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THEORY OF DETONATIONS

PROGRESS REPORT

October 1, 1951

OFFICE OF NAVAL RESEARCH

CONTRACT NUMBER

N7 onr 45107

PROJECT NUMBER

NR 056 239

u72222

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University of Utah
Salt Lake City

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Contract N7onr-45107

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THEORY OF DETONATIONS

Problem No. 1:- "Effect of Charge Radius on Detonation Velocity"

The theory of the detonation wave in a finite charge is being investigated, following the general approach suggested in previous reports and publications from this laboratory and elsewhere (OSRD report numbers 2026, 3794, 3796; Chem. Rev. 45, 69 (1949)). → For a curved detonation front, it is possible to calculate the radial detonation velocity on the assumption that (1) the reaction zone length is constant, (2) the flow in any small region of the shock front is spherical and (3) of the thermodynamic-hydrodynamic continuity equations for a steady-state detonation wave only the equation for the conservation of matter is strongly perturbed by the edge effects. For an unconfined charge, the analysis leads to the result

$$y_c/a_0 = \frac{\gamma(\gamma + a)}{2(1 + \gamma)(1 - a)} K_c - \frac{\gamma - 2 + 2a}{2(1 - a)}$$

where

y_c = charge radius

a_0 = reaction zone length

γ = ratio of heat capacities for reaction products

a = (constant) co-volume in the equation of state:

$$P(V - V_0 a) = RT, (V_0 \text{ the initial specific volume})$$

and

$$K_c = \frac{2}{\delta \sqrt{1 - \delta^2}} \arctan(\sqrt{1 + \delta} / \sqrt{1 - \delta}) - \pi/2\delta$$

with

$\delta = D_0/D_1$, D_0 the stable detonation velocity in a finite charge of radius y_c , D_1 the ideal, hydrodynamic velocity for an infinite charge of the same composition and initial density.

Details of the analysis may be found in Technical Report Number 1, Contract N7onr-45107, T.O. 7. The present treatment also provides equations describing the cross-sectional shape of the detonation front, in terms of the reaction zone length and the physical parameters characterizing the explosive: since accurate experimental data on the curvature of detonation wave fronts is not presently at hand it has not been possible to verify the correctness of the predicted curvatures directly.

Certain approximations have been employed in order to permit a closed form result for the velocity - charge radius relationship. The terms neglected by these approximations become significant in the region near the edge of the charge where the wave-front becomes very highly curved, and in which the radius of curvature becomes of the same magnitude as the assumed reaction zone length. While it is possible to correct the mathematical treatment, by dropping the approximations in the equations, it will still be true that the physical assumption of a constant reaction zone length is almost certainly erroneous in this region. Since the first of these corrections will tend to decrease the apparent detonation velocity for a given charge diameter, and the second will tend to have the opposite effect, it is felt that the net effect will be to give essentially the same result for the corrected theory as has been obtained in the present treatment. In addition, because of the very rapid bending over of the wave front near the edge of the charge, the exact form of the equations is important only to the shock-front profile, not to the radius-velocity relationship. Work presently in progress is designed to provide quantitative justification of these assumptions.

Other proposed researches will include application of the equations above to experimental data on detonation velocities in finite charges, reduction of the equations to forms more suitable for such application, and an analysis of the theory of confined charges. Investigation of this problem is being carried out by Professors Parlin and Thorne and Mr. Robinson.

Problem No. 2:- "Oscillations of a Spherical Gas Bubble"

It is proposed to obtain a solution for the non-linear differential equation

$$d^2R/dt^2 + (3/2R)(dR/dt)^2 + a/R - b/R^{3n+1} = 0, \quad (1)$$

a,b,n constant,

which governs the oscillations of a spherical gas-filled cavity created in a fluid by an under-surface explosion.

An integral solution of (1) containing one arbitrary constant, to be

determined from the boundary condition used, has been arrived at by four different methods. For particular values of $n \leq 1$ closed solutions of (1) have been obtained.

Using the boundary condition

$$dR/dt = 0 \text{ when } R = S > 0, (S = \text{max. } R) \quad (2)$$

and taking $n = 4/3, 5/3$ or 2 , the minimum values of R corresponding to given maximum values have been found; in addition, lower and upper bounds for all maxima and minima, respectively, were established for given a and b . One can also show that $R > 0$ for all time.

After determining the constant of integration by utilizing condition (2), the numerical solution of (1) was carried through with $n = 4/3, 5/3$ and 2 .

An extension of these results for a general n , ($1 \leq n \leq 2$), is contemplated and a series expansion of the integral solution intended. We are also anticipating a testing of hypotheses on methods of energy loss after which a detailed report will be forthcoming.

This problem is being carried out by Professor C.J. Thorne and Mrs. L.C. Barrett.

Problem No. 3:- "Methods of Solution in Non-Linear Differential Equations."

Both new and standard methods have been compiled and developed for the solution of non-linear differential equations, especially solutions in terms of integrals and elementary functions, as contracted with approximate or numerical solutions. The emphasis has been upon equations with quite general functional coefficients, rather than in very highly specialized or restricted cases.

A method based on the reversal of the roles of dependent and independent variables is being studied for differential equations of order ≥ 2 . This approach yields for each type of equation already solvable by standard procedures a (usually) non-linear type that can be solved. A formula has been developed to reveal the cases in which this method is applicable, both for the general n -th order equation and particularly for the second order equation.

An investigation of equivalent forms among non-linear differential

equations is also in progress. This work is under the direction of Professor C. J. Thorne who is assisted by Mr. B. L. McAllister.

Problem No. 4:-

A catalogue of non-linear problems appearing in the literature is being assembled. At present the coverage includes the journals Mathematics Reviews and Mechanics Reviews and U. S. Government publications. Thorne and Robinson.