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EUROPEAN ATOMIC ENERGY COMMUNITY — EURATOM

COMPUTATION OF THE COMPRESSION OF A MAGNETIC FIELD BY MEANS OF A LINER DRIVEN BY AN EXPLOSION

by

L. GUERRI, P. STELLA and A. TARONI

1967

Joint Nuclear Research Center
Ispra Establishment - Italy

Scientific Data Processing Center — CETIS

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Summary

This report describes the numerical solution of the following problem. A cylindrical liner, surrounded by an explosive ring, bounds a magnetic field. This field exerts a pressure on the internal wall of the liner, while the diffusion of the field on the interior of the liner is neglected. A detonation front, started on the external side of the explosive ring, reaches the liner and pushes it concentrically towards the axis. First the propagation of the detonation front and the state of the gas behind it is computed. Afterwards the interaction liner-gas is treated. The computation is carried out under the hypothesis of axial symmetry.

Contents

1. Introduction

We consider the following problem:

Given a cylindrical liner surrounded by a ring of explosive. The internal wall of the liner is subject to a pressure:

$$p = \frac{B_0^2}{8\pi}\left[\left(\frac{X_\ell(0)}{X_\ell(t)}\right)^4 - 1\right]$$

X_ℓ being the internal radius of the liner. This pressure is due to a magnetic field bounded by the liner. It is assumed that the diffusion of the magnetic field in the liner is negligible. At a given instant a detonation is initiated on the external wall of the explosive. The detonation wave reaches the liner and compresses it. The liner moves concentrically towards the axis. The pressure on the internal wall of the liner increases first slowly and afterwards very rapidly so that the liner is strongly decelerated. Because the pressure in the interior of the liner has very high values, the liner is treated as an ordinary hydrodynamic medium.

The problem can be considered also with slab symmetry. The pressure on the wall is then:

$$p = \frac{B_0^2}{8\pi}\left[\left(\frac{X_\ell(0)}{X_\ell(t)}\right)^2 - 1\right]$$

A detailed description and analysis of this problem is carried out in (7) of bibliography. The aim of this report is the description of the method used to solve numerically the problem.

This problem has been studied on behalf of the Euratom Group on Fusion (Frascati, Roma).

2. The two phases of the problem

We can distinguish two phases in the problem:

a) The detonation propagates in the explosive and at a certain instant t reaches the external wall of the liner.

(*) Manuscript received on January 24, 1967.

b) For $t > \bar{t}$ a shock wave propagates in the liner and in the detonation gas. The liner moves towards the center and the shock wave in the liner reflects successively between the liner's walls.

The propagation of a detonation wave in an homogeneous medium at rest has been studied by Taylor, Zeldovich, Stanyukovich and other authors. In the slab case the Chapman-Jouguet hypothesis holds, as a consequence of which the front velocity is constant, the value of u, p, ρ on the front is constant and the flow behind the front is defined by a simple rarefaction wave centered in the origin of the detonation (Taylor's wave).

In the cylindrical or spherical case Zeldovich has shown that the Chapman-Jouguet hypothesis holds good only at the beginning of the detonation and the pressure on the front increases as the front approaches the axis or respectively the center.

To treat numerically the detonation in the cylindrical or spherical case, the solution is approximated for a short time with the corresponding slab solution. The solution is then continued by means of a implicit finite difference scheme.

The instant when the detonation wave reaches the liner is taken as the initial time of the second phase of the problem. In this phase two hydrodynamic media with given initial states are in contact. This phase is followed by means of an explicit lagrangean scheme.

3. Detonation phase

We have the usual symbols:

t	time	
h	lagrangean coordinate	
X	eulerian "	
x	" "	at initial time
u	velocity	

ρ density
p pressure
e specific internal energy
c sound speed
S entropy

$u_o, \rho_o, p_o, \ldots$ (uniform) velocity, density, pressure... of the unreacted explosive

$u_1, \rho_1, p_1, \ldots$ values of $u, \rho, p, \ldots$ of the gas (reacted explosive) on the detonation front.

D detonation front velocity. $D < 0$ since the detonation is convergent.

$$u_o = 0$$
$$p_o = 0$$

p_o is set equal to zero, because it is negligible compared to p_1.

The relation between X and h is :

$$\frac{h^{\nu+1}}{\nu+1} = \frac{1}{\rho_o} \int_{X(0,t)}^{X(h,t)} \rho(\xi,t)\,\xi^{\nu}\,d\xi + \frac{x_i^{\nu+1}}{\nu+1} \qquad (3.1)$$

$\nu = 0,1,2$ according to whether we consider slab, cylindrical or spherical geometry.

x_i and x_e are respectively the internal and external radius of the ring of explosive.

From (3.1) it follows that :

$$h = x = X(h, 0)$$

With regard to the state equation of the detonation gas it is usually assumed that p is dependent only on ρ and not on S:

$$p = p(\rho)$$

This is equivalent to the hypothesis that the internal energy is separable:

$$e(\rho, S) = e^{(1)}(\rho) + e^{(2)}(S)$$

The usual assumption is:

$$p = A\rho^{\gamma} \qquad (3.2)$$

A, γ constants and $\gamma = 3$.
The flow equations in lagrangean form are:

$$\left.\begin{aligned}
&\frac{1}{\rho} = \frac{1}{\rho_o}\left(\frac{X}{h}\right)^{\nu} X_h \\
&X_t = u \\
&u_t = -\frac{1}{\rho_o}\left(\frac{X}{h}\right)^{\nu} p_h \\
&e_t = \frac{p}{\rho^2}\rho_t \\
&p = p(\rho)
\end{aligned}\right\} \qquad (3.3)$$

As a consequence of the hypothesis that the energy is separable the first three equations do not depend on the fourth. We have then the system:

$$\left.\begin{aligned}
&\frac{1}{\rho} = \frac{1}{\rho_o}\left(\frac{X}{h}\right)^{\nu} X_h \\
&X_t = u \\
&u_t = -\frac{1}{\rho_o}\left(\frac{X}{h}\right)^{\nu} c^2 \rho_h \\
&p = p(\rho)
\end{aligned}\right\} \qquad (3.4)$$

i.d. we can determine the flow with regard to X, u, ρ, p independently from the energy equation. This equation can be taken into account if we are interested in the energy distribution.
System (3.4) may be put into the equivalent form:

$$\left.\begin{aligned} \frac{1}{\rho} &= \frac{1}{\rho_o}\left(\frac{X}{h}\right)^{\nu} X_h \\ X_{tt} &= K\left(\frac{X}{h}\right)^{\nu}\left[\left(\frac{X}{h}\right)^{\nu} X_h\right]_h \end{aligned}\right\} \qquad (3.5)$$

with:

$$\left.\begin{aligned} u &= X_t \\ p &= p(\rho) \\ K &= c^2\rho^2/\rho_o^2 \end{aligned}\right\} \qquad (3.6)$$

In particular, if $p = A\rho^{\gamma}$
then: $K = \gamma p\rho/\rho_o^2$

System (3.5) must be solved in the region:

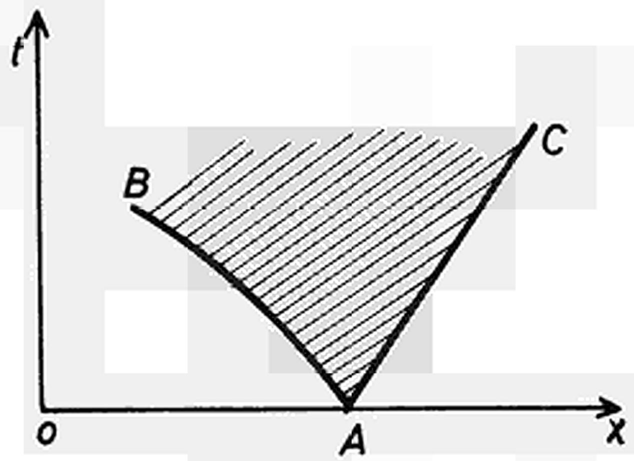

Fig. 1

A origin of the detonation
AB front trajectory
AC free trajectory of last particle

In AC we have the condition:

$$p = 0$$

This condition can be substituted with the equivalent condition:

$$u = \text{constant}$$

In fact, from : $p = 0$ on AC

it follows $c = 0$ on AC

and from : $u_t = -\frac{1}{\rho_o}\left(\frac{X}{h}\right)^{\nu} c^2 \rho_h$

it follows $u_t = 0$ i.d. $u = \text{constant}$ on AC

Hence the particle trajectory AC is a straight line. In lagrangean coordinates the region in which the flow must be determined is :

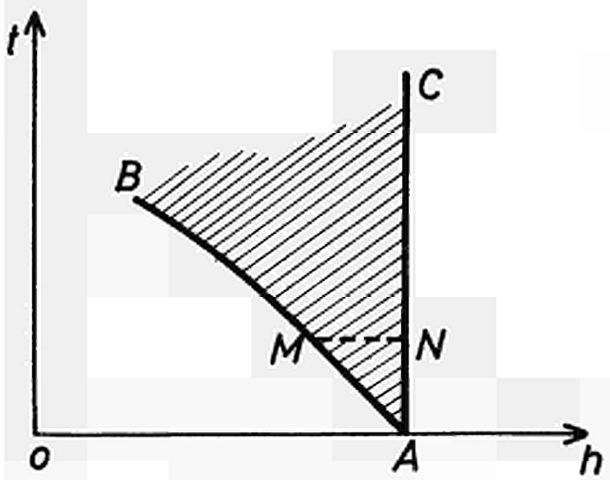

Fig. 2

In the region AMN the cylindrical or spherical solution is approximated with the slab solution. In the region BMNC the solution is computed by means of an implicite finite difference scheme. The initial data on MN are those provided by the slab approximation.

4. Taylor's wave

In the slab case the flow of the detonation gas is isentropic. For this reason on the front we need only to consider the Rankine-Hugoniot relations for the conservation of mass and momentum:

$$\rho_o D = \rho_1 (D-u_1) \tag{4.1}$$

$$\rho_o D^2 = p_1 + \rho_1 (D-u_1)^2 \tag{4.2}$$

For a backward-facing detonation front the Chapman-Jouguet condition is:

$$u_1 - c_1 = D \tag{4.3}$$

and the front speed D is constant. The state equation of the detonation gas is:

$$p = A\rho^{\gamma} \qquad \gamma = 3 \tag{4.4}$$

Hence :

$$c^2 = \gamma p/\rho \tag{4.5}$$

From (4.2) and (4.3) it follows:

$$\rho_o D^2 = p_1 + \rho_1 c_1^2$$

From this relation and from (4.5) it follows:

$$p_1 = \frac{\rho_o D^2}{\gamma+1} \tag{4.6}$$

From (4.1) and (4.2) it follows:

$$\rho_o D^2 = p_1 + \rho_o D(D-u_1)$$

i.d. $\qquad p_1 = \rho_o D u_1$

From this relation and from (4.6) it follows:

$$u_1 = \frac{D}{\gamma+1} \tag{4.7}$$

From (4.3) and (4.7):

$$c_1 = \frac{-\gamma D}{\gamma+1} \tag{4.8}$$

From (4.1) and (4.7) :

$$\rho_1 = \frac{\gamma+1}{\gamma} \rho_o \tag{4.9}$$

and substituting (4.6) and (4.9) into:

$$p_1/\rho_1^\gamma = A$$

we obtain:

$$A = \frac{D^2}{\gamma+1} \left(\frac{\gamma}{\gamma+1}\right)^\gamma \rho_o^{1-\gamma} \tag{4.10}$$

In the slab case the flow behind the detonation front is defined by a simple rarefaction wave centered in the origin of the detonation (Taylor's wave). This wave is defined by the equations:

$$X - x_e = (u-c)t \tag{4.11}$$

$$u - \frac{2c}{\gamma+1} = u_1 - \frac{2c_1}{\gamma-1} \tag{4.12}$$

The first equation is the equation of the C^- characteristics issuing from the origin of the detonation.

The second equation means that the Riemann invariant R_- is constant in the region behind the front.

The Taylor's wave is a complete wave since $p = 0$ on the line $h = h_e$ i.d. there is no external resistance to the expanding detonation gas.

The escape velocity u_e is then:

$$u_e = u_1 - \frac{2c_1}{\gamma+1}$$

If we substitute (4.7) and (4.8) for u_1 and c_1 in (4.11) and (4.12) we obtain:

$$u = -\frac{D+2c}{\gamma-1} \tag{4.13}$$

$$X = x_e - \frac{D+(\gamma+1)c}{\gamma-1}\, t \tag{4.14}$$

Moreover, from:

$$c^2 = \gamma p/\rho = \gamma A \rho^{\gamma-1}$$

it follows:

$$\rho = \left(\frac{c^2}{\gamma A}\right)^{\frac{1}{\gamma-1}} \tag{4.15}$$

and

$$p = A\left(\frac{c^2}{\gamma A}\right)^{\frac{\gamma}{\gamma-1}} \tag{4.16}$$

The state behind the front is then completely defined if c is given as function of h, t. To do this we first remark that in the slab case:

$$\rho_o h = \int_{X(0,t)}^{X(h,t)} \rho dX + \rho_o x_i$$

and from this:

$$\rho_o(h_e-h) = \int_X^{X_e} \rho dX = \int_c^{c_e} \rho \frac{\partial X}{\partial c}\, dc$$

$c_e = 0$ hence:

$$\rho_o(h_e-h) = -\int_0^c \rho \frac{\partial X}{\partial c}\, dc \tag{4.17}$$

Differentiating (4.14) with respect to c we obtain:

$$\frac{\partial X}{\partial c} = - \frac{\gamma+1}{\gamma-1}\, t \qquad (4.18)$$

and substituting (4.14) and (4.17) in (4.16):

$$\rho_o(h_e-h) = c^{\frac{\gamma+1}{\gamma-1}} \left(\frac{1}{\gamma A}\right)^{\frac{1}{\gamma-1}} t$$

from which :

$$c = \left[\frac{\rho_o(h_e-h)}{t}\right]^{\frac{\gamma-1}{\gamma+1}} (\gamma A)^{\frac{1}{\gamma+1}} \qquad (4.19)$$

From (4.10) :

$$(\gamma A)^{\frac{1}{\gamma+1}} = |D|^{\frac{2}{\gamma+1}} \left(\frac{\gamma}{\gamma+1}\right) \rho_o^{-\frac{\gamma-1}{\gamma+1}}$$

$$= \frac{|D|\gamma}{\gamma+1} |D|^{-\frac{\gamma-1}{\gamma+1}} \rho_o^{-\frac{\gamma-1}{\gamma+1}}$$

Substituting this expression into (4.18) we obtain:

$$c = \frac{-\gamma D}{\gamma+1} \left[\frac{h_e-h}{-Dt}\right]^{\frac{\gamma-1}{\gamma+1}} \qquad (4.20)$$

5. Finite difference scheme

Let us rewrite the flow equations for the gas:

$$\begin{cases} \dfrac{1}{\rho} = \dfrac{1}{\rho_o}\left(\dfrac{X}{h}\right)^{\nu} X_h \\ X_{tt} = K\left(\dfrac{X}{h}\right)^{\nu} \left[\left(\dfrac{X}{h}\right)^{\nu} X_h\right]_h \\ u = X_t \\ e_t = \dfrac{p}{\rho^2}\, \rho_t \\ p = A\rho^{\gamma} \\ K = \gamma p \rho/\rho_o^2 \end{cases} \qquad (5.1)$$

with $$A = \frac{D_o^2}{\gamma+1}\left(\frac{\gamma}{\gamma+1}\right)^{\gamma} \rho_o^{1-\gamma} \qquad (\gamma=3)$$

and D_o initial velocity of the front.

The energy equation has been added since in the second phase of the problem (liner-gas interaction) the momentum equation is no more independent from the energy equation. Hence, in the second phase we must consider the complete system (3.3). However, in the detonation phase X, u, ρ, p are determined independently from e.

System (5.1) is approximated with the following implicit scheme:

$$\left.\begin{array}{l}
\rho^n_{j+1/2} = \rho_o \Big/ \left[\alpha^n_{j+1/2} \dfrac{X^n_{j+1}-X^n_j}{\Delta h}\right] \qquad \alpha^n_{j+1/2} = \left(\dfrac{X^n_j+X^n_{j+1}}{2h_{j+1/2}}\right)^{\nu} \\[2ex]
p^n_{j+1/2} = A\left(\rho^n_{j+1/2}\right)^{\nu} \\[2ex]
K^n_j = \dfrac{\gamma}{\rho_o^2} \dfrac{p^n_{j-1/2}\,\rho^n_{j-1/2} + p^n_{j+1/2}\,\rho^n_{j+1/2}}{2} \\[2ex]
\dfrac{\dfrac{X^{n+1}_j-X^n_j}{\Delta t_n} - \dfrac{X^n_j-X^{n-1}_j}{\Delta t_{n-1}}}{\dfrac{\Delta t_n + \Delta t_{n-1}}{2}} = K^n_j \left(\dfrac{X^n_j}{h_j}\right)^{\nu} \left[\theta \dfrac{\alpha^n_{j+1/2}(X^{n+1}_{j+1}-X^{n+1}_j)-\alpha^n_{j-1/2}(X^{n+1}_j-X^{n+1}_{j-1})}{(\Delta h)^2}\right. \\[2ex]
\qquad\qquad + \left.(1-\theta)\dfrac{\alpha^n_{j+1/2}(X^n_{j+1}-X^n_j)-\alpha^n_{j-1/2}(X^n_j-X^n_{j-1})}{(\Delta h)^2}\right] \\[2ex]
u^{n+1}_j = \dfrac{X^{n+1}_j-X^n_j}{\Delta t_n} \\[2ex]
e^{n+1}_{j+1/2} - e^n_{j+1/2} = \dfrac{2(p^{n+1}_{j+1/2}+p^n_{j+1/2})}{(\rho^{n+1}_{j+1/2}+\rho^n_{j+1/2})} (\rho^{n+1}_{j+1/2} - \rho^n_{j+1/2})
\end{array}\right\} \quad (5.2)$$

This scheme is unconditionally stable if $\theta \geq 1/2$. Advantage is taken of this fact in order to set up a point mesh with constant step Δh and variable step Δt_n.

If $$t_o = 0$$

and $$t_n = t_{n-1} + \Delta t_{n-1} = \Delta t_o + \Delta t_1 + \dots + \Delta t_{n-1}$$

and $$h_F = h_F(t)$$

is the front trajectory in the h,t coordinates the steps Δt_n are chosen in such a way that

$$h_F(t_n)$$

be always coincident with a value h_j of the mesh (see fig. 3)

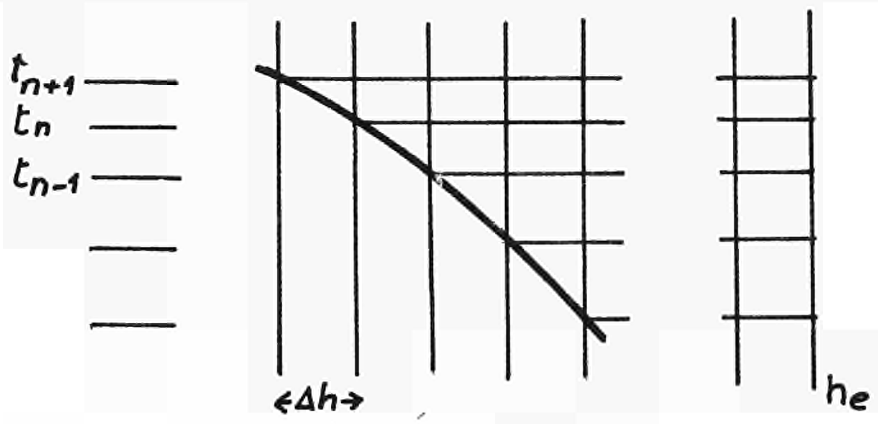

Fig. 3

On the line $h = h_e$

we have the condition $u = u_e$

It follows that:

$$X_e(t) = x_e + u_e t$$

or equivalently:

$$X_e(t+\Delta t) = X_e(t) + u_e \Delta t$$

The finite difference scheme (5.2) is applied to the mesh points internal to the region BMNC. The front trajectory is computed by means of the formula:

$$X_F(t_{n+1}) = X_F(t_n) + D(t_n)\Delta t_n$$

or :

$$X_F(t_{n+1}) = X_F(t_{n-1}) + D(t_n) \quad (\Delta t_{n-1} + \Delta t_n)$$

This second formula has higher precision under the assumption that $\Delta t_n \simeq \Delta t_{n-1}$.
It is:

$$X_F = h_F$$

In fact, until the moment a particle X is reached by the front, we have:

$$X(t) = x = h.$$

Δt_n is chosen in such a way that :

$$X(t_{n+1}) - X(t_n) = \Delta X = \Delta h$$

Hence:

$$\Delta t_n = \frac{\Delta h}{D(t_n)}$$

The finite difference scheme cannot be applied directly to the point adjacent to the front since we lack a point at the (n-1)-th level as shown in fig.4

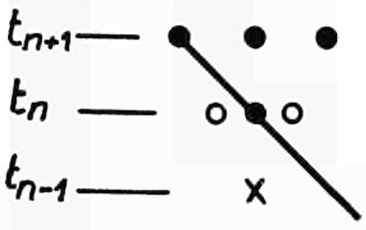

Fig. 4

The value of X at point (x) can be determined by linear or quadratic extrapolation on line $t = t_{n-1}$; in the same way

we obtain the values $\alpha^{n}_{j\pm1/2}$ at the points (o) on line $t = t_n$. Then the finite difference scheme can be used in a totally implicit form with $\theta = 1$.
Another possibility is schematically shown in fig. 5

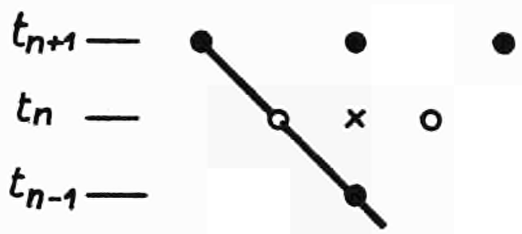

Fig. 5

The value of X at point (x) is extrapolated:

$$X(t_{n+1/2}) = X(t_n) + u(t_n)\,\frac{\Delta t_n}{2}$$

$X(t_n)$ and $u(t_n)$ are relative to point (.) on line $t = t_n$. The values of $\alpha^{n+1/2}_{j\pm1/2}$ at points (o) are obtained by interpolation and the difference scheme is applied in a totally implicit form. The value of $X(t_{n+1})$ at the point adjacent to the front could be obtained by direct extrapolation:

$$X(t_{n+1}) = X(t_n) + u(t_n)\,\Delta t_n$$

However, the results obtained in this way are not satisfactory since a pressure peak builds up behind the front. A possible explanation could be that with this direct extrapolation the values of X on the front and at the adjacent point are weakly related to the other values of X behind the front. This is unsatisfactory on physical grounds since the hydrodynamic quantities on the front depend on the flow behind the front. This drawback is avoided if $\rho^{n+1}_{j+1/2}$ is computed by means of the first equation (5.2) with the exception of the half-point near the front. For this we set:

$$\rho^{n+1}_{F-1/2} = \rho^{n+1}_{F-3/2}$$

(see also Fig. 6)

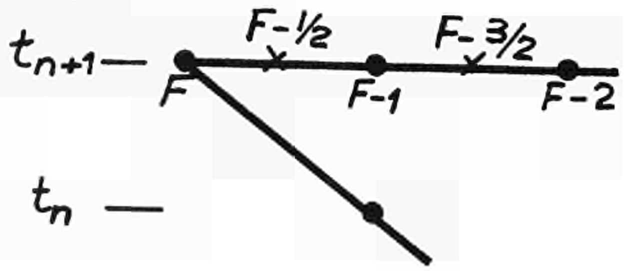

Fig. 6

In this way a good connexion is reestablished between the value of X on the front and the values of X behind the front. The profile of ρ is slightly flattened behind the front but this loss of precision in the computation of ρ is progressively reduced since ρ_h behind the front decreases as the time increases.

A possible variation of the finite difference scheme (5.2) would be to consider the h-differentiation for $t = t_{n+1}$ and $t = t_{n-1}$, together with suitable modifications for the two points near to the front.

Given X at time t_{n+1} we can compute u, ρ, p, e. In order to determine D, u_1, ρ_1, p_1 on the front at time t_{n+1} we use the Rankine-Hugoniot relations (conservation of mass and momentum only).

$$\rho_o D = \rho_1 (D - u_1) \tag{5.3}$$

$$\rho_o D^2 = p_1 + \rho_1 (D - u_1)^2 \tag{5.4}$$

From these relations it follows:

$$\rho_o D^2 = p_1 + \rho_o D(D - u_1)$$

hence:

$$D = \frac{p_1}{\rho_o u_1} \tag{5.5}$$

Introducing this expression into (5.3) we obtain:

$$u_i^2 = p_1\left(\frac{1}{\rho_o} - \frac{1}{\rho_1}\right)$$

and, more specifically:

$$u_1 = - \sqrt{p_1\left(\frac{1}{\rho_o} - \frac{1}{\rho_1}\right)} \qquad (5.6)$$

The sign - has been chosen since in (5.5) D is negative and ρ_o, p_1 positive. To conclude, on the front we have:

$$p_1 = A\rho_1^\gamma$$

$$u_1 = - \sqrt{p_1\left(\frac{1}{\rho_o} - \frac{1}{\rho_1}\right)}$$

$$D = \frac{p_1}{\rho_o u_1}$$

Actually, we have three unknowns D u_1 ρ_1 and two equations given by the Rankine-Hugoniot conditions. A third relation is supplied by the characteristic equation along the C^+ characteristic. However, to avoid the numerical difficulties connected with this last equation, it is better to find an approximate value for ρ_1 and to determine subsequently D, p_1, u_1 .

ρ_1 is approximated with the formula:

$$\rho_1(t_{n+1}) = \rho_o \Big/ \left[\left(\frac{X_F^{n+1}}{h_F}\right) \frac{X_F^{n+1} - X_{f-1}^{n+1}}{\Delta h}\right]$$

F being the h-index on the front.

As already said, in case we choose to compute X_{F-1}^{n+1} by direct extrapolation it is best to set

$$\rho_F^{n+1} = \rho_{F-3/2}^{n+1}$$

$\rho_{F-3/2}$ being computed with the first of equations (5.2).

The number of points to be considered increases with each iteration. In order not to increase unduly this number the step Δh can be periodically doubled, so that the corresponding number of points is halved. When Δh is doubled the (n-2)th time level must be substituted for the (n-1)th level.

6. Liner-gas interaction

Let $\bar{t}$ be the time at which the detonation front reaches the liner. If we take $\bar{t}$ as initial time we have then two hydrodynamic media which are going to interact. The initial state of the liner is uniform, the initial state of the gas is that defined by the flow behind the front at time $\bar{t}$.

We introduce the lagrangean coordinate h :

$$\frac{h^{\nu+1}}{\nu+1} = \frac{1}{\rho_o} \int_{X(0,t)}^{X(h,t)} \rho(\xi,t)\,\xi^{\nu}\, d\xi + \frac{x_{\ell}^{\nu+1}}{\nu+1}$$

$$= \frac{1}{\rho_o} \int_{x_{\ell}}^{\bar{x}} \bar{\rho}\, \xi^{\nu}\, d\xi + \frac{x_{\ell}^{\nu+1}}{\nu+1}$$

$\bar{x}$ being the eulerian coordinate at time $\bar{t}$.
Hence $\bar{x} = x$ for the liner and $\bar{x} = X(h,\bar{t})$ for the gas.
x_{ℓ} is the internal wall of the liner
x_i the interface liner-gas
For $\bar{x} < x_i$ ρ_o, ρ are relative to the liner and $\bar{\rho} = \rho_o$
For $\bar{x} > x_i$ ρ_o is the density of the unreacted explosive and $\bar{\rho}$ the gas density at time $\bar{t}$.

In this case we have

$$\frac{h^{\nu+1}}{\nu+1} = \frac{1}{\rho_e^o} \int_{x_i}^{\bar{x}} \bar{\rho}\, \xi^{\nu}\, d\xi + \frac{x_i^{\nu+1}}{\nu+1}$$

(ρ_e^o constant density of the unreacted explosive)

Hence for the gas we obtain the same h as defined by (3.1). h = x both for the liner and the gas at time t = 0.

The differential system to be solved, in lagrangean form, is:

$$\left.\begin{aligned} \frac{1}{\rho} &= \frac{1}{\rho_o}\left(\frac{X}{h}\right)^{\nu} X_h \\ X_t &= u \\ u_t &= -\frac{1}{\rho_o}\, p_h \\ e_t &= \frac{p}{\rho^2}\,\rho_t \\ p &= f(\rho,e) \end{aligned}\right\} \qquad (6.1)$$

the boundary conditionsare

$$p = \frac{B_o}{8\pi}\left[\left(\frac{X_\ell(0)}{X_\ell(t)}\right)^4 - 1\right] \qquad h = h_\ell$$

$$u = u_e \qquad h = h_e$$

This last condition can be substituted with the equivalent condition :

$$p = 0 \qquad h = h_e$$

h_ℓ, h_i, h_e are respectively the values of h corresponding to the internal wall of the liner, the interface, the external boundary of the expanding gas.

For $h < h_i$ we have the liner
For $h > h_i$ we have the gas
The state equation of the liner is:

$$p(\rho,e) = p_c(\rho) + \rho\gamma(\rho)\,(e - e_c(\rho))$$

with

$$p_c(\rho) = \sum_{j=1}^{6} a_j(\rho/\rho_{OK})^{1+j/3}$$

and $$e_c(\rho) = \int_{\rho_{OK}}^{\rho} \frac{p_c(\xi)}{\xi^2}\, d\xi = \frac{1}{\rho_{OK}} \sum_{j=1}^{6} \frac{3}{j} a_j \, (\rho/\rho_{OK})^{j/3}$$

$$\gamma(\rho) = \frac{1}{3} + \frac{\rho}{2} \frac{d^2p_c/d\rho^2}{dp_c/d\rho}$$

ρ_{OK} is the density at absolute temperature T = 0 and pressure p = 0.

This state equation is derived from the formulae:

$$p(\rho,T) = p_c(\rho) + \rho\gamma(\rho)c_v \, (T-T_o + \frac{E_o}{c_v})$$

$$e(\rho,T) = e_c(\rho) + c_v(T-T_o + \frac{E_o}{c_v})$$

The state equation of the gas is:

$$p = A\rho^{\gamma} \qquad (\gamma = 3)$$

The differential system (6.1) is approximated with the following finite difference scheme:

$$\left.\begin{aligned}
&\frac{u_j^{n+1}-u_j^n}{\Delta t} = -\frac{1}{\rho_o}\left(\frac{p_{j+1/2}^n-p_{j-1/2}^n}{\Delta h} + \frac{q_{j+1/2}-q_{j-1/2}^n}{\Delta h}\right)\\
&\frac{X_j^{n+1}-X_j^n}{\Delta t} = u_j^{n+1}\\
&\rho_{j+1/2}^{n+1} = \rho_o \Big/ \left[\left(\frac{X_j^{n+1}+X_{j+1}^{n+1}}{2h_{j+1/2}}\right)^{\nu} \frac{X_{j+1}^{n+1}-X_j^{n+1}}{\Delta h}\right]\\
&e_{j+1/2}^{n+1} - e_{j+1/2}^{n} = \frac{p_{j+1/2}^n}{(\rho_{j+1/2}^n)^2}\left(\rho_{j+1/2}^n - \rho_{j+1/2}^n\right)\\
&p_{j+1/2}^{n+1} = f(\rho_{j+1/2}^{n+1}, e_{j+1/2}^{n+1})\\
&q_{j+1/2}^n = \begin{cases} a^2\rho_{j+1/2}^n(u_{j+1}^n-u_j^n) & \text{if } u_{j+1}^n-u_j^n < 0\\ 0 & \text{if } u_{j+1}^n-u_j^n > 0\end{cases}
\end{aligned}\right\} \qquad (6.2)$$

with the stability condition:

$$\Delta t < \frac{\Delta X}{c}$$

q is the pseudo-viscosity term with a=2.

The liner-gas interface should be coincident with a h-line of the mesh having integer index. Because the liner has greater density than the gas, it may be convenient to employ different steps $\Delta_\ell h$ and $\Delta_g h$ in the liner and in the gas, $\Delta_g h$ being the greater.
This change of step may be done in different ways. For instance, the step Δh in the gas can be lenghtened gradually.

Fig. 7

In this case the formulae of the finite difference scheme must be modified with regard to the gas, in order to take into account the fact that the intervals Δh are unequal.

A second solution is schematically represented in fig.8 : the index of the interface

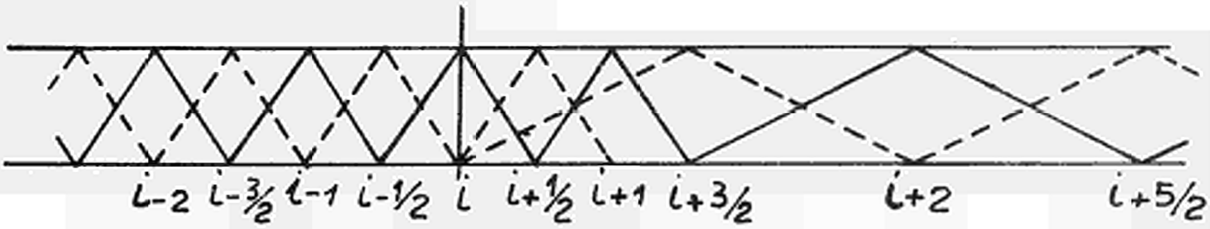

Fig. 8

Given $\Delta_\ell h$ and an odd integer (in the figure m=3) we define:

$$\Delta_g h = m \; \Delta_\ell h$$

and take m points after the i-th with step $\frac{1}{2}\,\Delta_\ell h$. The following points are taken with step $\frac{1}{2}\,\Delta_g h$.

X, u, ρ, p, e, q are given on the n-th line. We compute X_j^{n+1} and u_j^{n+1} for

$$j = \dots\ i-2,\ i-1,\ i,\ i+1,\ i+2,\ \dots$$

The computation for each point is schematically represented by a triangle with the base on the n-th line, vertex on the (n+1)th line and continuous sides. The state equation is that of the liner or of the gas according to whether $j \pm 1/2 \lessgtr i$.

We then compute

$$\rho^{n+1}_{j\pm1/2},\ e^{n+1}_{j\pm1/2},\ p^{n+1}_{j\pm1/2},\ q^{n+1}_{j\pm1/2}$$

(triangles with dashed sides)
A criterion for the choice of m could be:

$$m = \text{odd integer near to } \frac{\rho^o_\ell}{\rho^o_e}$$

(ρ^o_e constant density of the unreacted explosive).
This criterion is based on the following considerations:
From the definition of h it follows:

$$h^\nu dh = \frac{1}{\rho_o} X^\nu\, dX = \frac{1}{\rho_o}\, dm$$

m mass and ρ_o equal to ρ^o_ℓ or ρ^o_e according to whether the particle X belongs to the liner or to the gas.

For two contiguous layers of liner and gas we have:

$$\Delta m_\ell = \rho^o_\ell h^\nu_\ell \Delta h_\ell$$

$$\Delta m_g = \rho^o_e h^\nu_g \Delta h_g$$

It should be:

$$\Delta m_\ell \simeq \Delta m_g$$

since the layers are contiguous. Also, for the same reason:

$$h_\ell \simeq h_g$$

Hence:

$$\rho_e^o \; \Delta h_g \simeq \rho_\ell^o \; \Delta h_\ell$$

7. Numerical results

When $\nu = 0$ we have the slab case. It is then possible to compare the exact solution as given by formulae (4.13)...(4.19) with the numerical solution obtained by means of the finite difference scheme. The exact and numerical solution at a given time are presented in Table 1 and 2.

Table 3 gives the gas flow (cylinder geometry) behind the front at time $t = \bar{t}$.

Table 4 gives the trajectory of the two faces X_ℓ and X_i of the liner.

Tables 5 and 6 give the numerical results for two different times.

8. Acknowledgments

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PLANE DETONATION * TAYLOR WAVE

NH = 217 T = 2 7000E-06 D = -8.0000E 05 DH = 10.0000E-03

H	X	U	P	RH
9.0000E 00	1.0080E 01	4.0000E 05	0.	0.
8.9800E 00	9.7682E 00	3.4226E 05	2.4235E 08	2.1811E-01
8.9600E 00	9.6391E 00	3.1835E 05	6.8546E 08	3.0845E-01
8.9400E 00	9.5400E 00	3.0000E 05	1.2593E 09	3.7778E-01
8.9200E 00	9.4565E 00	2.8453E 05	1.9388E 09	4.3622E-01
8.9000E 00	9.3829E 00	2.7090E 05	2.7095E 09	4.8771E-01
8.8800E 00	9.3163E 00	2.5858E 05	3.5617E 09	5.3426E-01
8.8600E 00	9.2551E 00	2.4725E 05	4.4883E 09	5.7707E-01
8.8400E 00	9.1982E 00	2.3670E 05	5.4836E 09	6.1691E-01
8.8200E 00	9.1447E 00	2.2679E 05	6.5433E 09	6.5433E-01
8.8000E 00	9.0941E 00	2.1743E 05	7.6636E 09	6.8972E-01
8.7800E 00	9.0460E 00	2.0851E 05	8.8414E 09	7.2339E-01
8.7600E 00	9.0000E 00	2.0000E 05	1.0074E 10	7.5556E-01
8.7400E 00	8.9559E 00	1.9183E 05	1.1359E 10	7.8641E-01
8.7200E 00	8.9135E 00	1.8398E 05	1.2695E 10	8.1609E-01
8.7000E 00	8.8725E 00	1.7639E 05	1.4079E 10	8.4474E-01
8.6800E 00	8.8329E 00	1.6906E 05	1.5510E 10	8.7244E-01
8.6600E 00	8.7945E 00	1.6195E 05	1.6987E 10	8.9929E-01
8.6400E 00	8.7573E 00	1.5505E 05	1.8507E 10	9.2536E-01
8.6200E 00	8.7210E 00	1.4834E 05	2.0071E 10	9.5072E-01
8.6000E 00	8.6857E 00	1.4180E 05	2.1676E 10	9.7542E-01
8.5800E 00	8.6513E 00	1.3542E 05	2.3322E 10	9.9951E-01
8.5600E 00	8.6177E 00	1.2920E 05	2.5007E 10	1.0230E 00
8.5400E 00	8.5848E 00	1.2311E 05	2.6732E 10	1.0460E 00
8.5200E 00	8.5526E 00	1.1716E 05	2.8494E 10	1.0685E 00
8.5000E 00	8.5212E 00	1.1132E 05	3.0293E 10	1.0906E 00
8.4800E 00	8.4903E 00	1.0561E 05	3.2129E 10	1.1121E 00
8.4600E 00	8.4600E 00	10.0000E 04	3.4000E 10	1.1333E 00
8.4400E 00	8.4303E 00	9.4495E 04	3.5906E 10	1.1541E 00
8.4200E 00	8.4011E 00	8.9087E 04	3.7847E 10	1.1746E 00
8.4000E 00	8.3724E 00	8.3772E 04	3.9821E 10	1.1946E 00
8.3800E 00	8.3441E 00	7.8545E 04	4.1829E 10	1.2144E 00
8.3600E 00	8.3164E 00	7.3401E 04	4.3869E 10	1.2338E 00
8.3400E 00	8.2890E 00	6.8337E 04	4.5941E 10	1.2529E 00
8.3200E 00	8.2621E 00	6.3350E 04	4.8045E 10	1.2718E 00
8.3000E 00	8.2355E 00	5.8435E 04	5.0181E 10	1.2904E 00
8.2800E 00	8.2094E 00	5.3590E 04	5.2346E 10	1.3087E 00
8.2600E 00	8.1836E 00	4.8812E 04	5.4543E 10	1.3267E 00
8.2400E 00	8.1581E 00	4.4097E 04	5.6769E 10	1.3445E 00
8.2200E 00	8.1330E 00	3.9445E 04	5.9024E 10	1.3621E 00
8.2000E 00	8.1082E 00	3.4852E 04	6.1309E 10	1.3794E 00
8.1800E 00	8.0837E 00	3.0315E 04	6.3622E 10	1.3966E 00
8.1600E 00	8.0595E 00	2.5834E 04	6.5964E 10	1.4135E 00
8.1400E 00	8.0356E 00	2.1406E 04	6.8334E 10	1.4302E 00
8.1200E 00	8.0120E 00	1.7029E 04	7.0731E 10	1.4468E 00
8.1000E 00	7.9886E 00	1.2702E 04	7.3156E 10	1.4631E 00
8.0800E 00	7.9655E 00	8.4220E 03	7.5608E 10	1.4793E 00
8.0600E 00	7.9426E 00	4.1886E 03	7.8087E 10	1.4953E 00
8.0400E 00	7.9200E 00	-1.9531E-02	8.0593E 10	1.5111E 00
8.0200E 00	7.8976E 00	-4.1452E 03	8.3124E 10	1.5268E 00
8.0000E 00	7.8755E 00	-8.2483E 03	8.5682E 10	1.5423E 00
7.9800E 00	7.8535E 00	-1.2311E 04	8.8265E 10	1.5576E 00
7.9600E 00	7.8318E 00	-1.6333E 04	9.0874E 10	1.5728E 00
7.9400E 00	7.8103E 00	-2.0317E 04	9.3508E 10	1.5879E 00
7.9200E 00	7.7890E 00	-2.4264E 04	9.6167E 10	1.6028E 00
7.9000E 00	7.7679E 00	-2.8174E 04	9.8850E 10	1.6175E 00
7.8800E 00	7.7469E 00	-3.2049E 04	1.0156E 11	1.6322E 00
7.8600E 00	7.7262E 00	-3.5890E 04	1.0429E 11	1.6467E 00
7.8400E 00	7.7056E 00	-3.9697E 04	1.0705E 11	1.6611E 00
7.8200E 00	7.6853E 00	-4.3471E 04	1.0983E 11	1.6753E 00
7.8000E 00	7.6650E 00	-4.7214E 04	1.1263E 11	1.6895E 00
7.7800E 00	7.6450E 00	-5.0925E 04	1.1546E 11	1.7035E 00
7.7600E 00	7.6251E 00	-5.4606E 04	1.1831E 11	1.7174E 00
7.7400E 00	7.6054E 00	-5.8258E 04	1.2118E 11	1.7312E 00
7.7200E 00	7.5858E 00	-6.1880E 04	1.2408E 11	1.7449E 00
7.7000E 00	7.5664E 00	-6.5475E 04	1.2700E 11	1.7585E 00
7.6800E 00	7.5472E 00	-6.9042E 04	1.2994E 11	1.7719E 00
7.6600E 00	7.5281E 00	-7.2582E 04	1.3291E 11	1.7853E 00
7.6400E 00	7.5091E 00	-7.6095E 04	1.3589E 11	1.7986E 00
7.6200E 00	7.4903E 00	-7.9583E 04	1.3890E 11	1.8118E 00
7.6000E 00	7.4716E 00	-8.3046E 04	1.4193E 11	1.8248E 00
7.5800E 00	7.4530E 00	-8.6484E 04	1.4498E 11	1.8378E 00
7.5600E 00	7.4346E 00	-8.9898E 04	1.4806E 11	1.8507E 00
7.5400E 00	7.4162E 00	-9.3288E 04	1.5115E 11	1.8635E 00
7.5200E 00	7.3981E 00	-9.6655E 04	1.5427E 11	1.8763E 00
7.5000E 00	7.3800E 00	-1.0000E 05	1.5741E 11	1.8889E 00
7.4800E 00	7.3621E 00	-1.0332E 05	1.6057E 11	1.9014E 00
7.4600E 00	7.3442E 00	-1.0662E 05	1.6375E 11	1.9139E 00
7.4400E 00	7.3265E 00	-1.0990E 05	1.6695E 11	1.9263E 00
7.4200E 00	7.3089E 00	-1.1316E 05	1.7017E 11	1.9386E 00
7.4000E 00	7.2915E 00	-1.1640E 05	1.7341E 11	1.9508E 00
7.3800E 00	7.2741E 00	-1.1962E 05	1.7667E 11	1.9630E 00
7.3600E 00	7.2568E 00	-1.2281E 05	1.7995E 11	1.9751E 00
7.3400E 00	7.2396E 00	-1.2599E 05	1.8325E 11	1.9871E 00
7.3200E 00	7.2226E 00	-1.2915E 05	1.8657E 11	1.9990E 00
7.3000E 00	7.2056E 00	-1.3229E 05	1.8992E 11	2.0109E 00
7.2800E 00	7.1888E 00	-1.3541E 05	1.9328E 11	2.0227E 00
7.2600E 00	7.1720E 00	-1.3852E 05	1.9666E 11	2.0344E 00
7.2400E 00	7.1553E 00	-1.4160E 05	2.0006E 11	2.0461E 00
7.2200E 00	7.1388E 00	-1.4467E 05	2.0348E 11	2.0576E 00
7.2000E 00	7.1223E 00	-1.4772E 05	2.0692E 11	2.0692E 00
7.1800E 00	7.1059E 00	-1.5076E 05	2.1038E 11	2.0806E 00
7.1600E 00	7.0896E 00	-1.5377E 05	2.1385E 11	2.0920E 00
7.1400E 00	7.0734E 00	-1.5679E 05	2.1735E 11	2.1034E 00
7.1200E 00	7.0573E 00	-1.5976E 05	2.2086E 11	2.1147E 00
7.1000E 00	7.0413E 00	-1.6273E 05	2.2440E 11	2.1259E 00
7.0800E 00	7.0253E 00	-1.6569E 05	2.2795E 11	2.1370E 00
7.0600E 00	7.0094E 00	-1.6862E 05	2.3152E 11	2.1481E 00
7.0400E 00	6.9936E 00	-1.7155E 05	2.3511E 11	2.1592E 00
7.0200E 00	6.9779E 00	-1.7446E 05	2.3872E 11	2.1702E 00
7.0000E 00	6.9623E 00	-1.7735E 05	2.4234E 11	2.1811E 00
6.9800E 00	6.9468E 00	-1.8023E 05	2.4599E 11	2.1920E 00
6.9600E 00	6.9313E 00	-1.8310E 05	2.4965E 11	2.2028E 00
6.9400E 00	6.9159E 00	-1.8595E 05	2.5333E 11	2.2136E 00
6.9200E 00	6.9006E 00	-1.8878E 05	2.5703E 11	2.2243E 00
6.9000E 00	6.8853E 00	-1.9161E 05	2.6075E 11	2.2350E 00
6.8800E 00	6.8701E 00	-1.9442E 05	2.6448E 11	2.2456E 00
6.8600E 00	6.8550E 00	-1.9722E 05	2.6823E 11	2.2561E 00
6.8400E 00	6.8400E 00	-2.0000E 05	2.7200E 11	2.2667E 00

TABLE 1

PLANE DETONATION * FINITE DIFFERENCE SCHEME

NH = 217 T = 2.6993E-06 D = -8.0045E 05 DH = 10.0000E-03

H	X	U	P	RH
9.0000E 00	1.0080E 01	4.0000E 05	0.	0.
8.9800E 00	9.7645E 00	3.3746E 05	2.4712E 08	2.1953E-01
8.9600E 00	9.6361E 00	3.1461E 05	6.7559E 08	3.0697E-01
8.9400E 00	9.5373E 00	2.9660E 05	1.2525E 09	3.7710E-01
8.9200E 00	9.4538E 00	2.8123E 05	1.9330E 09	4.3579E-01
8.9000E 00	9.3803E 00	2.6755E 05	2.7024E 09	4.8728E-01
8.8800E 00	9.3138E 00	2.5522E 05	3.5503E 09	5.3369E-01
8.8600E 00	9.2526E 00	2.4395E 05	4.4878E 09	5.7704E-01
8.8400E 00	9.1957E 00	2.3335E 05	5.4841E 09	6.1693E-01
8.8200E 00	9.1422E 00	2.2349E 05	6.5417E 09	6.5428E-01
8.8000E 00	9.0916E 00	2.1411E 05	7.6520E 09	6.8938E-01
8.7800E 00	9.0435E 00	2.0525E 05	8.8422E 09	7.2341E-01
8.7600E 00	8.9975E 00	1.9662E 05	1.0079E 10	7.5568E-01
8.7400E 00	8.9534E 00	1.8834E 05	1.1365E 10	7.8654E-01
8.7200E 00	8.9110E 00	1.8062E 05	1.2687E 10	8.1592E-01
8.7000E 00	8.8701E 00	1.7315E 05	1.4082E 10	8.4479E-01
8.6800E 00	8.8305E 00	1.6575E 05	1.5519E 10	8.7261E-01
8.6600E 00	8.7921E 00	1.5858E 05	1.6983E 10	8.9922E-01
8.6400E 00	8.7548E 00	1.5171E 05	1.8516E 10	9.2551E-01
8.6200E 00	8.7186E 00	1.4497E 05	2.0059E 10	9.5054E-01
8.6000E 00	8.6833E 00	1.3836E 05	2.1665E 10	9.7526E-01
8.5800E 00	8.6489E 00	1.3210E 05	2.3361E 10	1.0001E 00
8.5600E 00	8.6153E 00	1.2597E 05	2.5082E 10	1.0240E 00
8.5400E 00	8.5824E 00	1.2001E 05	2.6819E 10	1.0472E 00
8.5200E 00	8.5503E 00	1.1388E 05	2.8551E 10	1.0692E 00
8.5000E 00	8.5188E 00	1.0822E 05	3.0385E 10	1.0917E 00
8.4800E 00	8.4880E 00	1.0243E 05	3.2234E 10	1.1134E 00
8.4600E 00	8.4578E 00	9.6777E 04	3.4110E 10	1.1346E 00
8.4400E 00	8.4281E 00	9.1299E 04	3.6011E 10	1.1553E 00
8.4200E 00	8.3989E 00	8.5841E 04	3.7967E 10	1.1758E 00
8.4000E 00	8.3702E 00	8.0603E 04	3.9951E 10	1.1959E 00
8.3800E 00	8.3420E 00	7.5479E 04	4.1997E 10	1.2160E 00
8.3600E 00	8.3143E 00	7.0326E 04	4.4010E 10	1.2351E 00
8.3400E 00	8.2870E 00	6.5345E 04	4.6074E 10	1.2542E 00
8.3200E 00	8.2601E 00	6.0345E 04	4.8204E 10	1.2732E 00
8.3000E 00	8.2336E 00	5.5459E 04	5.0331E 10	1.2916E 00
8.2800E 00	8.2074E 00	5.0612E 04	5.2516E 10	1.3101E 00
8.2600E 00	8.1817E 00	4.5860E 04	5.4762E 10	1.3285E 00
8.2400E 00	8.1562E 00	4.1318E 04	5.6995E 10	1.3463E 00
8.2200E 00	8.1311E 00	3.6508E 04	5.9217E 10	1.3636E 00
8.2000E 00	8.1064E 00	3.1890E 04	6.1542E 10	1.3812E 00
8.1800E 00	8.0819E 00	2.7481E 04	6.3847E 10	1.3982E 00
8.1600E 00	8.0577E 00	2.3006E 04	6.6240E 10	1.4155E 00
8.1400E 00	8.0339E 00	1.8626E 04	6.8583E 10	1.4320E 00
8.1200E 00	8.0102E 00	1.4266E 04	7.1012E 10	1.4487E 00
8.1000E 00	7.9869E 00	9.9811E 03	7.3468E 10	1.4652E 00
8.0800E 00	7.9638E 00	5.6156E 03	7.5948E 10	1.4815E 00
8.0600E 00	7.9410E 00	1.4552E 03	7.8455E 10	1.4976E 00
8.0400E 00	7.9184E 00	-2.7768E 03	8.0963E 10	1.5134E 00
8.0200E 00	7.8961E 00	-6.8704E 03	8.3499E 10	1.5291E 00
8.0000E 00	7.8740E 00	-1.0954E 04	8.6049E 10	1.5445E 00
7.9800E 00	7.8521E 00	-1.4996E 04	8.8648E 10	1.5599E 00
7.9600E 00	7.8304E 00	-1.8965E 04	9.1309E 10	1.5753E 00
7.9400E 00	7.8089E 00	-2.2882E 04	9.3973E 10	1.5905E 00
7.9200E 00	7.7876E 00	-2.6823E 04	9.6600E 10	1.6052E 00
7.9000E 00	7.7665E 00	-3.0692E 04	9.9282E 10	1.6199E 00
7.8800E 00	7.7456E 00	-3.4538E 04	1.0201E 11	1.6346E 00
7.8600E 00	7.7249E 00	-3.8412E 04	1.0476E 11	1.6492E 00
7.8400E 00	7.7044E 00	-4.2277E 04	1.0756E 11	1.6637E 00
7.8200E 00	7.6840E 00	-4.5931E 04	1.1035E 11	1.6780E 00
7.8000E 00	7.6639E 00	-4.9810E 04	1.1319E 11	1.6923E 00
7.7800E 00	7.6439E 00	-5.3379E 04	1.1603E 11	1.7063E 00
7.7600E 00	7.6240E 00	-5.7110E 04	1.1890E 11	1.7203E 00
7.7400E 00	7.6043E 00	-6.0674E 04	1.2172E 11	1.7338E 00
7.7200E 00	7.5848E 00	-6.4329E 04	1.2473E 11	1.7479E 00
7.7000E 00	7.5654E 00	-6.7811E 04	1.2761E 11	1.7613E 00
7.6800E 00	7.5462E 00	-7.1433E 04	1.3055E 11	1.7747E 00
7.6600E 00	7.5271E 00	-7.4920E 04	1.3355E 11	1.7882E 00
7.6400E 00	7.5082E 00	-7.8446E 04	1.3648E 11	1.8012E 00
7.6200E 00	7.4894E 00	-8.2005E 04	1.3959E 11	1.8147E 00
7.6000E 00	7.4707E 00	-8.5436E 04	1.4275E 11	1.8283E 00
7.5800E 00	7.4522E 00	-8.8785E 04	1.4570E 11	1.8409E 00
7.5600E 00	7.4337E 00	-9.2273E 04	1.4882E 11	1.8539E 00
7.5400E 00	7.4155E 00	-9.5694E 04	1.5203E 11	1.8671E 00
7.5200E 00	7.3973E 00	-9.8885E 04	1.5508E 11	1.8795E 00
7.5000E 00	7.3793E 00	-1.0231E 05	1.5824E 11	1.8922E 00
7.4800E 00	7.3614E 00	-1.0572E 05	1.6152E 11	1.9052E 00
7.4600E 00	7.3436E 00	-1.0886E 05	1.6466E 11	1.9175E 00
7.4400E 00	7.3259E 00	-1.1211E 05	1.6777E 11	1.9295E 00
7.4200E 00	7.3084E 00	-1.1540E 05	1.7108E 11	1.9421E 00
7.4000E 00	7.2909E 00	-1.1879E 05	1.7448E 11	1.9549E 00
7.3800E 00	7.2736E 00	-1.2184E 05	1.7773E 11	1.9669E 00
7.3600E 00	7.2563E 00	-1.2495E 05	1.8090E 11	1.9785E 00
7.3400E 00	7.2392E 00	-1.2806E 05	1.8413E 11	1.9902E 00
7.3200E 00	7.2222E 00	-1.3139E 05	1.8769E 11	2.0030E 00
7.3000E 00	7.2053E 00	-1.3459E 05	1.9121E 11	2.0154E 00
7.2800E 00	7.1884E 00	-1.3773E 05	1.9457E 11	2.0272E 00
7.2600E 00	7.1717E 00	-1.4061E 05	1.9775E 11	2.0382E 00
7.2400E 00	7.1551E 00	-1.4343E 05	2.0098E 11	2.0492E 00
7.2200E 00	7.1385E 00	-1.4644E 05	2.0432E 11	2.0605E 00
7.2000E 00	7.1221E 00	-1.4972E 05	2.0802E 11	2.0728E 00
7.1800E 00	7.1057E 00	-1.5299E 05	2.1180E 11	2.0853E 00
7.1600E 00	7.0895E 00	-1.5605E 05	2.1548E 11	2.0973E 00
7.1400E 00	7.0733E 00	-1.5882E 05	2.1873E 11	2.1078E 00
7.1200E 00	7.0572E 00	-1.6133E 05	2.2178E 11	2.1176E 00
7.1000E 00	7.0412E 00	-1.6392E 05	2.2479E 11	2.1271E 00
7.0800E 00	7.0252E 00	-1.6669E 05	2.2809E 11	2.1375E 00
7.0600E 00	7.0094E 00	-1.6978E 05	2.3178E 11	2.1489E 00
7.0400E 00	6.9936E 00	-1.7310E 05	2.3581E 11	2.1613E 00
7.0200E 00	6.9779E 00	-1.7670E 05	2.4024E 11	2.1748E 00
7.0000E 00	6.9623E 00	-1.8031E 05	2.4483E 11	2.1885E 00
6.9800E 00	6.9468E 00	-1.8376E 05	2.4931E 11	2.2018E 00
6.9600E 00	6.9314E 00	-1.8679E 05	2.5343E 11	2.2139E 00
6.9400E 00	6.9161E 00	-1.8915E 05	2.5674E 11	2.2235E 00
6.9200E 00	6.9008E 00	-1.9067E 05	2.5908E 11	2.2302E 00
6.9000E 00	6.8856E 00	-1.9153E 05	2.6039E 11	2.2340E 00
6.8800E 00	6.8704E 00	-1.9186E 05	2.6102E 11	2.2357E 00
6.8600E 00	6.8552E 00	-1.9193E 05	2.6114E 11	2.2361E 00
6.8400E 00	6.8400E 00	-1.9194E 05	2.6118E 11	2.2362E 00

IBJOB VERSION 2, 7090 - PR - 929

TABLE 2

CYLINDRICAL DETONATION

NH = 261 T = 6.4842E-06 D = -8.0976E 05 DH = 2.0000E-02

H	X	U	P	RH	E
9.0000E 00	1.1594E 01	4.0000E 05	0.	0.	0.
8.9400E 00	1.0717E 01	3.2254E 05	2.0609E 08	2.0664E-01	5.4215E 08
8.8800E 00	1.0382E 01	2.9897E 05	6.5906E 08	3.0444E-01	1.1476E 09
8.8200E 00	1.0124E 01	2.8004E 05	1.2554E 09	3.7739E-01	1.7513E 09
8.7600E 00	9.9059E 00	2.6439E 05	2.0141E 09	4.4180E-01	2.3915E 09
8.7000E 00	9.7130E 00	2.5078E 05	2.9065E 09	4.9926E-01	3.0478E 09
8.6400E 00	9.5384E 00	2.3849E 05	3.9344E 09	5.5228E-01	3.7248E 09
8.5800E 00	9.3775E 00	2.2720E 05	5.0741E 09	6.0115E-01	4.4093E 09
8.5200E 00	9.2273E 00	2.1663E 05	6.3277E 09	6.4706E-01	5.1044E 09
8.4600E 00	9.0861E 00	2.0662E 05	7.7170E 09	6.9132E-01	5.8213E 09
8.4000E 00	8.9521E 00	1.9690E 05	9.1747E 09	7.3237E-01	6.5281E 09
8.3400E 00	8.8244E 00	1.8789E 05	1.0745E 10	7.7198E-01	7.2473E 09
8.2800E 00	8.7021E 00	1.7917E 05	1.2421E 10	8.1019E-01	7.9757E 09
8.2200E 00	8.5846E 00	1.7069E 05	1.4185E 10	8.4686E-01	8.7072E 09
8.1600E 00	8.4714E 00	1.6265E 05	1.6065E 10	8.8272E-01	9.4533E 09
8.1000E 00	8.3619E 00	1.5486E 05	1.8006E 10	9.1694E-01	1.0195E 10
8.0400E 00	8.2558E 00	1.4709E 05	2.0074E 10	9.5076E-01	1.0956E 10
7.9800E 00	8.1529E 00	1.3968E 05	2.2215E 10	9.8343E-01	1.1667E 10
7.9200E 00	8.0527E 00	1.3247E 05	2.4444E 10	1.0153E 00	1.2393E 10
7.8600E 00	7.9552E 00	1.2537E 05	2.6764E 10	1.0464E 00	1.3127E 10
7.8000E 00	7.8600E 00	1.1843E 05	2.9170E 10	1.0769E 00	1.3868E 10
7.7400E 00	7.7672E 00	1.1158E 05	3.1678E 10	1.1069E 00	1.4620E 10
7.6800E 00	7.6763E 00	1.0498E 05	3.4230E 10	1.1359E 00	1.5366E 10
7.6200E 00	7.5874E 00	9.8351E 04	3.6880E 10	1.1645E 00	1.6122E 10
7.5600E 00	7.5004E 00	9.1846E 04	3.9621E 10	1.1926E 00	1.6887E 10
7.5000E 00	7.4150E 00	8.5577E 04	4.2376E 10	1.2197E 00	1.7639E 10
7.4400E 00	7.3312E 00	7.9231E 04	4.5283E 10	1.2469E 00	1.8415E 10
7.3800E 00	7.2490E 00	7.2948E 04	4.8279E 10	1.2738E 00	1.9199E 10
7.3200E 00	7.1681E 00	6.6725E 04	5.1342E 10	1.3002E 00	1.9985E 10
7.2600E 00	7.0887E 00	6.0809E 04	5.4466E 10	1.3261E 00	2.0771E 10
7.2000E 00	7.0106E 00	5.4796E 04	5.7668E 10	1.3516E 00	2.1562E 10
7.1400E 00	6.9337E 00	4.8798E 04	6.0918E 10	1.3765E 00	2.2351E 10
7.0800E 00	6.8580E 00	4.3024E 04	6.4237E 10	1.4011E 00	2.3143E 10
7.0200E 00	6.7834E 00	3.7127E 04	6.7647E 10	1.4254E 00	2.3943E 10
6.9600E 00	6.7098E 00	3.1331E 04	7.1133E 10	1.4495E 00	2.4747E 10
6.9000E 00	6.6374E 00	2.5632E 04	7.4697E 10	1.4733E 00	2.5557E 10
6.8400E 00	6.5659E 00	1.9921E 04	7.8327E 10	1.4968E 00	2.6369E 10
6.7800E 00	6.4954E 00	1.4320E 04	8.1995E 10	1.5198E 00	2.7178E 10
6.7200E 00	6.4258E 00	8.7249E 03	8.5800E 10	1.5430E 00	2.8004E 10
6.6600E 00	6.3571E 00	3.0861E 03	8.9620E 10	1.5656E 00	2.8823E 10
6.6000E 00	6.2893E 00	-2.4056E 03	9.3519E 10	1.5879E 00	2.9646E 10
6.5400E 00	6.2223E 00	-7.9214E 03	9.7500E 10	1.6102E 00	3.0476E 10
6.4800E 00	6.1561E 00	-1.3362E 04	1.0153E 11	1.6320E 00	3.1305E 10
6.4200E 00	6.0907E 00	-1.8767E 04	1.0564E 11	1.6538E 00	3.2141E 10
6.3600E 00	6.0260E 00	-2.4085E 04	1.0976E 11	1.6750E 00	3.2966E 10
6.3000E 00	5.9622E 00	-2.9521E 04	1.1406E 11	1.6966E 00	3.3817E 10
6.2400E 00	5.8990E 00	-3.4793E 04	1.1833E 11	1.7175E 00	3.4654E 10
6.1800E 00	5.8365E 00	-4.0133E 04	1.2271E 11	1.7384E 00	3.5505E 10
6.1200E 00	5.7747E 00	-4.5333E 04	1.2711E 11	1.7590E 00	3.6349E 10
6.0600E 00	5.7136E 00	-5.0694E 04	1.3165E 11	1.7797E 00	3.7205E 10
6.0000E 00	5.6531E 00	-5.5913E 04	1.3620E 11	1.7999E 00	3.8053E 10
5.9400E 00	5.5933E 00	-6.1070E 04	1.4073E 11	1.8197E 00	3.8886E 10
5.8800E 00	5.5341E 00	-6.6322E 04	1.4545E 11	1.8398E 00	3.9744E 10
5.8200E 00	5.4755E 00	-7.1440E 04	1.5010E 11	1.8592E 00	4.0582E 10
5.7600E 00	5.4175E 00	-7.6608E 04	1.5490E 11	1.8788E 00	4.1437E 10
5.7000E 00	5.3600E 00	-8.1859E 04	1.5983E 11	1.8985E 00	4.2309E 10
5.6400E 00	5.3032E 00	-8.7020E 04	1.6476E 11	1.9179E 00	4.3170E 10
5.5800E 00	5.2469E 00	-9.2024E 04	1.6959E 11	1.9364E 00	4.4008E 10
5.5200E 00	5.1912E 00	-9.7219E 04	1.7462E 11	1.9554E 00	4.4873E 10
5.4600E 00	5.1360E 00	-1.0245E 05	1.7981E 11	1.9746E 00	4.5757E 10
5.4000E 00	5.0813E 00	-1.0748E 05	1.8482E 11	1.9927E 00	4.6602E 10
5.3400E 00	5.0272E 00	-1.1248E 05	1.8988E 11	2.0107E 00	4.7449E 10
5.2800E 00	4.9735E 00	-1.1762E 05	1.9513E 11	2.0291E 00	4.8322E 10
5.2200E 00	4.9204E 00	-1.2275E 05	2.0044E 11	2.0473E 00	4.9195E 10
5.1600E 00	4.8678E 00	-1.2782E 05	2.0574E 11	2.0652E 00	5.0061E 10
5.1000E 00	4.8157E 00	-1.3275E 05	2.1092E 11	2.0824E 00	5.0901E 10
5.0400E 00	4.7641E 00	-1.3782E 05	2.1629E 11	2.1000E 00	5.1766E 10
4.9800E 00	4.7130E 00	-1.4289E 05	2.2168E 11	2.1173E 00	5.2627E 10
4.9200E 00	4.6623E 00	-1.4806E 05	2.2727E 11	2.1349E 00	5.3514E 10
4.8600E 00	4.6121E 00	-1.5310E 05	2.3273E 11	2.1519E 00	5.4373E 10
4.8000E 00	4.5624E 00	-1.5800E 05	2.3808E 11	2.1682E 00	5.5210E 10
4.7400E 00	4.5131E 00	-1.6296E 05	2.4349E 11	2.1845E 00	5.6051E 10
4.6800E 00	4.4643E 00	-1.6784E 05	2.4886E 11	2.2005E 00	5.6881E 10
4.6200E 00	4.4159E 00	-1.7290E 05	2.5439E 11	2.2167E 00	5.7729E 10
4.5600E 00	4.3680E 00	-1.7816E 05	2.6027E 11	2.2336E 00	5.8625E 10
4.5000E 00	4.3206E 00	-1.8331E 05	2.6611E 11	2.2502E 00	5.9507E 10
4.4400E 00	4.2736E 00	-1.8823E 05	2.7162E 11	2.2656E 00	6.0338E 10
4.3800E 00	4.2270E 00	-1.9317E 05	2.7713E 11	2.2808E 00	6.1164E 10
4.3200E 00	4.1809E 00	-1.9827E 05	2.8286E 11	2.2964E 00	6.2016E 10
4.2600E 00	4.1353E 00	-2.0333E 05	2.8862E 11	2.3119E 00	6.2870E 10
4.2000E 00	4.0900E 00	-2.0819E 05	2.9411E 11	2.3265E 00	6.3680E 10
4.1400E 00	4.0452E 00	-2.1286E 05	2.9930E 11	2.3401E 00	6.4443E 10
4.0800E 00	4.0008E 00	-2.1755E 05	3.0444E 11	2.3534E 00	6.5196E 10
4.0200E 00	3.9568E 00	-2.2283E 05	3.1019E 11	2.3681E 00	6.6032E 10
3.9600E 00	3.9133E 00	-2.2970E 05	3.1816E 11	2.3882E 00	6.7171E 10
3.9000E 00	3.8704E 00	-2.3709E 05	3.2783E 11	2.4122E 00	6.8535E 10
3.8400E 00	3.8280E 00	-2.4137E 05	3.3331E 11	2.4256E 00	6.9316E 10
3.8000E 00	3.8000E 00	-2.4259E 05	3.3395E 11	2.4271E 00	6.9425E 10

TABLE 3

TABLE 4

t	X_ℓ	X_i
6.483 10^{-6}	3.5	3.8
6.765 "	3.5	3.729
6.913 "	3.490	3.706
7.005 "	3.446	3.693
7.223 "	3.349	3.659
7.390 "	3.285	3.621
7.537 "	3.234	3.574
7.701 "	3.179	3.510
7.83 "	3.137	3.453
7.964 "	3.090	3.390
8.104 "	3.037	3.326
8.249 "	2.970	3.270
8.402 "	2.890	3.213
8.620 "	2.764	3.132
8.857 "	2.628	3.037
9.050 "	2.524	2.953
9.257 "	2.420	2.857
9.405 "	2.344	2.785
9.642 "	2.223	2.665
9.812 "	2.133	2.576
1.009 10^{-5}	1.980	2.431
1.039 "	1.802	2.291
1.060 "	1.672	2.198
1.082 "	1.525	2.097
1.107 "	1.348	1.981
1.138 "	1.127	1.841
1.201 "	6.742 10^{-1}	1.560
1.246 "	3.524 "	1.365
1.271 "	2.507 "	1.260
1.292 "	2.453 "	1.181
1.313 "	2.670 "	1.104
1.337 "	2.965 "	1.057
1.360 "	3.224 "	1.120
1.377 "	3.440 "	1.193
1.398 "	3.694 "	1.275
1.424 "	4.173 "	1.390
1.451 "	4.957 "	1.50
1.478 "	5.924 "	1.591
1.504 "	6.910 "	1.667
1.529 "	7.883 "	1.730
1.553 "	8.883 "	1.784

ITER = 600 T = 6.7943E-06 DT = 5.8437E-10

H	R	U	RH	P	Q
8.8446E-02	3.5001E 00	2.0348E 01	8.9304E 00	1.0000E 06	0.
1.7689E-01	3.5006E 00	-7.2855E 00	8.9304E 00	5.9478E 07	2.4550E 05
2.6534E-01	3.5011E 00	-3.4919E 01	8.9299E 00	1.0000E 06	0.
3.5378E-01	3.5021E 00	-1.9417E 01	8.9295E 00	1.0000E 06	-0.
4.4223E-01	3.5031E 00	-3.9137E 00	8.9296E 00	1.0000E 06	0.
5.3068E-01	3.5046E 00	-2.1557E 01	8.9297E 00	1.0000E 06	1.0006E 05
6.1912E-01	3.5061E 00	-3.9199E 01	8.9298E 00	1.0000E 06	0.
7.0757E-01	3.5081E 00	-3.2817E 01	8.9299E 00	1.0000E 06	-0.
7.9601E-01	3.5101E 00	-2.6434E 01	8.9300E 00	1.0000E 06	0.
8.8446E-01	3.5126E 00	-2.4021E 01	8.9300E 00	1.0000E 06	-0.
9.7291E-01	3.5151E 00	-2.1609E 01	8.9301E 00	1.1188E 07	0.
1.0614E 00	3.5181E 00	-2.0898E 01	8.9301E 00	2.4389E 07	-0.
1.1498E 00	3.5211E 00	-2.0187E 01	8.9311E 00	1.7454E 08	0.
1.2382E 00	3.5245E 00	-1.9178E 02	8.9320E 00	3.2468E 08	9.4681E 06
1.3267E 00	3.5280E 00	-3.6338E 02	8.9441E 00	2.2355E 09	0.
1.4151E 00	3.5320E 00	-2.1422E 03	8.9561E 00	4.1464E 09	1.0201E 09
1.5036E 00	3.5359E 00	-3.9210E 03	9.0261E 00	1.5883E 10	0.
1.5920E 00	3.5403E 00	-1.2097E 04	9.0971E 00	2.7620E 10	2.1879E 10
1.6805E 00	3.5447E 00	-2.0273E 04	9.2817E 00	6.4120E 10	0.
1.7689E 00	3.5493E 00	-3.6959E 04	9.4740E 00	1.0062E 11	9.4861E 10
1.8574E 00	3.5540E 00	-5.3645E 04	9.7747E 00	1.7714E 11	0.
1.9458E 00	3.5588E 00	-7.6661E 04	1.0095E 01	2.5366E 11	1.9226E 11
2.0343E 00	3.5636E 00	-9.9678E 04	1.0490E 01	3.8426E 11	0.
2.1227E 00	3.5684E 00	-1.2534E 05	1.0917E 01	5.1486E 11	2.5846E 11
2.2111E 00	3.5732E 00	-1.5101E 05	1.1362E 01	6.9918E 11	0.
2.2996E 00	3.5780E 00	-1.7486E 05	1.1845E 01	8.8350E 11	2.4235E 11
2.3880E 00	3.5828E 00	-1.9872E 05	1.2261E 01	1.0883E 12	0.
2.4765E 00	3.5876E 00	-2.1643E 05	1.2707E 01	1.2932E 12	1.4334E 11
2.5649E 00	3.5924E 00	-2.3414E 05	1.2991E 01	1.4494E 12	0.
2.6534E 00	3.5973E 00	-2.4226E 05	1.3288E 01	1.6055E 12	3.1503E 10
2.7418E 00	3.6022E 00	-2.5038E 05	1.3336E 01	1.6360E 12	0.
2.8303E 00	3.6074E 00	-2.4606E 05	1.3385E 01	1.6664E 12	-0.
2.9187E 00	3.6126E 00	-2.4175E 05	1.3228E 01	1.5855E 12	0.
3.0072E 00	3.6182E 00	-2.3346E 05	1.3075E 01	1.5047E 12	-0.
3.0956E 00	3.6239E 00	-2.2518E 05	1.2984E 01	1.4614E 12	0.
3.1841E 00	3.6299E 00	-2.2360E 05	1.2895E 01	1.4181E 12	-0.
3.2725E 00	3.6359E 00	-2.2202E 05	1.2902E 01	1.4255E 12	0.
3.3609E 00	3.6422E 00	-2.2302E 05	1.2909E 01	1.4330E 12	4.6465E 08
3.4494E 00	3.6485E 00	-2.2402E 05	1.2914E 01	1.4403E 12	0.
3.5378E 00	3.6552E 00	-2.2358E 05	1.2919E 01	1.4476E 12	-0.
3.6263E 00	3.6618E 00	-2.2314E 05	1.2874E 01	1.4326E 12	0.
3.7147E 00	3.6688E 00	-2.1927E 05	1.2829E 01	1.4176E 12	-0.
3.8032E 00	3.6757E 00	-2.1539E 05	1.2691E 01	1.3634E 12	0.
3.8916E 00	3.6832E 00	-2.0689E 05	1.2556E 01	1.3093E 12	-0.
3.9801E 00	3.6906E 00	-1.9839E 05	1.2317E 01	1.2269E 12	0.
4.0685E 00	3.6987E 00	-1.8770E 05	1.2087E 01	1.1445E 12	-0.
4.1570E 00	3.7067E 00	-1.7700E 05	1.1804E 01	1.0683E 12	0.
4.2454E 00	3.7155E 00	-1.7108E 05	1.1534E 01	9.9210E 11	-0.
4.3339E 00	3.7243E 00	-1.6515E 05	4.4482E 00	9.8057E 11	0.
4.4223E 00	3.7620E 00	-1.2789E 05	2.7554E 00	9.6905E 11	0.
4.5107E 00	3.7997E 00	-9.0622E 04	2.7789E 00	9.7284E 11	0.
4.5992E 00	3.8754E 00	-8.1458E 04	2.8029E 00	9.7664E 11	0.
4.8645E 00	3.9512E 00	-7.2295E 04	3.2626E 00	1.0187E 12	0.
5.1299E 00	4.0375E 00	-8.3197E 04	3.9029E 00	1.0607E 12	1.6700E 10
5.3952E 00	4.1239E 00	-9.4099E 04	3.7945E 00	9.4561E 11	0.
5.6606E 00	4.2203E 00	-1.1737E 05	3.6920E 00	8.3055E 11	7.1966E 10
5.9259E 00	4.3167E 00	-1.4064E 05	3.6057E 00	7.5866E 11	0.
6.1912E 00	4.4221E 00	-1.4147E 05	3.5233E 00	6.8676E 11	8.7766E 07
6.4566E 00	4.5276E 00	-1.4230E 05	3.5032E 00	6.6247E 11	0.
6.7219E 00	4.6380E 00	-1.3090E 05	3.4834E 00	6.3818E 11	0.
6.9873E 00	4.7484E 00	-1.1950E 05	3.4665E 00	6.1832E 11	0.
7.2526E 00	4.8631E 00	-1.0793E 05	3.4497E 00	5.9846E 11	0.
7.5179E 00	4.9778E 00	-9.6369E 04	3.4234E 00	5.7617E 11	0.
7.7833E 00	5.0971E 00	-8.5017E 04	3.3974E 00	5.5388E 11	0.
8.0486E 00	5.2163E 00	-7.3666E 04	3.3614E 00	5.2945E 11	0.
8.3140E 00	5.3405E 00	-6.2560E 04	3.3262E 00	5.0501E 11	0.
8.5793E 00	5.4647E 00	-5.1454E 04	3.2817E 00	4.7960E 11	0.
8.8446E 00	5.5942E 00	-4.0356E 04	3.2384E 00	4.5420E 11	0.
9.1100E 00	5.7238E 00	-2.9258E 04	3.1859E 00	4.2827E 11	0.
9.3753E 00	5.8592E 00	-1.8172E 04	3.1350E 00	4.0235E 11	0.
9.6407E 00	5.9946E 00	-7.0858E 03	3.0738E 00	3.7635E 11	0.
9.9060E 00	6.1367E 00	4.1714E 03	3.0150E 00	3.5036E 11	0.
1.0171E 01	6.2788E 00	1.5429E 04	2.9460E 00	3.2489E 11	0.
1.0437E 01	6.4283E 00	2.6798E 04	2.8801E 00	2.9943E 11	0.
1.0702E 01	6.5779E 00	3.8168E 04	2.8021E 00	2.7478E 11	0.
1.0967E 01	6.7363E 00	4.9830E 04	2.7282E 00	2.5014E 11	0.
1.1233E 01	6.8946E 00	6.1491E 04	2.6407E 00	2.2664E 11	0.
1.1498E 01	7.0634E 00	7.3558E 04	2.5587E 00	2.0314E 11	0.
1.1763E 01	7.2322E 00	8.5625E 04	2.4607E 00	1.8120E 11	0.
1.2029E 01	7.4139E 00	9.8291E 04	2.3700E 00	1.5927E 11	0.
1.2294E 01	7.5955E 00	1.1096E 05	2.2597E 00	1.3921E 11	0.
1.2559E 01	7.7935E 00	1.2444E 05	2.1592E 00	1.1915E 11	0.
1.2825E 01	7.9916E 00	1.3792E 05	2.0328E 00	1.0122E 11	0.
1.3090E 01	8.2118E 00	1.5273E 05	1.9204E 00	8.3288E 10	0.
1.3355E 01	8.4321E 00	1.6754E 05	1.7728E 00	6.7696E 10	0.
1.3621E 01	8.6849E 00	1.8425E 05	1.6462E 00	5.2103E 10	0.
1.3886E 01	8.9376E 00	2.0096E 05	1.4641E 00	3.9396E 10	0.
1.4151E 01	9.2457E 00	2.2109E 05	1.3182E 00	2.6688E 10	0.
1.4417E 01	9.5538E 00	2.4122E 05	1.0541E 00	1.7436E 10	0.
1.4682E 01	9.9975E 00	2.7030E 05	8.7822E-01	8.1847E 09	0.
1.4947E 01	1.0441E 01	2.9939E 05	8.7822E-01	4.0923E 09	0.
1.5213E 01	1.1718E 01	4.0000E 05	0.	0.	0.

TABLE 5

ITER = 4700   T = 1.2464E-05   DT = 3.3261E-09

H	R	U	RH	P	Q
8.8446E-02	3.5243E-01	-6.0612E 05	1.6780E 01	3.7827E 12	0.
1.7689E-01	3.5505E-01	-6.0623E 05	1.6780E 01	3.8188E 12	6.6105E 06
2.6534E-01	3.5768E-01	-6.0633E 05	1.6692E 01	3.7413E 12	0.
3.5378E-01	3.6287E-01	-6.0656E 05	1.6606E 01	3.6638E 12	3.1563E 07
4.4223E-01	3.6806E-01	-6.0679E 05	1.6453E 01	3.5415E 12	0.
5.3068E-01	3.7573E-01	-6.0744E 05	1.6303E 01	3.4192E 12	2.4674E 08
6.1912E-01	3.8339E-01	-6.0809E 05	1.6082E 01	3.2613E 12	0.
7.0757E-01	3.9341E-01	-6.0917E 05	1.5868E 01	3.1034E 12	6.6057E 08
7.9601E-01	4.0344E-01	-6.1024E 05	1.5595E 01	2.9210E 12	0.
8.8446E-01	4.1571E-01	-6.1182E 05	1.5332E 01	2.7387E 12	1.3643E 09
9.7291E-01	4.2799E-01	-6.1339E 05	1.5031E 01	2.5472E 12	0.
1.0614E 00	4.4238E-01	-6.1481E 05	1.4741E 01	2.3556E 12	1.0635E 09
1.1498E 00	4.5678E-01	-6.1623E 05	1.4435E 01	2.1748E 12	0.
1.2382E 00	4.7314E-01	-6.1656E 05	1.4141E 01	1.9939E 12	5.6197E 07
1.3267E 00	4.8951E-01	-6.1689E 05	1.3855E 01	1.8390E 12	0.
1.4151E 00	5.0767E-01	-6.1516E 05	1.3580E 01	1.6841E 12	-0.
1.5036E 00	5.2582E-01	-6.1343E 05	1.3333E 01	1.5619E 12	0.
1.5920E 00	5.4553E-01	-6.0928E 05	1.3095E 01	1.4398E 12	-0.
1.6805E 00	5.6524E-01	-6.0513E 05	1.2886E 01	1.3455E 12	0.
1.7689E 00	5.8628E-01	-5.9925E 05	1.2684E 01	1.2512E 12	-0.
1.8574E 00	6.0732E-01	-5.9337E 05	1.2511E 01	1.1782E 12	0.
1.9458E 00	6.2947E-01	-5.8653E 05	1.2342E 01	1.1053E 12	-0.
2.0343E 00	6.5163E-01	-5.7968E 05	1.2185E 01	1.0454E 12	0.
2.1227E 00	6.7475E-01	-5.7262E 05	1.2031E 01	9.8562E 11	-0.
2.2111E 00	6.9788E-01	-5.6557E 05	1.1888E 01	9.3529E 11	0.
2.2996E 00	7.2186E-01	-5.5872E 05	1.1748E 01	8.8496E 11	-0.
2.3880E 00	7.4585E-01	-5.5187E 05	1.1603E 01	8.4016E 11	0.
2.4765E 00	7.7064E-01	-5.4554E 05	1.1462E 01	7.9535E 11	-0.
2.5649E 00	7.9544E-01	-5.3920E 05	1.1358E 01	7.5488E 11	0.
2.6534E 00	8.2084E-01	-5.3342E 05	1.1256E 01	7.1440E 11	-0.
2.7418E 00	8.4624E-01	-5.2764E 05	1.1115E 01	6.7603E 11	0.
2.8303E 00	8.7238E-01	-5.2226E 05	1.0978E 01	6.3766E 11	-0.
2.9187E 00	8.9852E-01	-5.1688E 05	1.0842E 01	5.9855E 11	0.
3.0072E 00	9.2536E-01	-5.1160E 05	1.0710E 01	5.5943E 11	-0.
3.0956E 00	9.5220E-01	-5.0633E 05	1.0598E 01	5.1949E 11	0.
3.1841E 00	9.7961E-01	-5.0112E 05	1.0488E 01	4.7955E 11	-0.
3.2725E 00	1.0070E 00	-4.9591E 05	1.0351E 01	4.4095E 11	0.
3.3609E 00	1.0351E 00	-4.9103E 05	1.0217E 01	4.0234E 11	-0.
3.4494E 00	1.0632E 00	-4.8615E 05	1.0084E 01	3.6878E 11	0.
3.5378E 00	1.0920E 00	-4.8128E 05	9.9550E 00	3.3521E 11	-0.
3.6263E 00	1.1208E 00	-4.7641E 05	9.8311E 00	3.0771E 11	0.
3.7147E 00	1.1502E 00	-4.7099E 05	9.7102E 00	2.8020E 11	-0.
3.8032E 00	1.1796E 00	-4.6557E 05	9.5809E 00	2.5711E 11	0.
3.8916E 00	1.2097E 00	-4.5925E 05	9.4549E 00	2.3402E 11	-0.
3.9801E 00	1.2398E 00	-4.5292E 05	9.2923E 00	2.1338E 11	0.
4.0685E 00	1.2708E 00	-4.4589E 05	9.1352E 00	1.9274E 11	-0.
4.1570E 00	1.3018E 00	-4.3885E 05	9.0148E 00	1.7342E 11	0.
4.2454E 00	1.3335E 00	-4.3099E 05	8.8976E 00	1.5410E 11	-0.
4.3339E 00	1.3651E 00	-4.2312E 05	2.3535E 00	1.3607E 11	0.
4.4223E 00	1.5511E 00	-4.1521E 05	1.3561E 00	1.1804E 11	0.
4.5107E 00	1.7370E 00	-4.0729E 05	1.4254E 00	1.3412E 11	0.
4.5992E 00	1.9991E 00	-3.5920E 05	1.5021E 00	1.5019E 11	0.
4.8645E 00	2.2613E 00	-3.1110E 05	1.6200E 00	1.2354E 11	0.
5.1299E 00	2.5633E 00	-2.8647E 05	1.7581E 00	9.6888E 10	0.
5.3952E 00	2.8653E 00	-2.6185E 05	1.7372E 00	9.0367E 10	0.
5.6606E 00	3.1437E 00	-2.2408E 05	1.7167E 00	8.3845E 10	0.
5.9259E 00	3.4220E 00	-1.8632E 05	1.7207E 00	8.2368E 10	0.
6.1912E 00	3.6807E 00	-1.5986E 05	1.7247E 00	8.0890E 10	0.
6.4566E 00	3.9395E 00	-1.3339E 05	1.6926E 00	7.5166E 10	0.
6.7219E 00	4.1954E 00	-1.1075E 05	1.6617E 00	6.9443E 10	0.
6.9873E 00	4.4512E 00	-8.8099E 04	1.6499E 00	6.6821E 10	0.
7.2526E 00	4.7011E 00	-6.0841E 04	1.6383E 00	6.4199E 10	0.
7.5179E 00	4.9509E 00	-3.3583E 04	1.6575E 00	6.5449E 10	0.
7.7833E 00	5.1883E 00	-3.3234E 03	1.6772E 00	6.6698E 10	0.
8.0486E 00	5.4256E 00	2.6936E 04	1.7189E 00	7.0955E 10	0.
8.3140E 00	5.6472E 00	5.7014E 04	1.7627E 00	7.5213E 10	0.
8.5793E 00	5.8688E 00	8.7091E 04	1.8020E 00	7.9487E 10	0.
8.8446E 00	6.0783E 00	1.1013E 05	1.8430E 00	8.3762E 10	0.
9.1100E 00	6.2878E 00	1.3317E 05	1.8498E 00	8.3680E 10	0.
9.3753E 00	6.4941E 00	1.5108E 05	1.8567E 00	8.3598E 10	0.
9.6407E 00	6.7004E 00	1.6899E 05	1.8741E 00	8.5079E 10	0.
9.9060E 00	6.9017E 00	1.9450E 05	1.8919E 00	8.6559E 10	0.
1.0171E 01	7.1030E 00	2.2001E 05	1.9582E 00	9.5649E 10	0.
1.0437E 01	7.2902E 00	2.4364E 05	2.0293E 00	1.0474E 11	0.
1.0702E 01	7.4774E 00	2.6726E 05	2.0138E 00	1.0152E 11	0.
1.0967E 01	7.6673E 00	2.6643E 05	1.9986E 00	9.8303E 10	5.0297E 07
1.1233E 01	7.8572E 00	2.6559E 05	1.8791E 00	8.2945E 10	0.
1.1498E 01	8.0704E 00	2.6111E 05	1.7731E 00	6.7582E 10	1.2797E 09
1.1763E 01	8.2836E 00	2.5663E 05	1.6837E 00	5.8419E 10	0.
1.2029E 01	8.5174E 00	2.6217E 05	1.6028E 00	4.9255E 10	0.
1.2294E 01	8.7512E 00	2.6770E 05	1.5354E 00	4.3553E 10	0.
1.2559E 01	9.0025E 00	2.7499E 05	1.4734E 00	3.7851E 10	0.
1.2825E 01	9.2537E 00	2.8228E 05	1.3946E 00	3.2566E 10	0.
1.3090E 01	9.5290E 00	2.8899E 05	1.3239E 00	2.7282E 10	0.
1.3355E 01	9.8043E 00	2.9570E 05	1.2268E 00	2.2360E 10	0.
1.3621E 01	1.0117E 01	3.0210E 05	1.1430E 00	1.7438E 10	0.
1.3886E 01	1.0429E 01	3.0849E 05	1.0193E 00	1.3251E 10	0.
1.4151E 01	1.0807E 01	3.1518E 05	9.1970E-01	9.0631E 09	0.
1.4417E 01	1.1185E 01	3.2188E 05	7.3901E-01	5.9551E 09	0.
1.4682E 01	1.1723E 01	3.2949E 05	6.1767E-01	2.8471E 09	0.
1.4947E 01	1.2261E 01	3.3711E 05	6.1767E-01	1.4235E 09	0.
1.5213E 01	1.3985E 01	4.0000E 05	0.	0.	0.

TABLE 6

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Alfred Nobel

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