Massive Parallel Computations in Gas Dynamics

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The basic features of phenomena arising under conditions of high energy density are complicated 3D character of the gas dynamic flow, large deformations and large gradients of the flow parameters as well. These are numerous processes of dynamics of shock and detonation waves in condensed matter, hypervelocity impacts, action of laser, electron, ion and particles beams on materials. The numerical modeling is now the essential part of these investigations and advanced research and development projects. The great amount of calculations which run in a large calculation area requires one to use high-performance multi-processor computers and parallel methods of programming.

The modified method of "individual particles", previously used for 2D problems [1], has been developed for solving of the system of gas dynamic equations in 3D setup. The continuous media in this approach is represented as an ensemble of finite-size particles, which carry all flow parameters such as density, specific internal energy, and momentum components, body markers and others. This lagrangian approach makes it easy to add in the program the different models of the matter behavior, of the history-dependent parameters and others. From the other side, the rectangular regular eulerian grid is used to calculate the spatial derivatives.

The common problem for all PIC-like methods is the presence of oscillations induced by discrete representation and distribution of mass. Another problem is that PIC methods are using rather big amount of particles and, consequently, a big amount of the machine memory. The developed algorithm of splitting and merging of particles with identical markers occurring in the same eulerian cell solves these mentioned above problems partially. This numerical scheme does not require a big amount of particles in the expansion region, which are traditionally used to preserve the artificial voids.

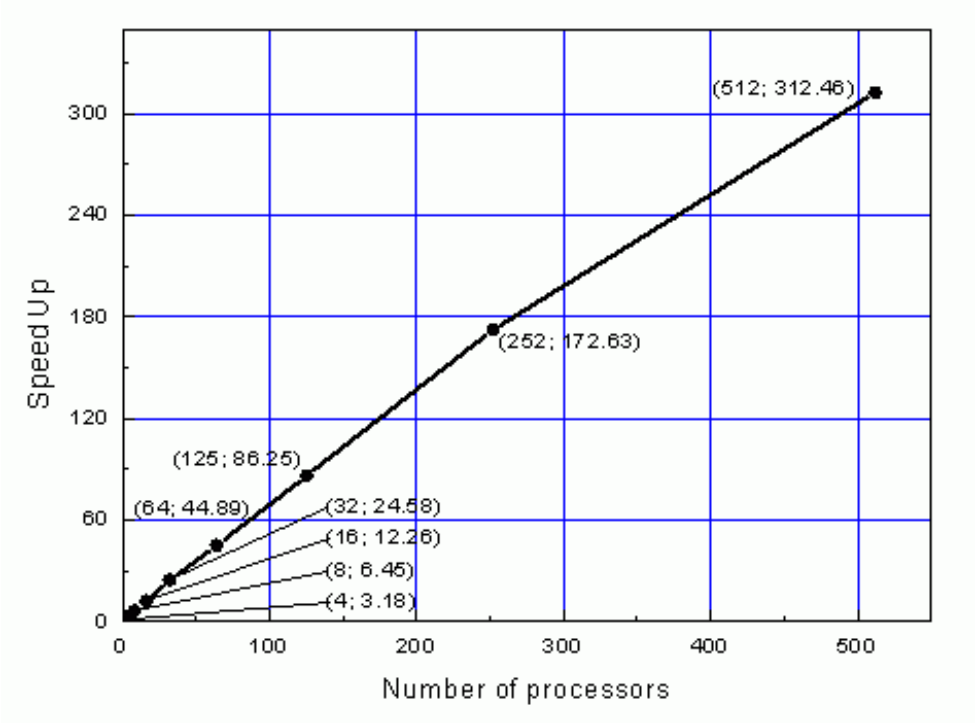

Fig. 1. Speed-up testing on MVS-1000M (JSCC, Moscow)

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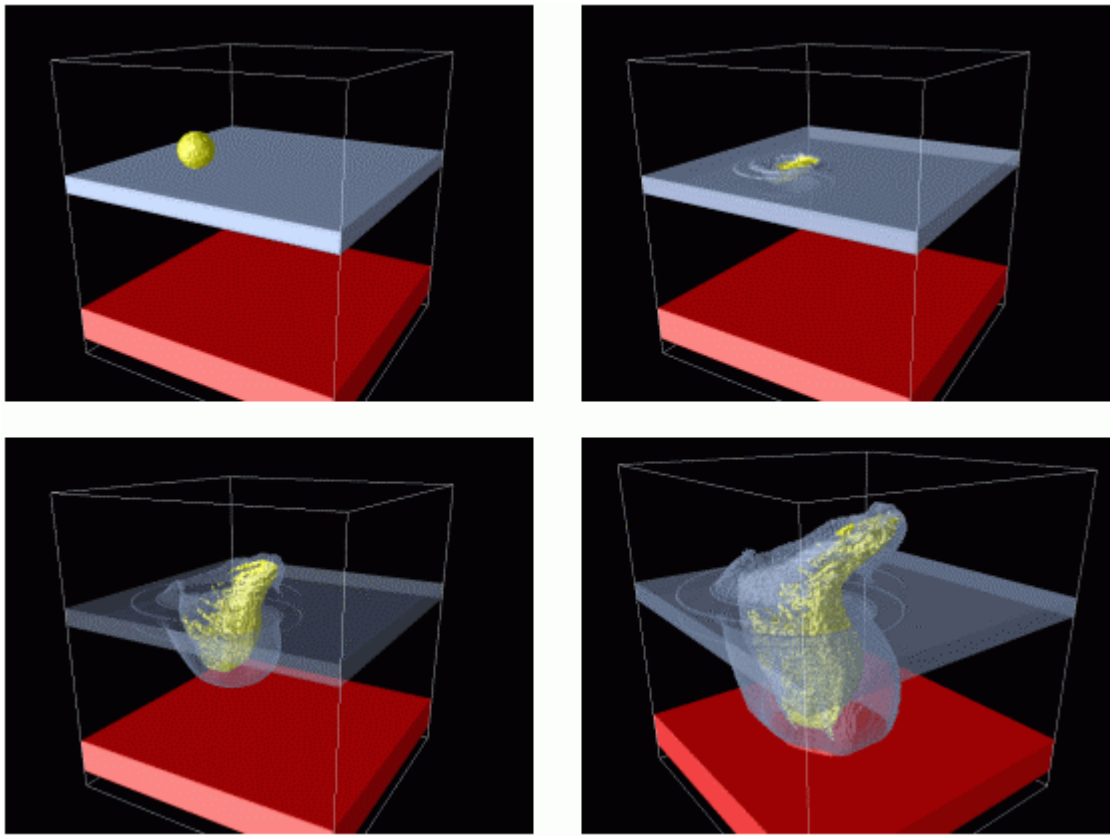

Fig. 2. Hypervelocity penetration of iron shield by the lead sphere in different moments of time (initial velocity 6.6 km/s)

The computation procedure in the modified "individual particles" method performs calculations with the only one particle per cell, while splitting particles are smoothly redistributed in the rarefaction regions.

The parallel realization of individual particles is based on SPMD programming paradigm using message-passing interface (C++, MPI, some blocks in FORTRAN). The coarse-grain data parallelism achieved by cutting calculation area on rectangular grid blocks (identical, as far as possible) and applying widespread ghosts-cells mechanism on the boundaries. The parallel performance has been tested on MVS-1000M (JSCC, Moscow) with the use up to 512 processors. The results of profiling-speed-up dependency are shown on Fig.1. There is 100*100*100 grid block filled with particles on each processor in test configuration. The acceleration in more than 300 times has been obtained for 512 processors.

Physical models library includes advanced equations of state for 150 structural materials (metals, alloys, polymers, composites, rocks and minerals), and constitutive relations.

The results of numerical modeling of process of high-velocity oblique penetration in different moments of time are presented on Fig.2. Lead spherical striker with initial velocity of 6.6 km/s impacts the double iron shield.

References

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