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The motion of weak cylindrical shock wave in a highly viscous medium

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ABSTRACT

The interaction of shock waves with viscosity is one of the central problems in the supersonic regime of compressible fluid flow. The motion of weak shock wave in highly viscous medium has been investigated by Chester-Chisnell- Whitham method. It is found that the shock velocity and shock strength both decreases as shock advances for low viscous region of a medium to the high viscous region. The dependence of mach number on propagation distance, Pressure, Particle velocity and shock velocity as well as on adiabatic index has also been analyzed for the cases. In the last comparison between the results obtained here are made mutually as well as with those obtained by other methods. The obtained expansions are computed and discussed through tables and graphs.

Keywords*- Shock Wave, CCW Method And Viscosity*

1. INTRODUCTION

Shock waves are rather common phenomena in the supersonic flows of any fluid. They arise in many areas that are related with hydrodynamics such as fluid mechanics, aerodynamics, astrophysics, solar physics, and space physics. If a medium is shocked, particles behind the shock front experience both compressive and shear forces. They push the particles away from their original equilibrium positions.

Shock waves arise in a wide range of physical phenomena such as gas dynamics, nuclear explosions, shallow water flows, supernovae, stellar winds, traffic flows, quantum fluids, and many others. The theory of shock waves has a rich history beginning with the fundamental contributions by Riemann in the mid of the 19th century. In fact, all natural fluids admit some compressibility and therefore support shock waves. Shock waves can only develop in a medium which behaves like a fluid. Shock waves may be produced in fluids such as sea water by a variety of natural and artificial mechanisms. The flow parameters such as pressure, density, temperature, particle velocity and entropy change very rapidly in the thin transition layer, through which the gas passes from its initial state of thermodynamic equilibrium into its final, also equilibrium state. Here, the thermodynamic equilibrium inside this region is called the shock front and it can be substantially disturbed. Therefore, in studying the internal structure of a shock front it is necessary to consider the dissipative processes due to viscosity (internal friction) and thermal conduction. The study of the internal structure of shock front has its importance for many reasons. At first this problem attracted attention as purely a theoretical one, the solution of which describes the physical mechanism of shock compression, as a truly remarkable phenomenon in gas dynamics and also in understanding the various processes which take place in gases at high temperatures, as for example, vibrational excitation in molecules, molecular dissociation, chemical reactions, ionization, and radiation. Obviously, the theoretical consideration of the structure of shock front permits one to deduce from the experimental data a good deal of valuable information about the rates of these processes. Shock waves are studied by many authors.**Vishwakarma et al. (2007)** self-similar adiabatic flow headed by a magnetogasdynamic cylindrical shock wave in a rotating non-ideal gas. **Vishwakarma and Nath (2008)** have discussed the. propagation of shock waves in an exponential medium with heat conduction and radiation heat flux. **G. Nath, (2010)** propagation of a strong cylindrical shock wave in a rotational axisymmetric dusty gas with exponentially varying density. **K. Zumbrun (2010)** The existence and effects of the viscous forces for the similarity solutions to shock wave problems were studied. **G. Nath (2011)** Magnetogasdynamic shock wave generated by a moving piston in a rotational axisymmetric isothermal flow of perfect gas with variable density. **Ramu et al. (2016)** have studied numerical study of shock waves in non-idea magnetogasdynamics. **Ramu et al. (2016)** Similarity solution of spherical shock waves - effect of viscosity.

The aim of the present part is to study the propagation of weak cylindrical shock waves propagating in a uniform medium. When shock moves freely. The shock strength, shock velocity, pressure and particle velocity both decreases as cylindrical shock. The effect of overtaking disturbances is to inhance the values. The results obtained here are compared with those **(Anand Raj and H.C.Yadav 2011)**.

Basic Equations:

The general equations of exploding shock waves in presence of uniform viscous medium

$$\frac{\eth u}{\eth t} + u\frac{\eth u}{\eth r} + \frac{1}{\rho}\frac{\eth P}{\eth r} - -\frac{4}{3}\mu\frac{\eth u}{\eth r} = 0$$

$$\frac{\eth \rho}{\eth t} + u\frac{\eth \rho}{\eth r} + \rho\frac{\eth \rho}{\eth t} + \frac{\alpha\rho u}{r} = 0$$

$$\frac{\eth P}{\eth t} + u\frac{\eth P}{\eth r} - a^2\left[\frac{\eth r}{\eth t} + u\frac{\eth \rho}{\eth r}\right] = 0$$

$$\frac{\eth P}{\eth t} + u\frac{\eth P}{\eth r} + a^2\rho\left[\frac{\eth r}{\eth t} + \frac{\alpha u}{r}\right] = 0$$

where,u(r,t), P(r,t) and ρ (r,t) denote particle velocity, pressure, density at a distance r from the origin at time t , γ is the adiabatic index of gas , μ is the coefficient of viscosity and $\alpha = 1$ for cylindrical waves.

Boundary Conditions:

Let P_0 and ρ_0 denotes the unperturbed values of pressure and density in front-

$$P = a_0{}^2\rho_0\left[\frac{2M^2}{(\gamma+1)} - \frac{(\gamma-1)}{(\gamma+1)}\right]$$

$$\rho = \rho_0\left[\frac{(\gamma+1)M^2}{(\gamma-1)M^2+2}\right].$$

$$U = \frac{2a_0}{(\gamma+1)}\left[M - \frac{1}{M}\right]$$

$$a = a_0\sqrt{\frac{[2\gamma M^2-(\gamma-1)][(\gamma-1)M^2+2]}{(\gamma+1)}}$$

where, $M = \frac{U}{a_0}$ is Mach number, U is the shock velocity, a and a_0 are the sound velocity in disturbed and undisturbed medium respectively.

Weak Shock Waves:

For weak shock waves i.e. ($U \ll a_0$) the boundary conditions, $M = 1+\varepsilon$ reduce to-

$$P = \frac{\gamma P_0}{(\gamma+1)}\left[\frac{(\gamma+1)}{\gamma} + 4\varepsilon\right]$$

$$\rho = \rho_0\left[1 + \frac{4\varepsilon}{(\gamma+1)}\right]$$

$$U = a_0[1+\varepsilon]$$

$$u = \frac{4a_0\varepsilon}{(\gamma+1)}$$

Characteristic Equation for Freely Propagation of Shock Waves:

The characteristic equation for exploding shock is given as-

$$dP + \rho a\, du + \frac{\alpha\rho\, a^2 u}{r}\frac{dr}{(u+a)} - \frac{4}{3}\frac{\mu\rho a\, du}{(u+a)} = 0$$

Solving, this equation-

$$\varepsilon = k\, r^{-\frac{\alpha}{\left[2-\frac{4\mu}{3a_0}\right]}}$$

The expression for shock velocity may be written as-

$$U = a_0 \left[1 + k\, r^{-\frac{\alpha}{\left[2 - \frac{4}{3}\frac{\mu}{a_0}\right]}} \right] \qquad (1)$$

The expression for shock strength may be written as-

$$M = \frac{U}{a_0} = \left[1 + k\, r^{-\frac{\alpha}{\left[2 - \frac{4}{3}\frac{\mu}{a_0}\right]}} \right] \qquad (2)$$

2. RESULTS AND DISCUSSION

Weak Cylindrical Shock Waves:

Expression (1) and (2) represents the shock strength and shock velocity for the freely propagation of weak shock, in uniform medium. Shock strength is a function of propagation distance r, adiabatic index γ and viscosity coefficient μ.

Table1:Variation of variable with propagation distance for strong cylindrical shock waves
$(\gamma = 1.4, \mu = 0.000172, \alpha = 1\ and \rho = 1.29)$

r	U	M	P	u
10.0	1.9789	1.9489	1.7300	1.6541
10.2	1.9694	1.9395	1.7246	1.6378
10.4	1.9602	1.9304	1.7195	1.6219
10.6	1.9512	1.9216	1.7144	1.6066
10.8	1.9425	1.9130	1.7095	1.5917
11.0	1.9341	1.9047	1.7048	1.5771

Table2:Variation of variable with adiabatic index for weak cylindrical shock waves
$(r = 2, \mu = 0.000172, \alpha = 1\ and \rho = 1.29)$

γ	U	M	P	u
1.33	1.9788	1.948911	1.7300	1.6541
1.40	2.0303	1.948912	1.7868	1.6957
1.66	2.2041	1.948913	1.9955	1.7718
1.69	2.2698	1.948914	2.0211	1.8537
1.75	1.51423	1.948915S	2.0811	1.9924

Table3:Variation of variable with viscosity coefficient for weak cylindrical shock waves

$(r = 2, \gamma = 1.4, \mu = 0.000172, \alpha = 1\ and \rho = 1.29)$

μ	U	M	P	u
0.0000172	1.9789	1.9489	1.7301	1.6541
0.0001720	1.9587	1.9283	1.7199	1.6329
0.0017200	1.9377	1.9177	1.6993	1.6127
0.0172000	1.8963	1.8765	1.6729	1.5326
0.1720000	1.8475	1.8196	1.9562	1.4287

3. CONCLUSIONS

It is concluded that shock strength, shock velocity, pressure and particle velocity decrease with propagation distance and viscosity coefficient. These parameter increases with adiabatic index. But similar results are found for strong shock propagating in non-uniform medium.

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BIOGRAPHY

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