In addition to this well known effect one sees a typical time-dependent effect in the downstream region where a particle gradient decreases and the opposite gas gradient pushes the gas towards the shock wave running to the right. The particle gradient occurs because the acceleration process takes some time to increase the particle pressure at the shock; initially the shock is essentially a pure gas shock and only later does the particle pressure become significant. For values $M = 4.4$, $N = 0.5$ and for different times the variables are shown in Figure 1. The transition from a gas dominated shock to a cosmic ray modified shock is clearly shown. Note however that this requires some thirty to forty diffusion time scales.

A shock with higher Mach number $M = 10$ and a lower value of $N = 0.05$ is depicted in Figure 2. The interesting result for this case is again the very long time scale; at $t = 1000$ (in units of the diffusion time scale) the solution still resembles a test particle solution and the particle pressure at the shock is decreasing.

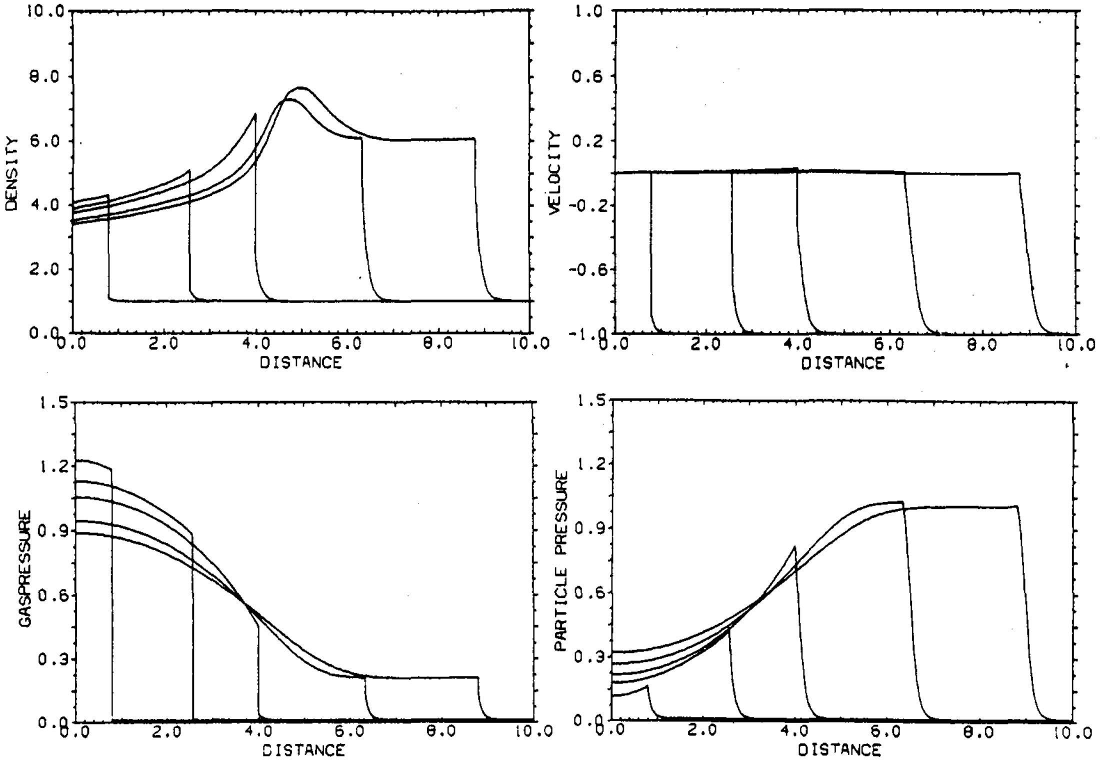

Figure 1:— Evolution of a shock with $M = 4.4$, $N = 0.5$. The curves correspond to times $t = 6, 20, 34, 60, 88$ in units of the diffusion time scale.

Discussion

These numerical solutions clearly indicate that much work needs to be done before we understand shock acceleration as a time dependent process. The slowness of the process is possibly due to the fact that there is a diffusive flux into the downstream region in addition to the usual advective losses. Analytic investigations of this phenomenon are required.

References

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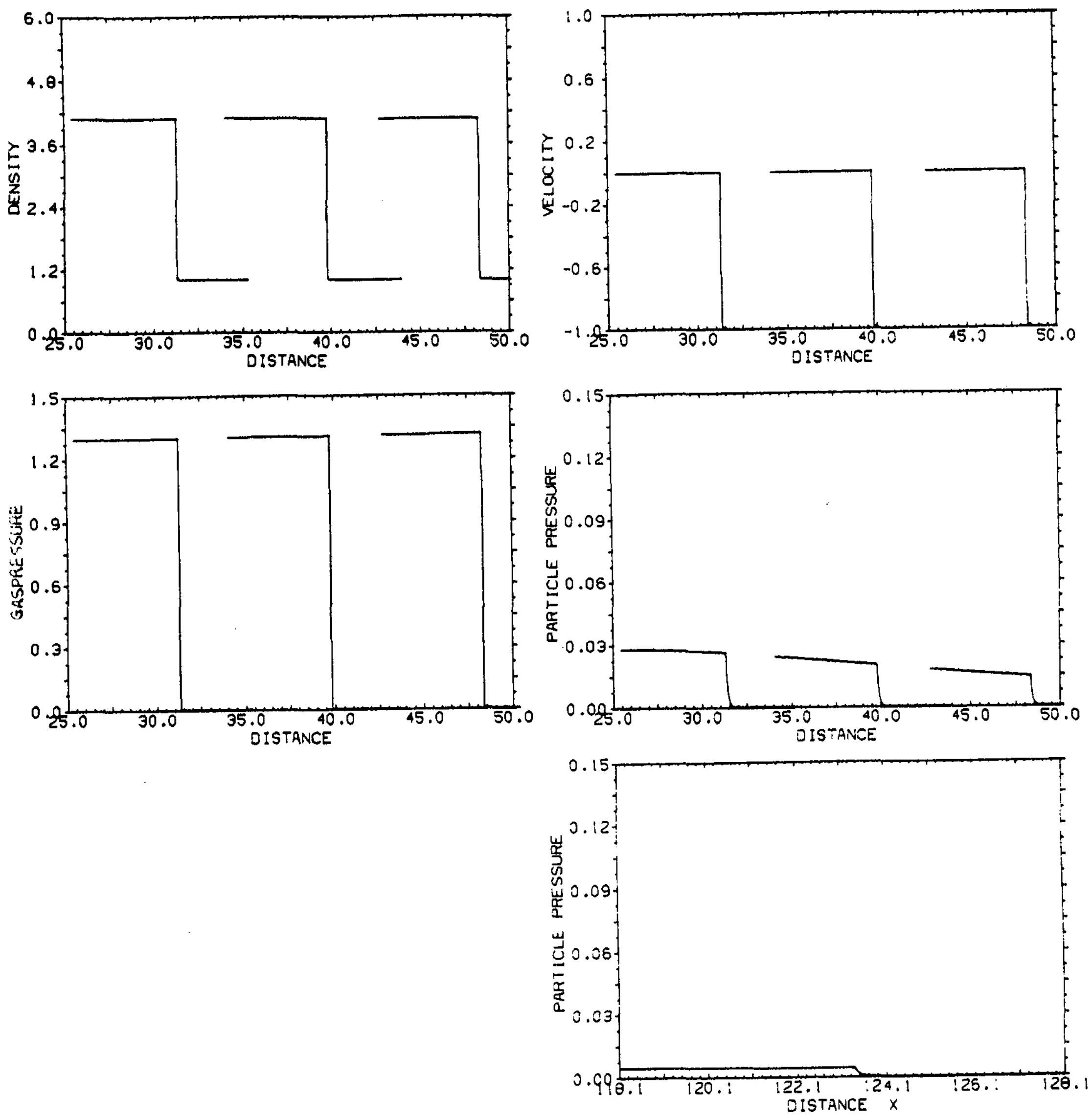

Figure 2:— Evolution of a shock with $M = 10$, $N = 0.05$. The curves correspond to times $t = 440, 560, 660$ in units of the diffusion time scale. The bottom right figure shows the cosmic ray pressure at $t = 1000$.