ABSTRACT

The application range of CFD (Computational Fluid Dynamics) has been spreading out greatly due to the development of the hardware and the progress of automatic mesh generation technology in recent years.

The progress of automatic mesh generation technology is made the analysis of the wing unit seen from before more easily. And, an analysis under the assembly condition including the rotating machinery is being made possible. Many phenomena in the rotating machinery are not steady, and the transient analysis is in dispensable. For the large-scale and transient problem, the system is required that high quality mesh can be made handily and it can be calculated at high speed. This paper is related to adaptability by automatic mesh generation in SCRYU/Tetra (SCTetra) and high-speed solver that is made a distributed and parallel computing by using MPI.

INTRODUCTION

CFD technology has developed with being supported by the development of the hardware in recent years. The application range for the complicated model was extended by the development of each technology, and the development cycle that more computer power was required had been done over again. This cycle was mainly controlled by mesh generation time and the calculation time, and the development of the hardware has contributed mainly in the latter. At present, it is not only the confirmation of the P-Q characteristics and phenomenon of applying for the simple fan unit but also (Of course, this is that it is important and indispensable.) to analyze a rotating machinery in the assembly level. When a fan was attached into the complex structure, many cases cannot get the P-Q characteristics shown in the catalog. It is necessary to predict how the flow behaves toward the structure as close to the actual level. Unless these problems are solved, a degree of a contribution to the product as CFD becomes small, and CFD in the enterprise disappears as to whom except for the cost, and decides to decline. The function of automatic mesh generation is equipped in SCRYU/Tetra for Windows, which we developed, solves the problem of the mesh generation dramatically (Fig.1). The application range for analysis model shape has expanded since the mesh generation time has decreased tremendously. As a result, the calculation time is dominant in the CFD working cycle. It came to be judged by the time and the cost (in the many cases, the time until it gets results by the experiment, and cost) due to the limitation of the application range of was practical. A solution plan can be chosen variously if it is possible that it spends the ample cost. Our market has expected a solution in the low cost. For these solution, “the low cost CPU that calculation ability is high” and “an upgradable system corresponding to the CPU development cycle” should be necessary. SCTetra equips solver that is operated on a cheap PC based system. By becoming parallel, it made it possible that the usual application range of was extended more drastically. This paper is related to the automatic mesh generation function, solver and parallelization in SCTetra and is introduced some of application cases.

SYSTEM OUTLINE

A system is composed of three modules of SCTpre, SCTsolver, SCTpost and the utility module(Fig.2).

### Table: System Outline

<table>
<thead>
<tr>
<th>Module</th>
<th>Description</th>
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<tbody>
<tr>
<td>SCTpre</td>
<td>Automatic mesh generation and making boundary condition</td>
</tr>
<tr>
<td>SCTsolver</td>
<td>Calculation</td>
</tr>
<tr>
<td>SCTpost</td>
<td>Visualization</td>
</tr>
<tr>
<td>SCTutil</td>
<td>Utility program</td>
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Fig.1 Example of meshing around CPU fan

Fig.2 SCRYU/Tetra for Windows
SCTpre creates mesh and prepares the boundary condition file and so on. SCTsolver performs a calculation. SCTpost visualizes the result and so on. SCTutil has the interface, which outputs a calculation result as a boundary condition of the structure analysis. These modules are performed on the Windows platform, and these provide the user-friendly interface. In addition to the Windows platform, SCTsolver also supports a UNIX platform.

**AUTOMATIC MESH GENERATION**

As previously described, automatic mesh generation function is equipped on SCTetra. At present, There is called a stable automatic mesh generation is using tetrahedral element basis, and SCTetra is the same. This function is inside of SCTpre module. The input/output files of SCTpre are as shown in the Fig.3. A CFD system often becomes an additional system toward the existent CAD system and it is important that to intake a shape data stably from the CAD system to the CFD system.

A STL format (Stereolithography Interface Format) was adopted for input of the shapes. As for the STL format, has been used in the optical molding field, it is the simple format that it is expressed in the surface shape set of triangle polygon. A system in the enterprise has often been composed some kind of CAD/Modeler. A system is made heavy, and it reflects on the cost of the application to cope with native format of these CAD/Modeler. Though IGES exists as a common format, that ambiguity often causes a trouble in the reappearance. STL excludes these problems and is excellent in the point that there are a few mathematical troubles about. Besides this, it is possible to import mesh data which is created by other applications. It can be used as an input of the shapes in place of STL and mesh for the analysis, and as an output for the structure analysis mesh, which makes a powerful automatic mesh generation interface. Mesh generation work is divided in four processes (Fig.4). The hybrid type was adapted, which the advantage of the Octree Method and Advancing Front Method was used for mesh preparation algorithm. The distribution of the element density is necessary by the element division to raise memory efficiency. SCTpre uses octree to give it element density intuitively. Octree decides mesh size specification. A user can set up the size of the final element and distribution by making the arrangement of octant on the screen. SCTpre makes surface mesh in accordance with octree (Fig.5).
Advancing Front Method makes volume mesh after the surface mesh generation within the territory. Volume mesh can be created continuously without considering between different material territories. Tetrahedral element mesh is completely created at this stage. It can be stated calculation using the mesh. However, precision on the surface is unstable because the distance dispersion from the surface appears for the tetrahedral element. It is necessary to insert the prism element on the wall boundary to improve precision on the surface. STpre can insert a prism element any specify regions. A prism element can specify a parameter such as element thickness and the number of layers (Fig.6).

The thickness of the surface element, which has close relationship with the adaptation of the turbulent model, can be controlled. Flexible I/O is possible by dividing the process of automatic mesh generation work into some like this with the existent system. It is possible to insert prism element using the imported structure analysis mesh for a CFD analysis.

SOLVER AND PARALLEL PROCESSING BASED ON MPI

SCTsolver solves the Navier-Stokes equations by an implicit iterative method. AMG and other matrix solvers can be selected by user to solve the discretized algebraic equations. The discretization adopts a class of control volume method which defines a control volume around each node of the computational mesh. Solver supports an element form to show in the Fig.7.

These are characteristics to realize the adoption of high precision, high-speed solver and small memory.
Main available functions are:
- 3D incompressible/compressible
- Laminar flow
- Turbulent flow (k-e method: standard/RNG/MP)
- Discontinuous mesh
- Arbitrary Lagrangian Eulerian (ALE) formuration
- Fluid-solid thermal coupling
- Diffusion of concentration species
- Gas mixing
- Radiation heat transfer
- Periodic conditions
- Particle trace

The function of ALE and discontinuous mesh is used for the rotation machine such as a fan.

Parallelization was done based on this solver. Though there were some techniques in parallelization, we chose using MPI (Message Passing Interface) method. MPI is the standard interface for the parallel program and has the high adaptability. Therefore MPI is used in many codes. The machine dispersed on LAN is considered one machine, and a parallel calculation is made simultaneously by MPI. In addition, it functions as a parallel even on the SMP (Shared Memory MultiProcessor) machine with no modification of program. An analytic area is divided into the number of CPU's, and each CPU does a calculation with MPI (Fig.8).
Divide into the number of CPU's (Example: Divided into 4 areas...)

Distributed to each processor

Calculated in each process on LAN, and each process exchange a message such as matrix information.

MPI BASED ON LINUX PLATFORM

The case adapted to the typical Beowulf type machine shown in the Fig.9 is stated.

Machine specifications:
OS: LINUX/RedHat6.2J
CPU: PentiumIII/933MHz x 2
Memory: 1GB(PC133)
Disk: 20GB IDE

Four LINUX machines were connected with the system in exclusive box. Each machine has two Pentium processors. And RedHat6.2J is working. This system has a machine for the control additionally. These are on FastEthernet LAN within switching HUB. A temperature sensor, a redundant power supply and other necessary peripherals as a server machine are provided. MPI library used the version 1.2.1 of MPICH which is free implementation. The fan analysis shown in Fig.10 was done, and that performance was seen. It is put on the market as a so-called "pipe fan" that a axial fan is built in a ventilation pipe.

Territory including fan is rotated using ALE function. Other territory is static. Two territory are calculated continuously by using discontinuous mesh function. The Analytic model is Fig.11. It has 864917 elements and 187680 nodes (rotational territory as 287221 elements and 60041 nodes, static territory has 577696 elements and 127639 nodes.).
The calculation time of 350 cycles is shown in Fig.14 for each used CPU number. Calculation time is between the inputting data and the completion of outputting the result as actual calculation time.

<table>
<thead>
<tr>
<th>CPU Number</th>
<th>Calculation Time</th>
<th>Magnification</th>
</tr>
</thead>
<tbody>
<tr>
<td>1cpu</td>
<td>11h51m6s</td>
<td>11.7</td>
</tr>
<tr>
<td>2cpu</td>
<td>6h56m45s</td>
<td>13.7</td>
</tr>
<tr>
<td>4cpu</td>
<td>3h12m42s</td>
<td>4.9</td>
</tr>
<tr>
<td>8cpu</td>
<td>2h24m41s</td>
<td>4.9</td>
</tr>
</tbody>
</table>

As seeing from the result (Fig. 14), very ideal performance improvement can be seen until 4CPUs; however, the stretch of the performance stops after that. This is not the overhead of FastEthernet, but it can be considered about overhead toward the memory bandwidth. Therefore, it can be said that efficiency of Cluster composition had a better system than 1 node 1CPU for the large-scale calculation. This machine contains the peripherals which should be necessary as a server. It cannot be said it is cheap; however, it has excellent cost performance when it is compared with the system called a usual computer server. In addition, it is easily upgraded because general parts are composed. It is possible the same thing by using the existent machine on LAN. In this case, Attention in the employment is necessary so that the traffic of MPI on LAN may not influence the whole of LAN.

**MPI BASED ON WINDOWS PLATFORM**

The adaptation to the Windows platform is introduced at this section. The cheapest and most stable hardware is a Windows' machine. Then, however it is easy to get. Though PC-LINUX has the same component as hardware, the differences between them are clear as a desktop environment. A part of our office is
shown in Fig. 15. One PC is supplied to each desk for the work. The average specifications of the machine are as the following.

CPU: PentiumIII866 x2
OS: Windows2000 or NT4.0SP5
Memory: 512MB – 1GB(PCI133)
Disk: 30GB IDE

Each machine is connected with FastEthernet LAN. The switching HUB is applied to every segment to hold general traffics.

![Network topology diagram](image)

Fig. 15 Network topology

The communication in segment A is controlled by HUB-A and never flows to the main HUB. When using MPI solver, One parallel machine can be made by the machine on LAN.

MPI library used MPICH,NT.1.2.1 that was transplanted to Windows platform at Argonne National Laboratory (ANL). There are also MPI communication tools in this library. These tools make up for the server function of remote-shell, which generally is not supported in the Windows platform. A machine in network is chosen dynamically when it is used, and it can be made a parallel machine by these tools. Fig. 16 indicates the result of adaptation in segment A using the same pipe fan data.

<table>
<thead>
<tr>
<th></th>
<th>1cpu</th>
<th>2cpu</th>
<th>4cpu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calculation time</td>
<td>12h26m48s</td>
<td>5h48m38s</td>
<td>3h45m8s</td>
</tr>
<tr>
<td>Magnification</td>
<td>1.00</td>
<td>2.08</td>
<td>3.24</td>
</tr>
</tbody>
</table>

Fig. 16

The same result as LINUX based MPI method(Fig.12) can get in this case. The difference in calculation time is a thing by the

difference in the number of CPU clock. But in the 2-CPU case Windows-based method is faster than LINUX-based method. In this case, the reason is considered that the size of the divided segment (including the traffic on LAN, etc) has more advantage for this system. Fig.17 show the time series data of pressure at the point of inlet.

![Time series data of pressure](image)

Fig. 17 Time series data of pressure

That difference is hardly seen in comparison with 1CPU at the time of using of more than one CPU. CGSTAB method based matrix solver is used in the all case. The speed of 2 times in SCTsolver is about equal to Alpha21264/667MHz.

DEATIL MODEL CASE

The case of the box fan is stated as a detailed model. Fan unit analysis often uses the model that only consists from bellmouse, wing and boss, which makes mesh generation easy. When automatic mesh generation is used, it can be analyzed closely to the actual level of details. The box fan configuration is shown Fig.18.

![Axial fan with a box type case](image)

Fig. 18 Axial fan with a box type case

The Analytic model is Fig.19. This case uses ALE and discontinuous mesh function. It has 4,597,700 elements and 936,432 nodes. Rotational territory including the fan has 3,073,557 elements and 660,448 nodes. Static territory has
1,524,143 elements and 275,984 nodes. For making P-Q curve, 5 cases were calculated.

Calculation conditions:
Inlet : Q=0.2,0.3,0.4,0.45,0.5m³/h , Outlet: P=0Pa
Revolution: 4000r.p.m.
Wall: Standard k-e
Transient

The result shows the tendency of agreement with experiment value.

CONCLUSIONS AND FUTURES
The effectiveness of the automatic mesh generation function mounted with SCteta was shown. A mesh generation engineer is not necessary if one knows how to use the Windows operation. Furthermore, the validity of the MPI parallel was shown in the improvement of the calculation speed. These extend the application range of CFD all the more in the development of the rotating machinery. In this paper, though the simple fan unit used, but the analysis of system which contains a rotating machinery is increasing. Adaptation to the large-scale and real model has begun already. CFD engineer has the desire to the exclusion of the vague of analytic model. Stated in the beginning, the modeling, which corresponded with the purpose, becomes an important element for applying CFD to engineering design. It is pleasure if our tools become to help all engineers.

ACKNOWLEDGMENTS
On the development of MPI parallelization of SCTsolder, Best Systems Inc., Sumisho Electronics Co., Ltd. and other hardware manufacturer are gratefully acknowledged for their support that they provide machines pleasantly.

REFERENCES
1. How To Build a Beowulf, Thomas L. Sterling et al. 1999
3. The Message Passing Interface (MPI) standard, (http://www-unix.mcs.anl.gov/mpi/)

Mesh generation time
Rotational territory: 2.5h
Static territory: 1.5h

Machine specification
PentiumIII 866Mhz
Windows2000
1GB memory
(No full memory required for this case)

Outlet Rotational territory 62mm
Static territory 1.5h

Fig. 19 Analytic model

**Fig. 20 P-Q curve**

The result shows the tendency of agreement with experiment value.