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Building-Cube Method; A CFD Approach for Near-Future PetaFlops Computers

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ABSTRACT

Impressive progress in computational fluid dynamics (CFD) has been made during the last three decades. In the early stages, one of the main targets of CFD for aeronautical fields was to compute flow around airfoils and wings accurately. Body-fitted-coordinate grids, commonly called as structured grids, were used in those days. From the late eighty's, the target was moved to full aircraft computations. This spawned a surge of activities in the area of unstructured grids because of the flexibility in tackling complex geometries such as shown in Fig. 1 [1].

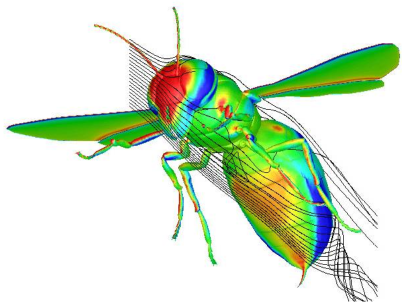

Fig.1 Flow computation around a hornet by unstructured-grid CFD.

The progress of CFD has been highly supported by the improvement of computer performance. The latest Top500 Supercomputers Sites [2] tell us that the performance improvement has reached a factor of 1000 in the last 10 years. Increase in the number of CPUs in a system, in addition to the degree of integration, contributes to this rapid progress. In the near future, we can expect to use PetaFlops computers for engineering purposes. On such computers, the allowable mesh size, currently up to an order of hundred-million points, will become giga points soon and tera points in the near future. This will accelerate the use the Large Eddy Simulation (LES) for aircraft analysis and design. Direct Numerical Simulation (DNS) may also be used for analysis of wings.

For such large-scale computations, however, a simple extension of the conventional CFD will be stuck soon. One of the difficulties is how to treat the huge data outputted from an unsteady flow computation with the high-density mesh.

Let's consider demands for next-generation CFD for engineering use on PetaFlops computers.

1. Easy and quick grid generation around complex geometries.
2. Easy adaptation of local resolution to local flow characteristic length.
3. Easy implementation of spatially higher-order schemes.
4. Easy massively-parallel computations.
5. Easy post processing for huge data output.

6. Algorithm simplicity for software maintenance and update.

Unstructured-grid CFD is a qualified candidate for the demands 1 and 2 as compared to structured-grid CFD. However, an implementation of higher-order schemes on unstructured grids is expensive in computational time and memory. The post processing of huge data output may become another bottleneck due to irregularity of the data structure.

Recently, studies of Cartesian-grid methods were revived in the CFD community, because of several advantages such as rapid grid generation, easy higher-order extension, and simple data structure for easy post processing.

In this talk, a Cartesian-mesh approach, named 'Building-Cube Method (BCM)' [3,4], is discussed as the next-generation CFD aimed for the use on PetaFlops computers.

Basic strategies employed here are; (a) building-up of cubic sub-domains of various sizes in a flow field in order for variable resolution, (b) uniform Cartesian mesh in each cube for easy implementation of higher-order schemes, (c) same grid size in all cubes for easy parallel computations, (d) staircase representation of wall boundaries for algorithm simplicity. A typical BCM grid is shown in Fig. 2 [5].

It is similar to a block-structured uniform Cartesian mesh approach, but unifying the block shape to a cube automates the domain decomposition of a computational field. Equality of computational cost among all cubes significantly simplifies the massively parallel computations [6]. It also enables to introduce data compression techniques for pre and post processing of huge data [4].

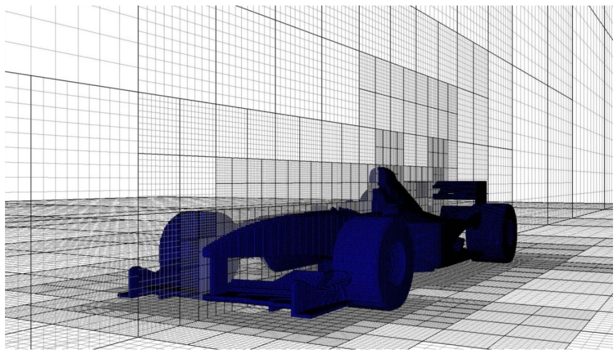

Fig.2. BCM grid around a F1-racing car model.

Although the Cartesian-mesh CFD has a difficulty at curved boundaries, it is probably correct to say that the simplicity of algorithms at all stages from the grid generation to the post processing will be a big advantage in the days of PetaFlops computers.

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