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Acceleration of Vortex Method Calculation using MDGRAPE-2: A special purpose computer

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Abstract

INTRODUCTION

N-body simulation was devised in 1950s and widely used since 1970s when digital computers became powerful and affordable. It is an orthodox method of studying particle systems nowadays. The N-body simulation problems require very high computational cost in which force calculation part is most expensive. The cost of direct summation algorithm for force calculation is $O(N^2)$, therefore calculation time grows rapidly as the number of body N increases. Our approach here is to reduce calculation cost of the N-body simulation by using a special-purpose computer MDGRAPE-2. It was shown that the MDGRAPE-2 can speed up force calculation significantly, about 100-1000 times faster than general-purpose computers.

THE MDGRAPE-2

In calculation of vortex methods, the largest computational load occurs in the routine that calculates the Biot-Savart law and the stretching term. Since calculation time also increases as the number of elements increases, efficient calculation of this routine is needed in order to accelerate the vortex method. These calculations have the same mathematical architecture as a multibody problem. Thus, the high speed technique of the molecular dynamics (MD) simulation can be used. MD simulation analyzes interaction between atoms or molecules by calculating the power from other particles and solving the motion. We consider the use of the hardware (MDGRAPE-2: a special purpose computer for molecular dynamics) which accelerates calculation of the interaction between particles developed for MD simulation (T. Narumi, 1997).

FLOW FIELD

The motion of a vortex ring is one of the most classical and fundamental problems in fluid mechanics. Knowledge of the speed of an axisymmetric vortex ring has been constantly accumulated for over a century. The velocity of the vortex ring depends on the logarithm of the effective radius of the cross section of the vortex ring and is infinite for zero radius.

HEAD-ON-COLLISON

Contributions to vortex methods for the computation of incompressible unsteady flows are presented. Using a core spreading method, the interactions of two identical rings moving on a collision course along parallel lines are studied. Evolution of a passive nondiffusing scalar carried initially with the vortices is visualized and analyzed. For the head-on collision, a periodic deformation is generated along the periphery of the colliding vortex rings, developing into smaller vortex rings which move in the radial direction, as demonstrated by experiments (Lim and Nickels 1992).

SIDE-BY-SIDE CONFIGURATION

We investigate the reconnection of vortex rings at high Reynolds numbers for a variety of configurations. The fusion of two vortex rings that are initially side by side is calculated. The investigation is closely related to the understanding of the interaction between three-dimensional vortex structures, a fundamental step towards the understanding of turbulent flows. We found two prominent reconnection processes: first, the two vortex rings merge into one by viscous annihilation of opposite vortcity and second, two new rings, which are connected by cutting each other during collision as demonstrated in previous calculations. (S. Kida et al 1989).

DEPENDENCE ON INITIAL SPEED

The behavior of two rings was observed by a flow visualization method and the three-dimensional structure of the cross-linking of the two vortex filaments was studied. These phenomena were classified into three patterns, depending on the initial speeds of the two rings. (1) at a lower speed, two rings merge into one distorted ring, (2) at a higher speed, it splits into two rings again after merging. The same results were obtained from experiments (Y. Oshima & S. Asaka 1977).

2D TEST CASE

We demonstrated here a bit different investigation to perform MDGRAPE-2 for our calculation. In figure the term 'Linux' represents calculations preformed without using MDGRAPE-2 calculation. The following figures represent the drag and lift coefficients and CPU time compared. First figure shows the time history where solid lines are used for Linux and dashed lines for MDGRAPE-2 calculation. It can be observed from the figure that after 5 seconds it has good agreement than earlier time. As mentioned earlier, the calculation time increases as the number of elements increase. We conclude that accuracy improved according to calculation time and number of elements increased. Similarly we can observe from the fluctuation of drag and lift coefficients. The third figure represents the CPU time calculation achieved. The red line represents the Linux iteration time and the blue line is for MDGRAPE-2. It is clearly observed that the MDGRAPE-2 consumed less time than Linux and the calculation cost is almost reduced to the order of $O(N)$. It has been confirmed that improvement in the speed was attained for the vortex method calculation accelerated by the proposed hardware. The total number of elements amounted to 12,800 for the present calculation.

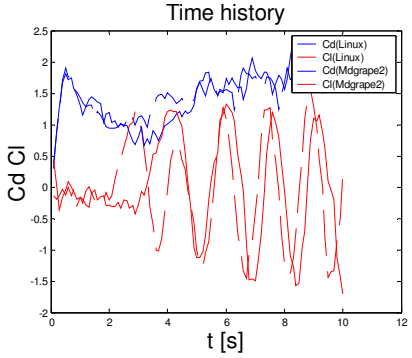

Fig. 1: Time history of Cd, Cl

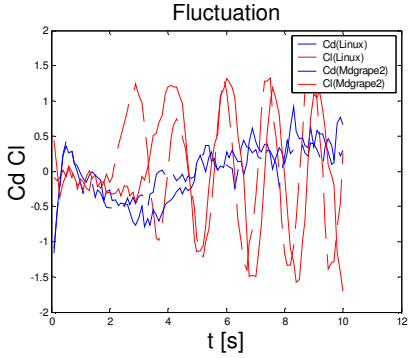

Fig. 2: Fluctuation of Cd, Cl

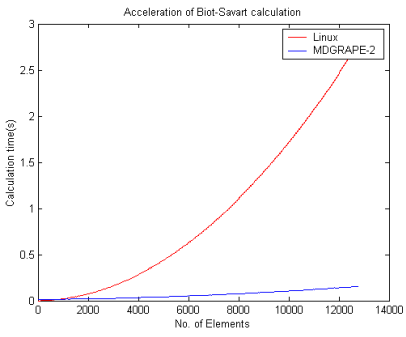

Fig. 3 Calculation time for 12,800 elements

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