Structural and Thermal Fluid Simulation and CAD System Linking

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High-accuracy simulation techniques and prompt presentation of simulation results are essential to improving quality, cost, and delivery (QCD) in product development. Fujitsu is constantly working to shorten the time required to create a model, perform computations, and analyze results in the simulation process and is promoting the application of simulations in a technical computing environment. These efforts have helped to accelerate product development and design, to improve quality within the manufacturing process, and to improve product use on the customer side. This paper describes simulation schemes in a technical computing environment and the linking of simulation with computer-aided design (CAD) systems. It also presents examples of structural and thermal fluid simulations as applied to the design of structures and cooling systems and discusses their effects.

1. Introduction

Thanks to advances in simulation software and enhanced computing resources, simulation has found widespread use in the fields of structural and thermal fluid analysis as applied to the development of diverse products such as servers, storage systems, telecommunications equipment, personal computers, mobile phones, and finance/distribution-related terminals.

It is essential that simulation be applied in the early stage of product development. We have implemented a variety of measures involving mathematical solvers (problem-solving programs), hardware, and application technologies to directly connect simulation with design. At present, we are applying simulation to upstream design, making use of a technical computing environment to shorten the development period and improve design quality.

In this paper, we present schemes for applying simulation in a technical computing environment, describe how simulation can be linked with computer-aided design (CAD) systems, and introduce examples and effects of applying various types of structural and thermal fluid simulations to the design of structures and cooling systems.[1)]

2. Examples of structural and thermal fluid simulation

In this section, we introduce a variety of structural and thermal fluid simulations and their effects.

2.1 Simulation of warp in printed circuit boards

A printed circuit board (PCB) can expand when exposed to a thermal load during the manufacturing process and can become warped as a result. Warping in boards is increasing due to the development of smaller and thinner electronic devices and higher wiring densities. It can be a factor in the exfoliation of solder joints used for mounting electronic parts and in wire disconnections. To achieve a level of design that reduces warp in PCBs and prevents such problems, the potential for such warp must be considered at the time of wiring design.

Since a PCB contains several thousand wires and many vias and pads, there is a need for a simulation model that can faithfully reproduce PCB structure and component layout. Focusing on the uneven distribution of copper in a PCB as a factor in warping, we developed numerical simulation modeling technology that derives the distribution of copper density in the PCB from the CAD data used in PCB design. Then, on the basis of that distribution, it subjects the form of the PCB to coarse graining (a technique for reducing information by discretizing a continuous physical quantity in a certain variable space by discretizing that variable in accordance with an arbitrary unit scale and taking the average of that physical quantity within that unit scale) [**Figure 1 (a)**].[2)]

An example of applying warp simulation to a PCB to be used in a mobile phone is shown in **Figure 1 (b)**. The amount of warp for the whole board was reduced to about one-third that identified at the time of initial design by changing wiring and adding vias. The computations for this example were performed in a technical computing environment containing four parallel CPUs achieving a computing speed that was high enough for feeding back results to the design process. Reducing warping before the fact in this way has been helping to raise the level of quality in wiring design.

2.2 Simulation of vibration in a supercomputer

In parallel with the trend toward high-performance servers and supercomputers with high-density installations, the green IT movement is progressing with a focus on using optimal and lighter materials in cabinets and racks. In this environment, it is important that the robustness of equipment including cabinets and racks be improved and that equipment be strong enough to withstand even major earthquakes given the events of recent years.

At Fujitsu, the earthquake resistance of equipment is evaluated by measuring its resistance to vibration corresponding to 1000 Gal or a seismic intensity of “6-upper” on the Japan Meteorological Agency Seismic Intensity scale of

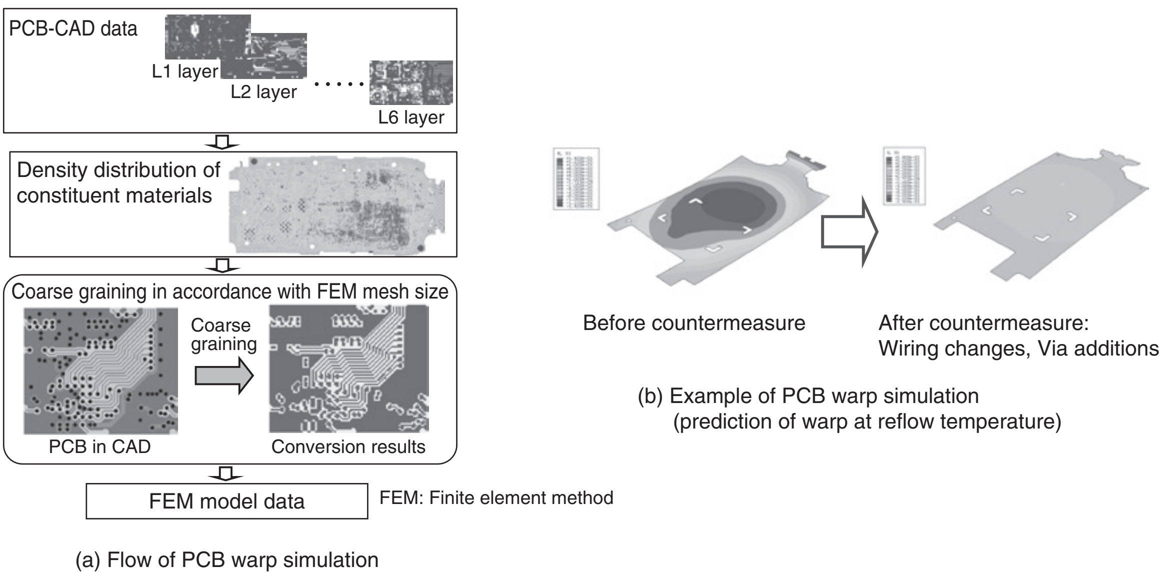


Figure 1
Simulation and evaluation of warp in PCBs.

0 to 7.[3] To satisfy vibration-evaluation criteria set down for Japan's K computer,[note)] which came on line in fiscal year 2011, the racks used to configure the supercomputer were targeted, and a vibration simulation of one entire rack was performed at the design stage. Results are shown in **Figure 2**.

Specifically, a dynamic vibration simulation was carried out for about 5000 component points in a technical computing environment, and resonant frequencies and stress distribution were calculated. These calculations were performed on eight parallel CPUs at a speed sufficient for providing feedback to design. To create a simulation model, detailed shapes unnecessary for simulation were removed from the rack using a shape-modification system. Using a rack shape optimal for simulation in this way kept the model from ballooning in size and reduced computational costs in the technical computing environment.

As shown in Figure 2, simulation showed that stress concentrates in lower-shelf corners and foot mounts in the lower portion of the rack. On the basis of the simulation results and the physical properties of the rack materials, the thickness of the metal plates used in the rack was changed and the overall structure was reinforced. These simulation results led to a reduction in the number of rack prototypes constructed and evaluations performed.

note) "K computer" is the English name that RIKEN has been using for this supercomputer since July 2010. "K" comes from the Japanese word "Kei," which means ten peta or 10 to the 16th power.

2.3 Simulation of drop impact in handsets

The reliability of mobile-phone equipment in the face of transient, external loads must be ensured, especially for impact loads that occur when a handset is dropped during use.

For example, while a handset case may be strong enough to withstand external forces, relatively large clearance between the mounting board and other elements inside the case means that the board may suffer significant bending at the time of impact. As a result, solder joints attaching large electronic components to the board may exfoliate, and the components themselves may be damaged. As mounting boards become increasingly thinner and smaller, this problem is even more likely to occur. It is therefore important that mounting boards inside handsets be evaluated in detail through drop-impact simulations.

Figure 3 shows an example of visualizing

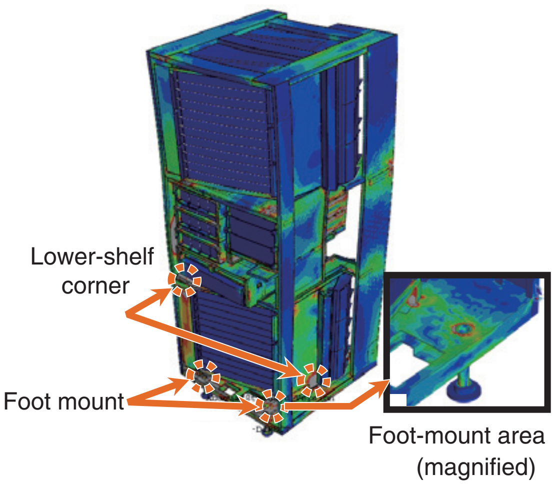


Figure 2
Stress in supercomputer rack during an earthquake.

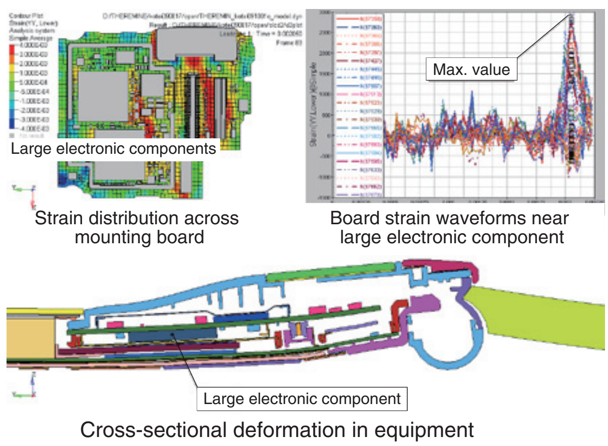


Figure 3
Handset mounting board subjected to drop-impact simulation.

and inspecting strain distribution across a mounting board through drop-impact simulation of a handset in a technical computing environment.[4] Simulation calculations were performed on four parallel CPUs at a speed high enough to provide feedback to design. To make the creation of a simulation model more efficient, the shape-modification system mentioned above was applied to the outer case. For the PCB unit, a link between the simulation solver and PCB CAD was established, and CAD information describing the board and electronic components was converted into three-dimensional shapes. Maximum strain appeared near large electronic components, but no problems were found in regard to the strength of those components.

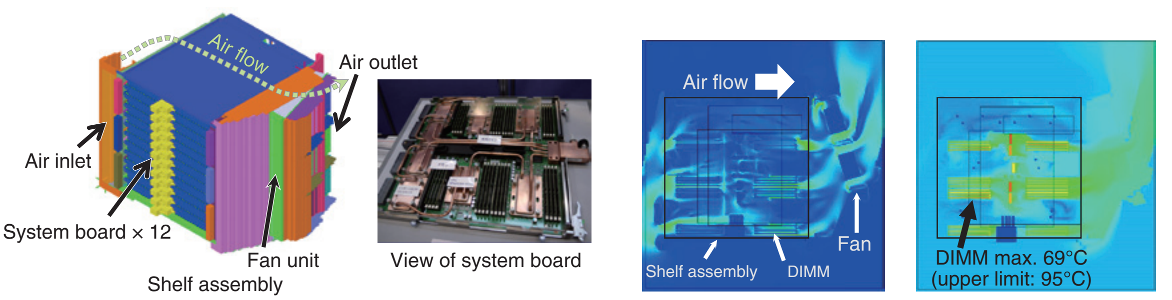
Simulations of this type have led to handset components with greater impact resistance, thereby improving the quality of handsets. They have also helped to reduce the number of prototypes constructed and evaluations performed.

2.4 Simulation of thermal fluid dynamics using a supercomputer

Countermeasures to the generation of heat in electronic devices are becoming extremely important as the performance of these devices continues to rise. This is because techniques that can minimize thermal generation while promoting energy saving in electronic devices are attractive from the viewpoint of environmental protection. In general, the mounting structure of server and supercomputer equipment supports optional configurations with respect to memory, CPUs, I/O, redundant power supplies, etc., and as a result, the flow paths for cooling air can take a variety of patterns. To ensure an optimal flow of cooling air for whatever the configuration might be, it is essential that high-accuracy thermal fluid simulations be performed in the early design stage. At Fujitsu, high-speed and high-accuracy thermal fluid simulations are being performed in batch for an entire piece of equipment, and optimal cooling designs for servers and supercomputers are being achieved.

The example presented here targets the cooling structure for the K computer. A hybrid method consisting of water cooling and air cooling is used for cooling each system board (W 480 × D 500 × H 44 mm) with a high-density configuration in which 12 system boards are mounted on top of each other in a shelf assembly. As shown in **Figure 4 (a)**, the air flow from the air inlet on one side of the shelf to the air outlet on the other side was designed to bend sharply to increase mounting efficiency within the rack. A batch simulation for an entire shelf was performed to verify proper cooling.[5]

The calculations were performed in a technical computing environment on four parallel CPUs with a computing speed high enough to feed



(a) Overview of simulation model (b) Air-flow distribution (c) Temperature distribution

Figure 4
Overview of simulation model, air-flow distribution of system board, and temperature distribution and resistance of mounted components.

back results to design. As in previous examples, a simulation model was created using a shape-modification system to remove unnecessary detailed shapes and provide shapes optimal for simulation. This kept the model from becoming huge, and by linking the simulation solver with a CAD system, information describing the PCB and electronic components on the system board could be converted into three-dimensional shapes. These measures reduced computational costs in the technical computing environment.

Analysis results obtained from the simulation are shown in **Figures 4 (b)** and **(c)**. The temperature distribution for the air-cooled components (mainly dual inline memory modules: DIMMs) on a system board was found to agree well with actual measurements. In addition, an air-flow routing structure that could provide a uniform flow of air over each system board by altering the original flow path for cooling air was fed back to design. As a result, the temperature of each component on the board fell within the allowed range.

2.5 Behavior of waterproofing sealant in mobile phones by SPH

Smoothed-particle hydrodynamics (SPH) is a computational method that models physical phenomena on the basis of particles instead of a mesh as in the conventional finite element method (FEM). With SPH, physical quantities such as density and pressure at various points in the computational space are expressed by summing up the contributions from neighboring particles. These neighboring particles can change position over time, thereby giving SPH some special features. Specifically, it has a high degree of freedom with respect to deformation compared with mesh-based methods and allows calculations to continue regardless of how the distribution of particles changes. The SPH method also negates the need for generating a mesh [**Figure 5 (a)**].[6)]

When being used to analyze large deformations in flexible materials like rubber and clay, the SPH method enables a computational model to be expressed solely on the basis of particle elements having positional coordinates. It also enables calculations to be performed without breakdowns, even for large deformation problems. The SPH method is therefore applicable to fields in which calculations by conventional FEM are difficult to perform.

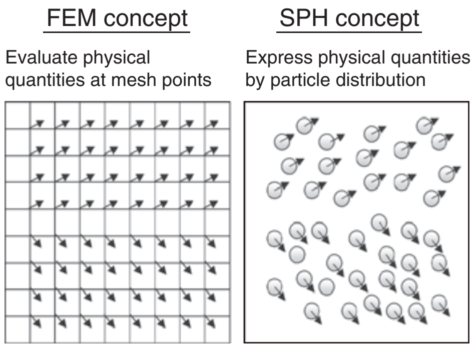
In this example, a simulation was performed to see whether waterproofing could be achieved by filling with gel the gap formed in a flexible pull-out section in a mobile phone. The objective was twofold: to determine whether sufficient gel is being inserted in the gap between the flexible cable and the case and inter-case gasket and to determine whether pressure at or above a certain value is being applied to the surface of the gel as needed to achieve waterproofing.

Simulation calculations were performed on 32 parallel CPUs in a technical computing environment at a computational speed sufficient for clarifying the behavior of gel-type sealant. The SPH computational model is shown in **Figure 5 (b)** and analysis results are shown in **Figures 5 (c)** and **(d)**. These results indicate that the gap was filled with the gel-type sealant in a normal manner as shown by a cross-sectional view of the waterproofed section and that a level of pressure necessary for waterproofing the flexible cable was being applied to the gel.

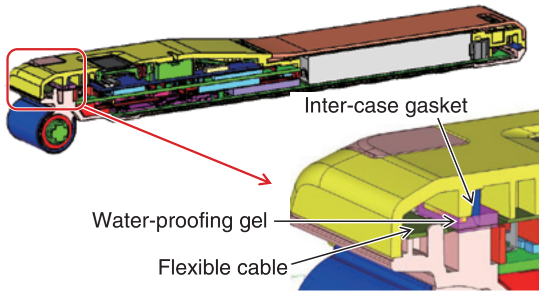
In future research, we aim to clarify the behavior of not only sealants as introduced here but also of flexible structures used particularly in electronic devices. We also plan to accumulate more simulation examples that can contribute to improved quality in the manufacturing process.

3. Results to date and future issues

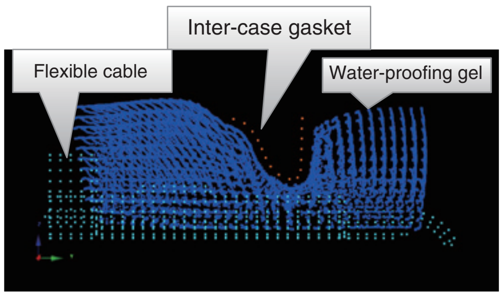
Fujitsu now has the ability to perform large-scale calculations in a technical computing environment while linking CAD and simulation tools so that high-accuracy and quick-turnaround



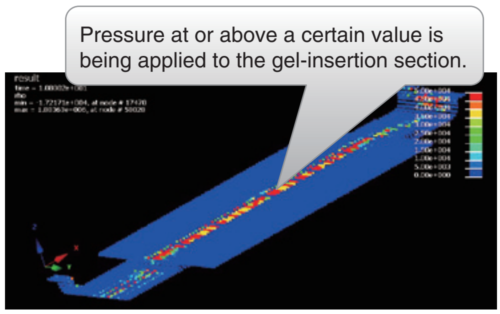
(a) FEM versus SPH



(b) SPH computational model



(c) Computational results: cross-sectional view of waterproofed section



(d) Computational results: Pressure distribution on flexible cable

Figure 5
SPH features and application example.

simulations can be performed in actual product development and design problem solving. Designing and testing on the basis of theoretical analysis at the initial stage of development was found to enable high-quality equipment to be developed in an efficient manner and improvements in QCD to be made.

Looking forward, there will be a need to support the massive and ever-increasing amount of calculations in simulations. To this end, we will endeavor to further consolidate computer resources in a cloud-computing environment, to achieve massively parallel processing, and to improve the handling and data-transfer speeds of simulation-modeling data and simulation results to facilitate model verification.

4. Conclusion

In this paper, we described examples and effects of applying simulation to the design of actual products. From here on, the trend toward higher performance levels and smaller and lighter equipment is expected to accelerate while development periods shorten and demand for greater reliability increases. To deal with this situation, we will work to develop and apply techniques for achieving high-accuracy and quick-turnaround simulations and will strive to make simulation an indispensable tool for achieving optimal product designs.

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