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The Motion of Strong Plane Shock Wave in Highly Viscous Medium

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Abstract

Neglecting the effect of overtaking disturbances, the motion of strong plane shock wave in highly viscous medium has been investigated by Chester-Chisnell- Whitham method. The analytical expressions for shock strength 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 and Particle velocity as well as on adiabatic index has also been analyzed for the cases. The results obtained here are also compared Yadav *et al.*[2] for a freely propagating shock. The obtained expansions are computed and discussed through table.

Key words : shock wave, CCW method and viscosity

Inroduction

Many interesting phenomena that occur in oblique shock wave reflection have been discovered in the past. The main feature herein is the existence of two possible configurations of shocks, regular and irregular. Regular reflection consists of an incident shock wave and a reflected shock wave with supersonic flow behind the reflected shock. Irregular reflection, which is in most cases called Mach reflection after E. Mach who first discovered this phenomenon, is a complex shock wave pattern that combines incident and reflected shock waves and a Mach stem. A contact discontinuity (slip surface) emanates from the triple point due to inequality of entropy in the flow passing through the incident and reflected shocks and the flow passing through the Mach stem. Classical theoretical methods such as shock polar analysis and the three-shock theory based on the Rankine–Hugoniot jump conditions across the oblique shocks were developed by von Neumann to describe the shock wave configurations at various flow parameters and to predict transitions between different types of shock wave interaction. These theoretical methods were mainly developed for pseudo-steady flow, i.e. for diffraction of a plane incident shock on a rigid ramp of an infinite span. Later, the theoretical models were applied to the interaction of standing incident shock waves generated by symmetrical wedges in a steady supersonic flow.

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.

Shock waves are studied by many authors. Vishwakarma *et al.*[1] self-similar adiabatic flow headed by a magnetogasdynamic cylindrical shock wave in a rotating non-ideal gas. Yadav *et al.*[2] the motion of strong shock wave in highly viscous medium. Yadav *et al.*[3] effect of overtaking disturbences on converging strong spherical shock waves in a rotating dusty gas. G. Nath,[4] propagation of a strong cylindrical shock wave in a rotational axisymmetric dusty gas with exponentially varying density. K. Zumbrun[5] The existence and effects of the viscous forces for the similarity solutions to shock wave problems were studied. G. Nath[6] Magnetogasdynamic shock wave generated by a moving piston in a rotational axisymmetric isothermal flow of perfect gas with variable density. Kumar Arvind *et al.*[7] the variation of strength of earthquake in sea water. Ramu *et al.*[8] Similarity solution of spherical shock waves - effect of viscosity. Kumar Arvind *et al.*[9] the motion of weak spherical shock wave in highly viscous medium.

The aim of the present part is to study the propagation of strong plane shock waves propagating in a uniform medium. When shock moves freely. The shock strength, pressure and particle velocity both decreases as plane shock. The effect of overtaking disturbances is to inhance the values.

Basic Equations :

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

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

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

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

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

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 $\alpha = 0$ for plane shock waves.

Boundary Conditions :

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

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

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

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

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

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.

Strong Shock Waves :

For strong shock waves *i.e.* $(U \gg a)$ the boundary conditions are reduce-

$$P = \frac{2\,\rho_0\,U^2}{(\gamma+1)}$$

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

$$u = \frac{2\,U}{(\gamma+1)}$$

$$S = \sqrt{\frac{2\,\gamma}{(\gamma-1)}}$$

Characteristic Equation for Freely Propagation of Shock Waves :

The characteristic equation for exploding shock is given as-

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

Now using boundary conditions and solving the characteristic equation-

$$\frac{dU}{U} + \frac{S^2\,(\gamma-1)\,\alpha}{[2+S\,(\gamma-1]\left[2+S-\frac{4\,\mu\,S\,(\gamma-1)}{3\,[2+S\,(\gamma-1]}\right]}\frac{d\,r}{r} = 0$$

The expression for shock velocity may be written as-

$$U = k\,r^{-2\,\gamma\,\alpha/[2+S\,(\gamma-1)\,]\,[(2+S)-4\,\mu\,S\,(\gamma-1)/3[2+S\,(\gamma-1\,)\,]\,]} \quad (1)$$

The expression for shock strength may be written as-

$$M = \frac{U}{a_0} = \frac{\rho_0}{\gamma P_0}\;k\,r^{-2\,\gamma\,\alpha/[2+S\,(\gamma-1)\,]\,[(2+S)-4\,\mu\,S\,(\gamma-1)/3[2+S\,(\gamma-1\,)\,]\,]} \quad (2)$$

Results :

Strong Plane Shock Waves :

Expression (1) and (2) represents the shock velocity (U) and shock strength (M) for the freely propagation of strong shock, in uniform medium. Shock strength is a function of propagation distance r, adiabatic index γ and viscosity coefficient μ. It is concluded that shock strength (M), pressure (P) and particle velocity (u) decrease with adiabatic index and shock velocity (U) is constant for adiabatic index. The results obtained here are compared with those Yadav *et al.*[3].

Table 1. Variation of variable with adiabatic index for strong plane shock waves

$(r = 2, \mu = 0.000172, \alpha = 0\ and \rho = 1.29)$

Adiabatic index (γ)	Shock velocity (U)	Shock strength (M)	Pressure (P)	Particle velocity (u)
1.33	13.6905	13.483	207.351	11.6868
1.40	13.6905	13.142	201.252	11.3426
1.66	13.6905	12.105	182.073	10.2619
1.69	13.6905	11.997	180.009	10.1458
1.75	13.6905	11.757	175.365	9.88463
1.80	13.6905	11.589	172.188	9.70609

Discussion

The shock strength (M) varies from 13.483 to 11.589. Then shock strength decreases with adiabatic index. Pressure (P) varies from 207.351 to 172.188 with the variation of adiabatic index 1.33 to 1.80. Particle velocity (u) varies from 11.6868 to 9.70609 with adiabatic index 1.33 to 1.88. These parameter decreases as plane shock advances in uniform medium. But shock velocity (U) is constant for adiabatic index (γ). Strong plane shock wave passes through the propagation distance and viscosity coefficients are constant. These tables are constant variable for shock strength, shock velocity, pressure and particle velocity.

Conclusions

It is concluded that shock strength, pressure and particle velocity decrease with adiabatic index and shock velocity is constant for adiabatic index. But similar results are found for strong shock propagating in non-ideal gas Vishwakarma *et al.*[1]. The present study provides results useful for future studies including dissipative shocks. These types of shock waves arise frequently in the cases where the velocity of fluid is greater than the local sound speed; they find an application in gas dynamics, fluid mechanics, aerodynamics, astrophysics, solar physics, and space physics, for both magnetised and unmagnetised fluid motions. It is planned to use the present algorithm and its results to be applied to solar coronal shock waves.

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