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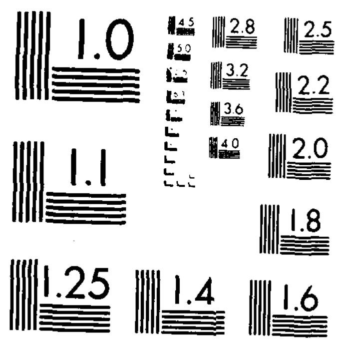
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FINAL REPORT

OFFICE OF NAVAL RESEARCH

CONTRACT N00014-85-K-0403

California Institute of Technology

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Shock waves, solitons, roll waves; nonlinear wave propagation; numerical methods.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

N.A.

This final report is a summary of work under Contract.

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1. Summary of scientific work.

(a) Shock Dynamics.

Most of the work has been on shock dynamics, a term we use for problems of the focusing of curved shocks, the diffraction of shocks by bodies or density layers, the propagation of shocks down curved tubes and channels, and the stability of converging shocks. Our earlier theoretical work is described in the book "Linear and Nonlinear" by G.B. Whitham, and references given there.

This theoretical work on shock dynamics had been found by experimenters to be extremely useful in practical situations. However, the analytic results had been limited to fairly simple situations. The numerical scheme originally proposed was again limited and could not hope to handle some of the interesting practical situations. Specific experimental results include (1) the complicated patterns that are formed when concave shock waves focus, (Sturtevant and Kulkarney 1976) (2) the diffraction/refraction patterns that are produced when a plane shock wave passes a sphere of gas (Sturtevant and Haas), (3) shock propagation in curved pipes (Edwards, Fearnley and Nettleton 1983), (4) evacuation of shock into a large chamber (Sloan and Nettleton 1975 and 1978), and (5) the stability of converging shocks (many investigators).

The theory is a nonlinear version of geometrical optics in which the ray geometry is coupled nonlinearly with the geometry of the advancing shock fronts. The whole network has to be determined simultaneously.

Appropriate partial differential equations to describe this system can be obtained and the analytic solutions referred to above were found. The original proposal for numerical calculations was simply to compute solutions of these partial differential equations by finite differences or by the method of characteristics. But the fitting in of the Mach shocks (a main feature of these problems) becomes prohibitive even in fairly simple situations. It was true for the two-dimensional cases considered at that time. This approach to calculations for the three dimensional theory would seem to be out of the question.

In the current work under this contract we started on a new approach. The idea is very simple. Successive positions of the shock front are computed from the relation to the ray tube evolution by advancing directly a set of points on the shock by its appropriate velocity determined from the latest ray tube area. The whole art is in managing the Mach shock discontinuities. We have been successful in doing this satisfactorily, and ultimately with great ease, for all the cases noted above, as well as to cases involving a number of interacting Mach shocks in both two and three dimensions.

Publication No. 1 describes the basic method with applications to diffraction by solid bodies, propagation down curved tubes and focusing of curved shocks. This simplifies and extends earlier work and allows further checks with experimental results, with very good agreement.

Publication No. 5 describes the extensions required for the application to shock interaction with density layers. In particular diffraction and refraction by wedges and spheres of heavier and by lighter gases were studied in detail since these have been the subject of considerable experimental work. Again there is excellent agreement.

Publication No. 3 is on the stability of converging cylindrical shocks. Here, new analytic results for the stability of polygonal shapes were found. Together with numerical work on neighboring shapes, these results show that converging shocks should be quite stable.

Publication No. 4 is a brief note on a technical point about the basic theory which had been raised in the literature.

All the above is for two-dimensional problems. The highly non-trivial extensions to three-dimensions are developed in Publication No. 6.

(b) The generation of upstream solitons and downstream wave pattern in free surface flow over an obstacle.

When water of finite depth flows over a submerged body at speeds close to the critical speed for gravity waves, experiments and numerical analysis show curious wave patterns which are crucially nonlinear. The most distinct feature is an unsteady series of 'free' solitons heading upstream. We have developed analytic approaches to describe these patterns and this analysis greatly aids the understanding of the phenomena.

There are other applications to atmospheric flow over ground topography. The work is described in Publication No. 2.

(c) Roll waves.

There are various unstable flows that lead to the development of a series of successive shock waves. The classic case concerns water waves in steep flood channels. But analogous cases arise in traffic flow and we suspect possibly in certain situations of oil extraction by water flooding.

The water wave case is referred to as "rollwaves" and stresses the appearance of a periodic solution with equally spaced shocks (hydraulic jumps in this case). We developed a theory to follow in detail the build-up of small perturbations into the final nonlinear form.

If the initial perturbation is periodic, the final form will be also. But there is no tendency for a general perturbation to approach a periodic form, as has sometimes been suggested in the literature. Experiments had already shown this and our theory explains it.

These specific problems may not be of direct interest to the Navy, but the general mathematical question of what final nonlinear forms develop from small initial disturbances is a general one. For example, it is basic in questions of hydrodynamic instability and the development of turbulent slugs and spots. Our hope is to veer in this direction.

(d) Other current work.

This has been beginning attempts on the problems described in the proposed renewal submitted in June 1987. However, it is in a partial form, too loose and extensive to describe here. And the renewal was not approved, which might indicate a lack of interest on O.N.R's part.

2. Technical Reports.

With the approval of successive scientific officers, we have been issuing published articles as technical reports. For the current contract:

Publications 1 and 2 were issued as T.N. 51 and 52.
Publications 3 and 4 are about to be issued as T.N. 53 and 54.
Publications 5 and 6 will be issued as T.N. 55 and 56 when reprints are available. Of course manuscripts are available if required.

3. Publications.

1. "Numerical shock propagation using geometrical shock dynamics" by W.D. Henshaw, N.F. Smyth and D.W. Schwendeman. Journal of Fluid Mechanics, Vol.171, 519-545, 1986.

2. "Modulation theory for resonant flow over topography" by N.F. Smyth. Proc. Royal Society, Vol.A409, 79-97, 1987.

3. "On converging shock waves" by D.W. Schwendeman and G.B. Whitham. Proc. Royal Society, Vol.A413, 297-311, 1987.

4. "On shock dynamics" by G.B. Whitham. Proc. Indian Academy of Sciences (Math. Sci.), Vol.96, 71-73, 1987.

5. "Numerical shock propagation in nonuniform media" by D.W. Schwendeman. To appear in Journal of Fluid Mechanics.

6. "A numerical scheme for shock propagation in three dimensions" by D.W. Schwendeman. To appear in Proc. Royal Society.

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