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Imploding Shock Waves on Explosive Driven Cylinder

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Abstract: ***In present paper, we consider a cylindrical shell, whose thickness is very small as compared to its radius. An explosion (Pentaerythritoltetranitrate PETN) occur on the outer surface of the cylindrical shell. As we initiate the material; the initiation energy is negligible as compared to the chemical energy of the explosion, the shock is formed. The velocity of the imploding shock and detonation wave increases as they come closer to the axis of the shell, but they never reach the axis. Operator splitting technique has been used to analyse the flow. Imploding shock can produce ultra high temperature, pressure and density. Such rare conditions can be used to synthesize the material e g. from graphite to diamond.***

Keywords: Shock Wave, Explosive, Cylinder, Pentaerythritoltetranitrate, PETN

1. Introduction

First we talk about imploding shock, the shock that converges towards an axis is called imploding shock. Imploding shock problem have been studied in fluid dynamics, applied physics and engineering. Guderly [1] solved such problem, in which the Inaillarity solution was presented and self amplifying character of wave was suggested. Experimental demonstration of such shock wave was given by Perry and Kantrowitz [2]. Dennen and Wilson (3) produced shock waves in air by electrically exploding thin metallic film on the inner surface of glass cylinder. The trajectories of the shockwaves were compared to the similiarity solution. Lee (41. Glass [5], Saito and Glass (6) and Matsuo et al [7] have done works in this field. In fluid dynamics, implosion problems have been used to test the numerical methods e.g. random choice method Lee [8] and Matsuo (9] have taken the practical side of such problem. The initial propagation of shocks generated by an instantaneous energy deposition at the cylindrical surface was analysed by using perturbation technique. Matsuo (10) gave the global solution, the solution which describes the whole history of the fluid motion, i.e. from initial stage to focusing stage, of such problem using the method of integral relation. The behaviour of the problem was compared in detail with the similarity solution. It was shown that the shock trajectory approaches quickly the similiarity solution but the spatial distribution of flow properties approaches it very slowly and never reaches the self similiar implosion limits. Saito and Glass [6] adopted the random choice method to analyse the explosive driven hemispherical imploding shock. The imploding shock is assumed to propagate through the combustion product, the motion is prescribed by similiarity solution. The estimated temperature was compared with spectroscopically measured temperature. Van Dyke and Guttman [11] solved the spherical and cylindrical problem using series expansion in powers of time. Matsuo (12] simulated strong mploding shocks travelling through atmospheric air.

From the application point of view, imploding shock and detonation waves can be used to produce ultra high temperature, pressure and density. The most important application is expected in synthesizing the material, e.g. diamond from graphite. Srivastava and Srivastava (13) have studied on spherical imploding shock. In the present work the flow induced by the generation and propagation of a cylindrical imploding shock is numerically simulated. The shock is generated by detonating cylindrical shells. The problem is closely associated with the explosion chamber developed by Matsuo for producing an extreme condition of ultra high pressure and temperature (35000 K). Operator splitting method has been used to simulate the problem.

2. Formulation of Problem

We consider a cylindrical explosive shell of thickness '*d*' and radius 'R_0' we assume that the thickness '*d*' of the shell is sufficiently small as compared to the radius '*R*'. The field inside the shell is air. The shell explosions are initiated and initiation energy is negligible as compared to the chemical energy of the explosive. The explosive is Pentaerythritoltetranitrate PETN) in this problem. After the shell explosion, a cylindrical shock wave propagate towards the axis of the shell and finally converges there. We do not take into account the multiple interaction and propogation through the air. Therefore the detonation front form a given boundary with known flow properties. The conservation laws may be written as follows.

$$\frac{\partial U}{\partial t}+\frac{\partial F}{\partial r}+H=0 \quad , \qquad (1)$$

where

$$U=\begin{pmatrix}\rho\\ \rho v\\ E\end{pmatrix}, F=\begin{pmatrix}\rho v\\ \rho v^2+p\\ u(E+p)\end{pmatrix} and\ H=\begin{pmatrix}\dfrac{\rho v}{r}\\ \dfrac{\rho v^2}{r}\\ \dfrac{v(E+p)}{r}\end{pmatrix}$$

Where '*t*' and '*r*' are independent variables, that represent time and space coordinates respectively and , *v*, *p* and *E* are density, particle velocity, pressure and total energy per unit volume. Equation (1) has been applied to air and combustion gas. Both the gases, air and combustion gas are assumed to be inviscid and non-conducting, Assuming polytropic gas, E is given by

$$E = \frac{1}{2}\rho u^2 + \frac{p}{\gamma - 1}$$

Where γ is the ratio of specific heats.

The boundary conditions on the front are

$\rho = \rho_{CJ},\ u = u_{CJ},\ p = p_{CJ}$

Where ρ_{CJ} ,u_{CJ} and p_{CJ} are density, particle velocity and pressure at Chapman Jouquet detonation front.

These constants values are known when the explosive is specified. Another boundary condition is imposed on the outer surface of explosive, i.e.

$u = 0$ at $r = R$.

Now, we define the non-dimensional quantities as follows

$$r^1 = \frac{r}{R_0}, t^1 = \frac{C_0 t}{\sqrt{\gamma_0} R_0}, p^1 = \frac{p}{p_0}, \rho^1 = \frac{\rho}{\rho_0}, T^1 = \frac{T}{T_0}$$

and

$$e = \frac{R_0 - R_S}{R_0}$$

where T is the temperature, γ_0, ρ_0, p_0 and C_0 are respectively the ratio of spec heats, density, pressure, velocity of sound and temperature in undisturbed idane R the coordinate of the shock front.

3. Numerical Calculation

Let Δr and Δt be the increments in the variables r and t where $\Delta r = R_0/N.N$ being the number of mesh which is contained inside the cylindrical shell $r = R_0$. The operator spliting technique applied to the problem is as follows

$$\frac{\overset{*}{U}j - \overset{n}{U}j}{\Delta t} = -F_r\left(U_j^n\right) \tag{2}$$

and

$$\frac{U_j^{n+1} - \overset{n}{U}j}{\Delta t} = -W\left(U_j^*\right) \tag{3}$$

Where the subscript r denote the partial differentation with respect to space coordinater ‘r’ and

$$U_n^{n+1} = U(j\,\Delta\,r,\ n\,\Delta\,t) \tag{4}$$

From (2) we can say that U* is a solution of the plane flow problem, the increment may be given as Courent – Friedrichs – Lewy condition as

$$\Delta t \leq \frac{\Delta r}{|u| + c} \tag{5}$$

where$c$ is the velocity of sound.

The condition of symmetry is used for the boundary condition at the rigid wall r - R_0 i.e.

$$\rho_{N-\frac{1}{2}} = \rho_{N+\frac{1}{2}},\quad U_{N-\frac{1}{2}} = U_{N+\frac{1}{2}},\quad p_{N-\frac{1}{2}} = p_{N+\frac{1}{2}} \tag{6}$$

Whare N indicates the mesh point on the wall, for the present problem the number of meshes N is taken 1000. The explosive Pentaerythritoltetranitrate (PETN) has been taken for calculation. The characteristic values are

$\rho_{CJ} = 1.34 \times 10^3$ kg / m^3,

$u_{CJ} = 1.0 \times 10^3$ m / sec

$P_{CJ} = 7.68 \times 10^9$ pa,

$u_{CJ} = 5.55 \times 10^3$ m /sec

γ = 2.98 and

e = 5.65 *MJ / kg.*

where u_{CJ} is the Chapman - Jouget wave velocity and e is the specific chemical energy of PETN. Here y which is larger than the maximum value that perfect gas can take i.e. 5/3 . It implies that the combustion gas of PETN is not a real prefect gas. The ratio of specific heats of air, (γ_0) is assumed to be 1.4

4. Result

As the shock approaches the axis more closely, the distribution of flow properties would become steeper and steeper in a very small region just behind the shock front. At a later stage of implosion, the shock wave is accelerated by self amplifying effect as a result of decreasing frontal area. Spatial distribution of flow properties are shown in Figures 1 and 2.

The flow induced by the generation and propagation of cylindrical imploding shock is numerically analysed. The shocks are supposed to be generated by detonating explosive shell. The distribution of flow variables are shown. The rate of implosion is faster in case of cylindrical shock wave.

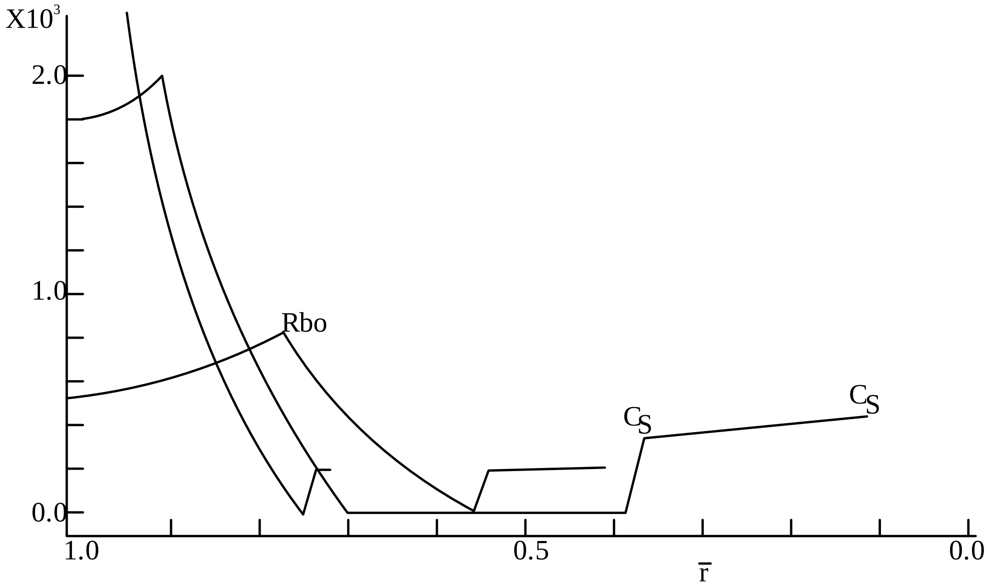

Figure 1: The spatial distribution of density for the outer surface initiation at various time steps = 0.3, 0.6 and 0.9; d/R0 = 0.1

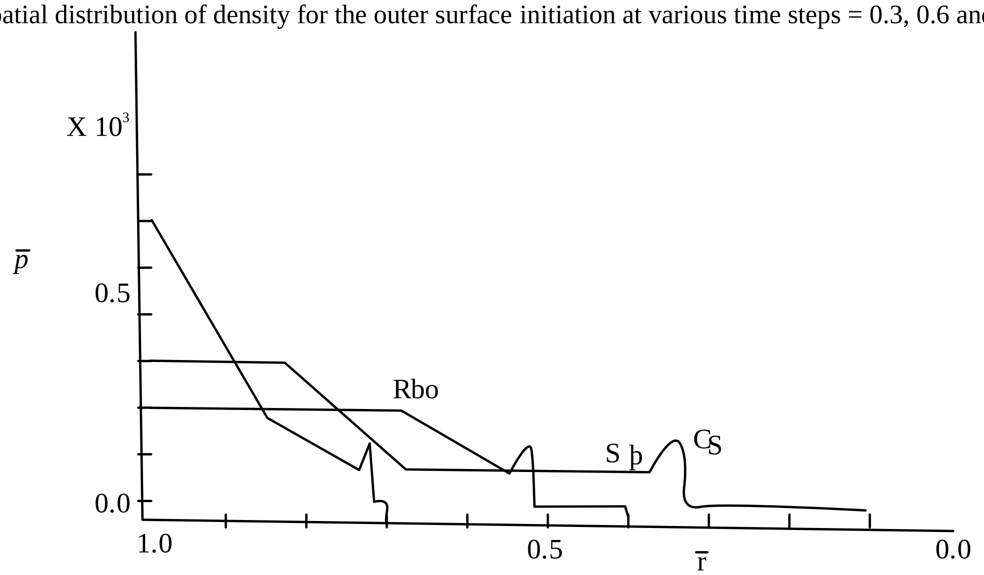

Figure 2: The spatial distribution of pressure for the outer surace initiation at various time steps = 0.3, 0.6 and 0.9; d/R0 = 0.1

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