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A study of variable energy blast waves in magnetogas dynamics

Amit K. Ray*

Department of Mathematics, M.G.P.G. College, Gorakhpur-273001, U P, India

Abstract

In this paper, we have studied the propagation of shock waves in a gaseous medium in presence of magnetic field. The flow fields being spherical, cylindrical or planar, respectively. Salient differences between the instantaneous energy and the variable energy are also presented.

Keywords: Blast Waves, Instantaneous Energy, Variable Energy, Azimuthal Magnetic Field.

INTRODUCTION

The classical blast wave theory refers generally to the propagation of shock waves in a gaseous medium due to an instantaneous energy input in an infinitesimally small region of that medium. The energy input can be in a point, along a line or in a plane with the resultant wave and attendant flow fields being spherical, cylindrical or planar, respectively. With appropriate assumptions, the pertinent conservation equations have been shown to be amenable to similarity solutions [1-2] resulting in functional relationships between time, energy input, wave distance and original gas density.

It has been indicated by Sakurai [3] that the instantaneous constant energy blast wave is a special case of a class of variable energy blast waves in which the energy input varies proportionally to some power of time. Another special case of this class in which the energy is assumed to vary linearly with time has been explored in great detail by Freeman [4] It is the purpose of this investigation to show the salient differences between the instantaneous to show the salient differences between the instantaneous energy and the variable energy blast waves and to indicate some possible applications of the latter. Since the effect of magnetic field on blast waves are also presented in this paper hence we have used a new notation for pressure which is called effective pressure i.e. $p^* = p + H^2/2$ where p is fluid pressure and $H^2/2$ is magnetic pressure.

NUMERICAL DISCUSSION

We take a relation between E_α, W_α and t^β given by Freeman [4] is

$$E_\alpha = W_\alpha t^\beta \tag{1}$$

then the energy equation is written by

$$\frac{E_\alpha / p_0^*}{R^{\alpha+L}} = \frac{J_0}{y} \tag{2}$$

where

$$J = \int_0^1 \left(\frac{\gamma}{2} h f^2 + \frac{g^*}{\gamma - 1} \right) x^n \, dx \tag{3}$$

Where E_α = energy input/unit area (α= 0)

$= \frac{1}{2\pi}$ – energy input/unit length (α= 1)

$= \frac{1}{4\pi}$ – energy input (α= 2)

W_α is proportionality constant, p_0^* is effective pressure in undisturbed medium, R is shock distance, $x = r/R$, $y = a_0^2/U^2$ a_0 is speed of sound in undisturbed medium, U is shock velocity, r is ratio of specific heats, f is non dimensional velocity g^* is no dimensional effective pressure, h is non dimensional density, α = 0 (planar), 1 (cylindrical), 2 (spherical), β is time exponent.
then the shock radium R can be expressed as

$$R = K t^n \tag{4}$$

where

$$K = \left(\frac{W_\alpha a_0^2}{p_0^* n^2 J_0} \right)^{1/(\alpha+3)} \tag{5}$$

and $$n = \frac{(2+\beta)}{(\alpha+3)} \tag{6}$$

The counter pressure term has been neglected in equation (2). Equation (3) can be numerically evaluated in a straight forward manner from the conservation equations and the appropriate "strong wave" boundary conditions. The value of J_0 thus obtained gives the zero-order solution for the wave propagation through equation (4-6). For the instantaneous energy blast wave, $\beta = 0$ in equation (1) and the corresponding values of J_0 can be found in the literature [3] for $\alpha = 1$ and 2 and several values of the specific heats ratio, γ. Freeman [4] calculated J_0 for $\alpha = 1$ and $\beta = 0, 1$ for different values of γ. In this paper, J_0 is numerically evaluated, after solving for the flow field inside the wave, using the fourth order Runge-Kutta technique for $\alpha = 0, 1, 2$ and $\gamma = 1.4$, varying β from 0 to 5. The results are

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*Corresponding Author
Amit K. Ray
Department of Mathematics, M.G.P.G. College, Gorakhpur-273001, U P,India

Tel: +91-7398578198; Fax:
Email: amit_ray786@yahoo.com

shown in Figure 1 indicating that for $\beta > 1$, J_0 remains practically constant.

It should be pointed out that the cases for $\beta \neq 0$ correspond to the "piston problem" and it has been found in our flow field solutions, in agreement with Freeman, that the gas inside the wave in confined in a thin shell close the wave.

It is of interest to compare the instantaneous energy case with that of the variable energy when the total energy in both cases are exactly the same. For the variable energy case, if the input time is t_i, then from equation (1)

$$W_\alpha = \frac{E_\alpha}{t_i^\beta} \tag{7}$$

combining equations (4-7), then using the scale radius

$$R_0 = \left(\frac{E_\alpha}{p_0^*}\right)^{1/(\alpha+1)} \tag{8}$$

we obtain

$$\frac{R}{R_0} = \left[\left(\frac{\alpha+3}{\beta+2}\right)^2 / J_0\right]^{1/(\alpha+3)} \left(\frac{t\,a_0}{R_0}\right)^{2/(\alpha+3)} \left(\frac{t}{t_i}\right)^{\beta/(\alpha+3)} \tag{9}$$

If $\beta = 0$ the equation (9) reduces to the zero-order classical solution. For $\beta \neq 0$, equation (9) is valid for $t < t_i$. The locus of solutions for R at $t = t_i$ will have the same variation with time as the classical case. It should be noted that the coefficient will be different due to differences in J_0 and to the fact that $\beta \neq 0$. For illustration purposes, figure 2 shows the classical case for $\alpha = 2$ and the locus of R at $t = t_i$ and $\beta = 1$ which is just below the classical case. On the same figure, equation (9) is plotted for three values of t_i, namely, $a_0 t_i/R_0 = 0.5$, 1 and 2 and again $\beta = 1$. Thus, as expected, at a given time and longer the input time the smaller would be the wave radius. As β increases the constant t_i curves will be more widely separated and as β decreases the locus curve will approach the classical curve and so would the constant t_i curves as well.

APPLICATIONS OF BLAST WAVES :

Here first we specifically look at the experimental work of Hall [5] in which he focused a Q-switched ruby laser on a tantalum target to induce spherical blast wave in Argon. Although the duration of the laser is reported to be 20 nsec, it is possible that the time for the transfer of energy to the gas from the target may have been say of the order of $1\ \mu$ sec. Most of the Hall's measurements have been at times lower that $1\ \mu$ sec and we make the assumption that this is the order of the magnitude of t_i. Hall grouped his result on the basis of the following relations. From equation (9), for $t < t_i$, the following can be obtained when $\alpha = 2$.

$$R(\rho_0/E)^{1/5} \propto t^{(\beta+2)/5} \tag{10}$$

and for a given R

$$t \propto (\rho_0/E)^{1/(\beta+2)} \tag{11}$$

Also the arrival times of the shock at two different fixed radii are related by

$$t_2/t_1 = (R_2/R_1)^{5/(\beta+2)} \tag{12}$$

Hall reports that for data plotted according to relation (10) the time exponent is 0.42 which leads to $\beta = 0.1$. Using this value of β we obtain a value of the exponent of (ρ_0/E) in relation (11) to be 0.476 where as Hall obtains 0.48 for a corresponding value. Finally for the exponent of R_2/R_1 we obtain 2.38 which is exactly the same value obtained experimentally by Hall. Considering this class agreement, it would appear that indeed the energy to the gas from the target can be considered to vary with time, and that the variable energy blast wave theory can be useful in analyzing similar experimental results.

The motivation for Freeman's work [4] was the analysis of spark discharge [6]. Indeed it appears that the data of Freeman and Craggs [6] show values of the wave radius at early times to be smaller than what the instantaneous energy blast wave theory would predict which seems to be qualitatively in the proper direction as Figure 2 indicates.

Two other applications can be cited. In two phase detonations [7], experimental evidence shows that blast waves are part of the mechanism involved. In as much as the energy release responsible for the blast wave is time dependent due to the chemical nature of the problem, it appears that variable energy analysis would be fruitful in this regard. In a preliminary investigation [8], the author shown that such an analysis is useful. Srivastava, Roesner and Leutloff [9] gave detail discussion on reflection of blast wave in magnetogasdynamic. Finally detailed analysis of the so-called "explosive reative center" [10] could very well be simplified to obtain the magnitude of the induced effective pressure wave by consideration of the variable energy blast wave. How ever it is recongnized that because the pressure wave in weak, better than zero-order solutions would be necessary.

RESULTS

The salient features of a time variable energy blast wave as compared to the instantaneous energy blast wave have been presented and also we have checked the effect of magnetic field on variable energy blast waves. The results have been applied to a set of data on laser induced blast waves, and other applications have been suggested.

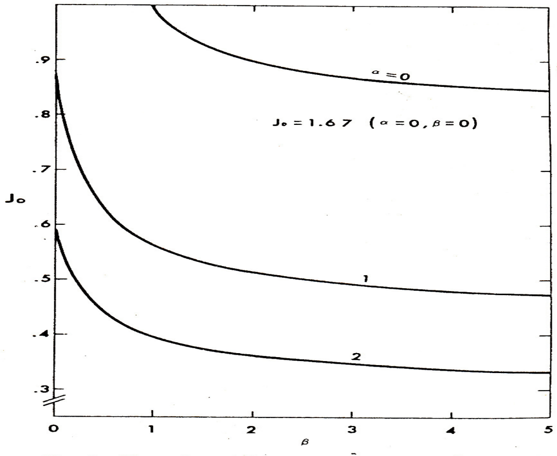

Fig. 1 The value of J_0 as a function of β, $^{R}\gamma = 1.4$).

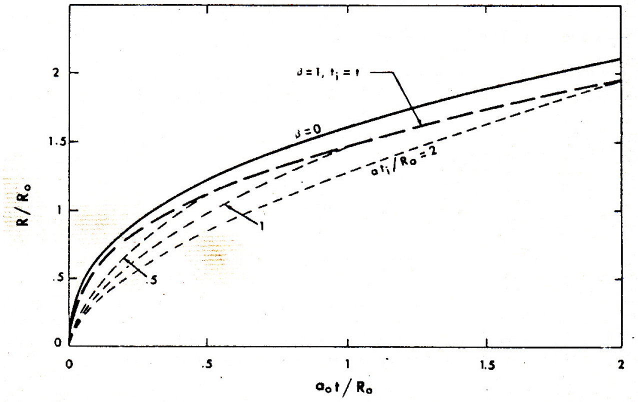

Fig. 2 The variation of the spherical blast wave radius with time.

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