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Analytical and Numerical Study of Sequential Contact Surface Turbulization in Richtmyer–Meshkov Instability

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Abstract. Analytical solutions of plane shock wave refraction on an inclined interface at its transition in a denser matter are compared with numerical results calculated with sequentially decreased grids. The finite-difference code properties are studied for all basic cases of gas dynamic discontinuity decays. The numerical simulation results of the single-mode contact surface sequential turbulization for the 2D and 3D cases are presented.

1 Introduction

Richtmyer–Meshkov instability development starts from a shock wave refraction on the disturbed interface. The processes, taking place during this period, determine many physical phenomenon peculiarities observed experimentally later. The shock wave refraction on the plane interface may be studied analytically in some cases.

2 Comparative Study of a Shock Wave Refraction on an Inclined Interface at its Transition to a Denser Matter

Analytic solution is obtained considering piecewise constant self–similar flow character [1]. Rankine–Hugoniot equations for transmitted and reflected shock waves, equations for tangential discontinuities and correlations between shock wave velocities form the system of thirteen algebraic equations which may be transformed to one algebraic equation of the eighth power in the case of the $M = 2.5$ shock wave transition from helium to xenon and at the initial pressure of 0.5 bar. This analytic solution doesn't exist if the initial plane interface inclination is less than the critical value which is equal to 48.18^o in this case. The regular refraction regime is changed with the irregular one. The refraction numerical study was carried out with the help of Euler equations system solution with the grid-characteristic method. Computational results showing the Mach reflection and the distorted form of the shock wave are shown in Figures 1 and 2.

3 The Test Computations

The model calculations are concerned with the arbitrary discontinuity decay with the formation: 1) two shock waves, 2) one rarefaction and one shock wave, and 3) two centered rarefaction waves where the discontinuity jump value achieves the order of six–seven for one or several gas-dynamic parameters. The calculations have been performed to examine characteristics of the computational code [2]. There are analytic solutions for these cases which have been compared with the numerical calculation results performed on the sequentially doubled space-time dependent finite grids. As an example, the task of two colliding infinite plane layers of aluminum with a density of 2.7g/cm^3, $\gamma = 5/3$ has been studied. One layer has 10μk thickness, the other 50μk. At the first moment there temperature is the same and equals 250^{o}K. The layers are surrounded by stationary aluminum vapors having a density of 10^{-5}g/cm^3 and the same temperature. The thicker layer runs into the thin one at the relative speed of 80km/s. The density (Fig. 3) and negative velocity (Fig. 4) versus the Cartesian coordinate x are presented at the moment 150 ps after the interaction begins. The task [3] may be used as an example of 3D computations with the help of this solver.

4 Interface Turbulization in Richtmyer–Meshkov Instability

Let's trace sequentially the process of the interface turbulization when the initial disturbance satisfies the condition $a \approx \lambda$ where a = 10mm (amplitude), λ = 8mm (sine disturbance wavelength). The M = 2.5 shock wave passes from helium into xenon at the initial pressure of 0.5 bar. In this case the regular refraction regime is observed at the distance of 13 mm from the disturbance amplitude maximum, then it is changed by an irregular one which was examined above in item 1. As the result severely distorted reflected shock waves (from adjacent half-lengths of the initial disturbance wave) interact between themselves before the refraction process completion [4]. On the other hand, because of the lesser refracted shock wave inclination in xenon (in comparison with the case of the regular refraction [5]), the higher pressure domain forms in the latter, that leads to the more accelerated interface turbulization in comparison with the case of $a \ll \lambda$ (Fig. 5). In the 3D case, there is one more dimensional direction in which the initial interface is disturbed as well. As the result, the pressure in the high pressure domain forming in xenon increases more than in the 2D case (Fig. 6). The developed program package for 2D and 3D processes numerical simulation enable to analyze physical phenomena in the course of slide-film seeing and to receive the numerical information about basic physical parameter at the same time.

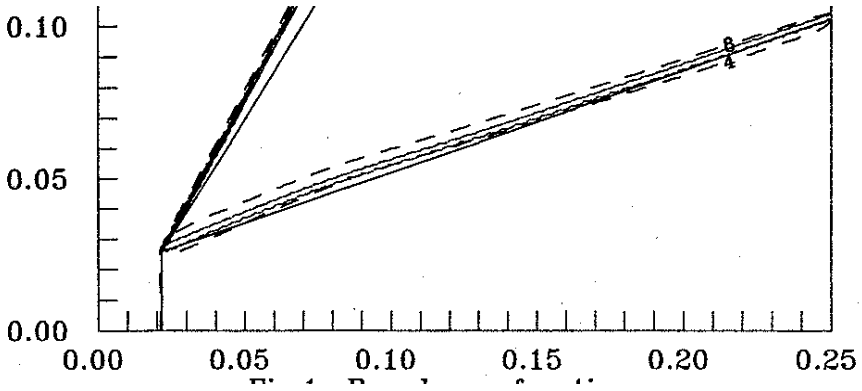


Figure 1: Regular refraction: Isobars corresponding to an initial contact interface inclination of 50^o for two computations on uniform grids with mesh $h_x = h_y = 7.3 * 10^{-4}$ (dotted line), $h_x = h_y = 7.3 * 10^{-4}$ (solid line).

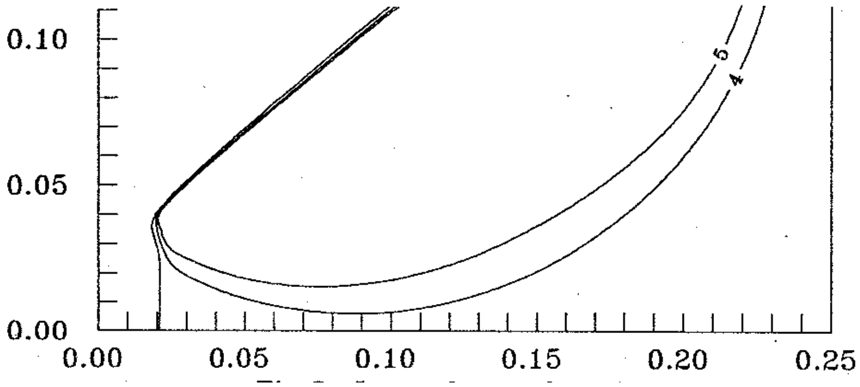


Figure 2: Irregular refraction: The pressure distribution for initial contact surface inclination 30^o, and for a mesh of $h_x = 7.3 * 10^{-4}$, $h_y = 7.2 * 10^{-4}$.

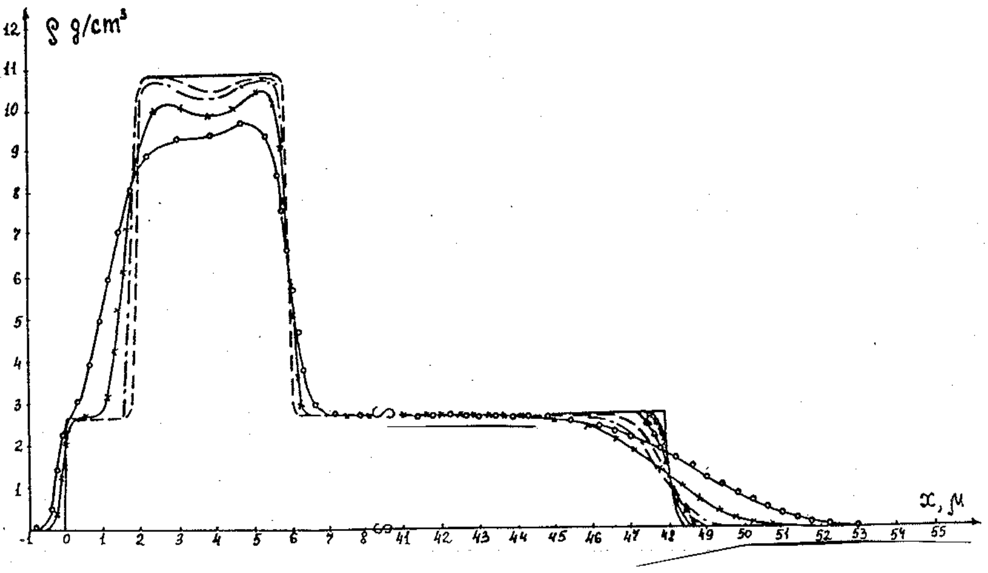


Figure 3: $-\circ-$ $h = 4{\cdot}10^{-5}$ cm, $-\times-$ $h = 2{\cdot}10^{-5}$ cm, $-\cdot-$ $h = 1{\cdot}10^{-5}$ cm, $-\ -$ $h = 5{\cdot}10^{-6}$ cm, $-\triangle-$ $h = 2.5{\cdot}10^{-6}$ cm, $-\square-$ $h = 1.25{\cdot}10^{-6}$ cm, and $-*-$ $h = 6.25{\cdot}10^{-7}$ cm.

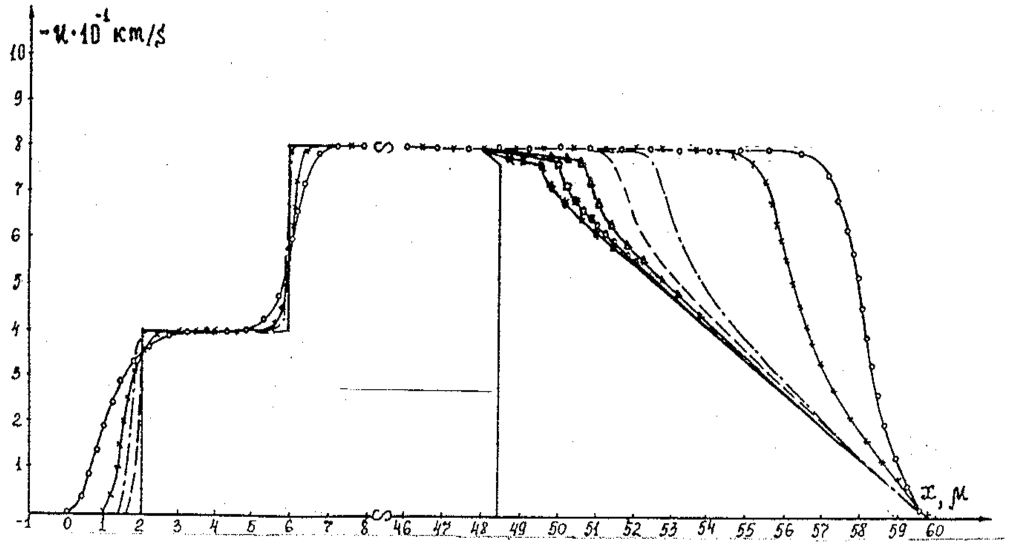
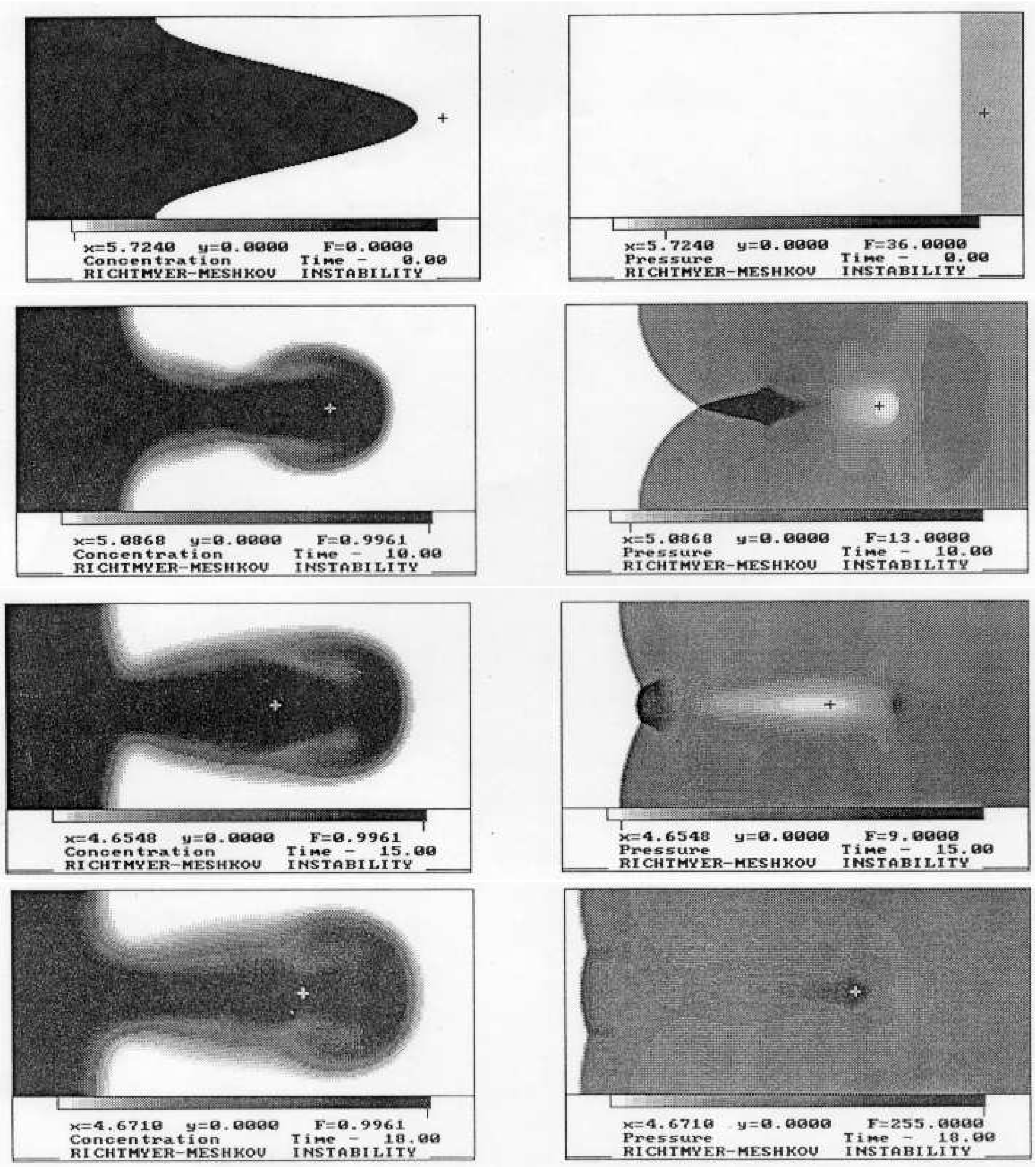


Figure 4: See Figure 6 for legend.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RICHTMYER-MESHKOV INSTABILITY
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Pressure Time - 0.00
RICHTMYER-MESHKOV INSTABILITY
x=5.0868 y=0.0000 F=0.9961
Concentration Time - 10.00
RICHTMYER-MESHKOV INSTABILITY
x=5.0868 y=0.0000 F=13.0000
Pressure Time - 10.00
RICHTMYER-MESHKOV INSTABILITY
x=4.6548 y=0.0000 F=0.9961
Concentration Time - 15.00
RICHTMYER-MESHKOV INSTABILITY
x=4.6548 y=0.0000 F=9.0000
Pressure Time - 15.00
RICHTMYER-MESHKOV INSTABILITY
x=4.6710 y=0.0000 F=0.9961
Concentration Time - 18.00
RICHTMYER-MESHKOV INSTABILITY
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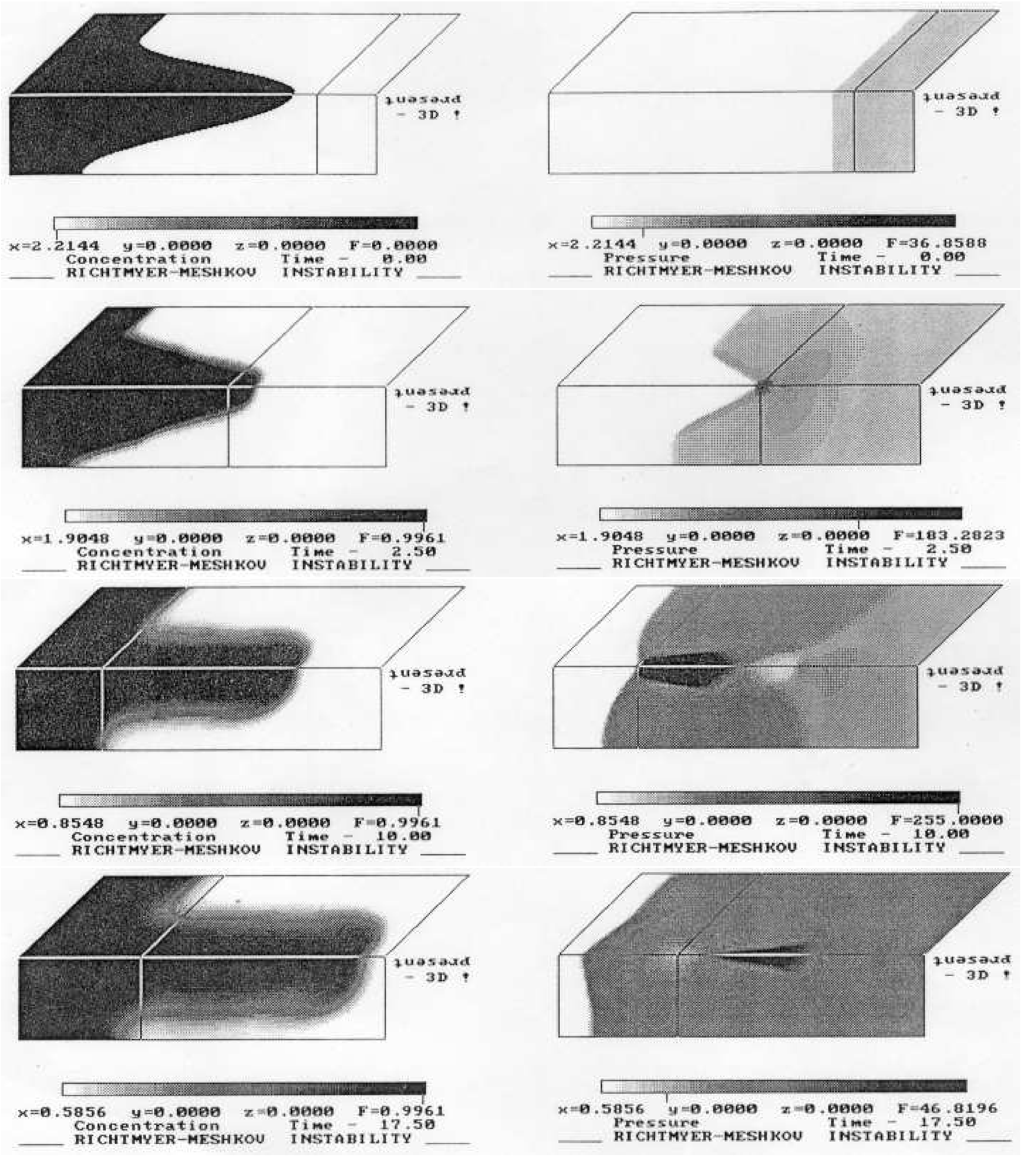
Pressure Time - 18.00
RICHTMYER-MESHKOV INSTABILITY

Figure 5: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Pressure Time - 0.00
RICHTMYER-MESHKOV INSTABILITY
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Concentration Time - 2.50
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Pressure Time - 2.50
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Concentration Time - 10.00
RICHTMYER-MESHKOV INSTABILITY
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Pressure Time - 10.00
RICHTMYER-MESHKOV INSTABILITY
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Concentration Time - 17.50
RICHTMYER-MESHKOV INSTABILITY
x=0.5856 y=0.0000 z=0.0000 F=46.8196
Pressure Time - 17.50
RICHTMYER-MESHKOV INSTABILITY
- 3D !

Figure 6:

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