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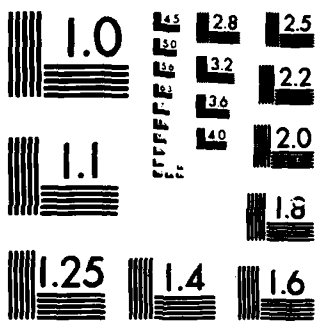

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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Shock wave, Mach stem, Mach triple point, contact discontinuity, detonation wave, Chapman-Jouget point, ZND theory, Riemann problem, slip line

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

The front tracking method has been shown to be correct and useful for a range of gas dynamics problems containing shock waves, slip lines, material boundaries and detonation waves. Validation tests compared to laboratory experiment, analytic solutions and independently validated numerical computations showns this method to be correct. Several definitive successes, both

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theoretical and numerical, have been achieved as part of this effort.

Classification of two dimensional elementary waves and a correct formulation of the two dimensional Riemann problem were first achieved under this contract. Models for curved detonation fronts were studied, to find wave speed dependence on front curvature. This was a major open problem in the modeling of detonation waves.

Computations of many elementary wave interactions were tested, including the Mach triple point, regular reflection, and the shock-contact interactions of two basic types. Detailed validation of density contours was made possible because of the high quality experimental data available. Certain interactions between tracked waves, leading to bifurcation of wave topology, were completed.

The level of success achieved went well beyond that expected by others at the outset of this study.

The main conclusion is that front tracking has been shown to be a useful and promising method for pratical shock wave computations.

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Computational Techniques for Shock Wave Diffraction Problems

Final Report

James Glimm

January 2, 1986

U. S. ARMY RESEARCH OFFICE

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COMPUTATIONAL TECHNIQUES FOR SHOCK WAVE DIFFRACTION PROBLEMS

1. Introduction

Front tracking has been demonstrated to work: it is scientifically correct and it is usable on a wide range of scientific problems. It shows promise for use in practical problems. These conclusions settle a major controversy concerning this methodology. Ongoing work in needed to demonstrate practical usability.

Front tracking uses analytic knowledge concerning solution singularities within the computational process. Where necessary, such information is developed, so that this method requires both numerical and theoretical thrusts within the research.

A general discussion of the methods and the results obtained can be found in various survey papers [2, 5, 6, 12, 15].

2. Scientific Modeling

Front tracking requires and uses a deeper analytic knowledge of solution behavior. Often this knowledge is contained in a Riemann problem, which gives idealized behavior near an isolated jump discontinuity in a solution. A major advance for the mathematical modeling of detonation waves has come out of the front tracking effort. In order to move a curvilinear detonation front in two or higher dimensions, it is necessary to know the detonation velocity. While the velocity of a planar front can be determined from the solution of an ordinary differential equation without a detailed knowledge of the chemistry, a curved (especially an expanding) detonation front has a velocity which depends on an interaction between the front curvature and the chemistry. In [17] a theory has been developed to give this velocity, to leading order in powers of the inverse radius of curvature. This theory solves a major open problem in the mathematical modeling of detonation fronts.

The interaction of nonlinear waves with nonconvex flux functions is highly complex. In work supported elsewhere, very interesting new phenomena has been uncovered in the study of Riemann problems in the large. Much of this work was a direct outgrowth of the front tracking program and its requirements for deeper analytic knowledge of solution behavior.

The meeting of fronts in higher dimensions defines discontinuities of higher codimension. The general conceptual issues surrounding such higher dimensional Riemann problems had been rather opaque, but were resolved in work included within this report [13, 14]. The main idea is that a Riemann problem is scale invariant, as is its solution (in general); the further symmetry of being stationary in some frame defines an elementary wave. In general, the solution of a Riemann problem will break up into distinct elementary waves, just as the outgoing wave operator in a scattering problem resolves an incoming signal into distinct outgoing scattering centers. For the case of a gamma law gas, the elementary waves in two space dimensions were classified, and a remarkably simple answer was obtained, which waves classified as: Mach triple point, cross, overtake, diffraction and transmission [9, 10]. In work supported elsewhere, it was also found that symmetry breaking solutions of Riemann problems may play a role. A construction was also presented which indicates that the solutions will not in general be piecewise smooth.

3. Numerical Methods

A series of numerical issues have arisen and have been solved within the front tracking studies. The coupling of the front to the interior has been resolved on the basis of considering nonlocal Riemann problems so that the front states obtain information from the full domain of dependence in an interval of up to one mesh spacing on each side of the front [3, 7]. Furthermore the interior scheme difference stencil obtains states only from its own component, so that there are no numerical derivatives connecting states on distinct sides of the front. Further study of such questions is still desired. Corrections for radially induced source terms were studied in [4]. Methods for computation of Mach triple points were reported in [9, 10]. Changes of front topology are equivalent to solving certain two dimensional Riemann problems. This issue is an important aspect of the ability to handle problems of moderate complexity. Progress has been reported in [2, 16]. Extension of the front tracking method to detonation waves was accomplished in [1], and the validation of Jones' theory for curvature effects on the wave speed velocity was accomplished by comparison to a radially symmetric calculation with both geometrical and chemical effects fully resolved in work in progress by Bukiet.

4. Simulation

Front tracking computations have been compared to experiment [3, 9, 10], to show agreement between detailed computed and experimental flow features. Front tracking has been used to study interface instabilities for incompressible [8] and compressible [2] fluids. Because of the high resolution of this method, it appears likely that if will be helpful in the study of the transition to chaos, in which the interfaces become highly convoluted and entrained.

5. Software

The minimization of software complexities inherent in the front tracking methodology has been of critical importance. This goal has been achieved by the use of several strategies, including modular programming in terms of well thought through software packages and data structures. As an example software packages have been developed for the tracking and manipulation of multiple fronts or interfaces. The purely geometrical aspect of this package has been described in detail in [11]. It consists of data structures, calling sequences and support routines as well as basic utility functions such as a locate routine to determine efficiently on which side of various curves (i.e. in which connected component) a given point lies. This code is now available for public release.

It is planned to prepare for release other portions of the front tracking code, including higher level functions such as Riemann solvers and shock polars which depend on equation of state tables.

In work associated with this project but supported elsewhere, software for elliptic equations, utilities and graphics has been developed. Considerable effort has been devoted to ensure the generality of these packages, which are still in evolution due to the complexity of the computer science issues involved.

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