Embedded Mesh Boosts CFD Performance

Technology radically simplifies thermal and flow modeling, while shrinking model size.

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Embedded mesh technology adds impressive capabilities to computational fluid dynamics (CFD) thermal and flow analysis for electronics cooling. It simplifies model building while increasing model fidelity and accuracy. It dramatically reduces cell counts making it possible to model complex systems and boards that were impossible to model before. It eliminates dependence on approximate model building techniques, such as resistor networks and lumped parameter (compact) models. And it significantly reduces calculation times over existing approaches.

Though not a new concept, embedded mesh technology has eluded CFD software developers' attempts to implement it for some time. Only recently has it been successfully transformed into a working tool for engineers. The first implementation is Coolit v5.0 from Daat Research of Hanover, NH, which was benchmarked for this article to evaluate the benefits of the new technology.

Too Little Detail; Too Big a Problem

An engineer performing CFD thermal or flow analysis on electronic systems faces a quandary. Often a model contains complex components and layouts, making it highly impractical, if not impossible to handle as a single simulation. A single mega model can demand over 24 hours of calculating time—assuming the workstation doesn't croak under the load.

In CFD, the domain is split into a set of control volumes (cells) tailored to the size, shape and physics of the particular space (Figure 1). Larger, slower changing spaces are overlaid with larger cells, while smaller parts demand fine grids (meshes) that can send cell counts soaring. Fine grids also must be used on abrupt geometry changes, which have a propensity to disrupt airflow and create unexpected hot spots. If they are not finely detailed, these problems may be missed.

Typically, a model grid is a mix of cell sizes, where abrupt transitions between large and small cells must be avoided because they can cause major accuracy and stability losses. In order to modulate the transitions, extra grid cells are added, further aggravating the cell count. The more cell count goes up, the more calculation speed goes down. Doubling the count will at least double the computer time.

Finally, there is the computer memory hurdle. Most commercial CFD software will choke on models with as few as one million cells, a number frequently required to accurately model a complex system or board. As a result, the engineer is forced to trade-off accuracy with cell count just to get the job done in a reasonable time and with the computer resources available.

The alternative is sub-modeling: creating models within models. The goal is to simplify the problem by replacing parts of the system with approximate

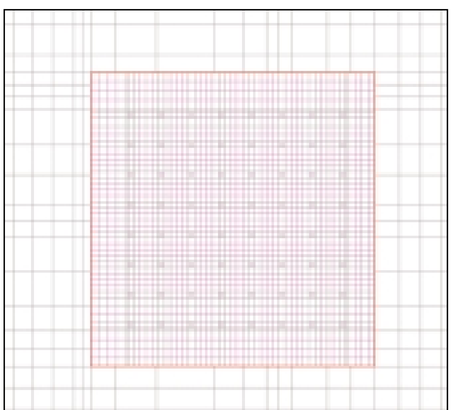

Figure 1 2-D cross-section through PC board model shows smaller grids around components where geometry and physics change rapidly. Larger grids are adequate outside of components where changes are gradual.

What is CFD?

As designers squeeze more and more electronics into smaller and smaller packages heat becomes a major problem. Slight changes in the position of electronic components, poor selection of vent or fan location or inadequate heat sinks can bring a laptop or portable test equipment to meltdown.

Traditionally, engineers have gone through a prototype-test-modify-and-prototype again cycle in order to optimize heat dissipation. This approach is both costly and time consuming. An alternative method is to simulate designs using computational fluid dynamics, or CFD, a mathematical approach that applies the conservation laws of physics to model airflow and heat transfer. Three dimensional CFD models can show temperature, pressure and other variables at every location in the design, something impossible using other techniques. Models can be quickly changed and recalculated, so the engineer can examine a variety of what-if scenarios in a fraction of the time of prototype testing approaches.

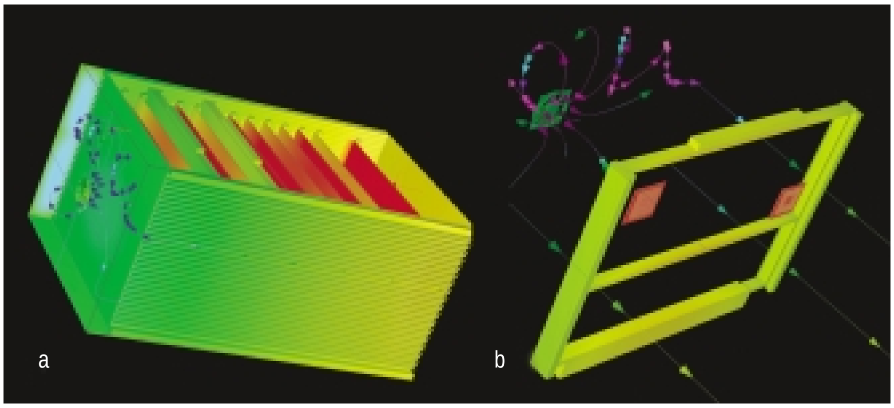

Figure 2 In 2a, military CPU used in F-16 contains 12 VME cards with two modeled down to the die level. The detailed view (Figure 2b) shows two of the chips in their carrier. The entire Coolit model, including system, boards and chips, used embedded mesh technology to shrink the cell count to 770,000. Without embedded mesh capability, the analysis would have required over 4 million cells.

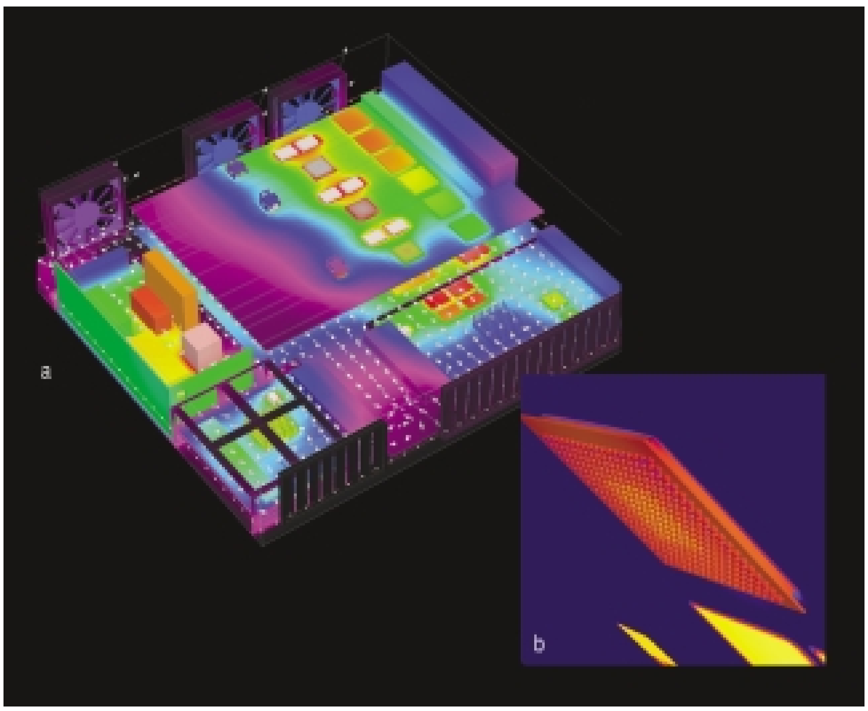

Figure 3 In 3a, a thermal model of the Avaya telecom chassis includes details ranging from full 19-inch wide chassis down to chip components measuring a fraction of a millimeter. In 3b, one detailed PBGA is shown with 324 ball contacts clearly visible. Without embedded mesh technology, it would be impossible to model such disparate sizes without resorting to approximations of compact models.

models based on lumped parameter models (compact models) or resistor networks. Theoretically, the replacements mimic the original system. In reality, they take time to develop; are accurate only under certain conditions, and a model developed for one problem cannot be used in another. Defining these sub-models is a formidable task.

The Solution

Theoretically cells can be distributed arbitrarily both in terms of their size and position, but in practice, the cell distribution freedom is restricted due to the need to efficiently identify neighbor cells and the requirements of accuracy. The system of grid cells can be thought of as a system of observers (or probes) in physical experiments. Each observer records information at his location and passes it on to other observers as each location measurement depends on other locations. Therefore transferring the observer information efficiently is essential for fast computation. Managing these communications for reliable, fast and stable convergence among multiple zones is the key to embedded mesh technology's performance.

Embedded mesh technology eliminates the guess-work associated with standard sub-modeling techniques. It sets up individual mesh subsets for objects within the system using a grid based on the length scales and the physics of each zone. The key is to manage communications among the multiple zones ensuring reliable, fast and stable convergence. The entire system can be modeled in one swoop with a dramatic reduction in solution time. In a problem simulating the use of multi-zone grids, embedded mesh-based software computed the flow through four pin-fin heat sinks with a reduction in cell count from over one million to just sixty-two thousand and a resultant savings in compute time—from over 8 hours to less than 15 minutes.

Applications

In order to compare the impact of embedded mesh technology on modeling performance, CAS benchmarked two designs. The first was a 250 W military computer designed for the F-16 aircraft. The computer was housed in an aluminum VME chassis, measuring 265 mm wide x 200 mm high x 365 mm deep with the chassis exterior cooled by natural convection and radiation.

Within the chassis, 12 conduction-cooled VME cards were fastened to the inside of a heat exchanger by Calmark wedge-locks. The plate-fin heat exchanger contained 31 horizontal fins mounted on each side of the chassis. The heat exchanger, in turn, was cooled externally by 4.3 CFM forced air entering at 4 degrees Celsius.

While the heat exchanger was modeled in detail, in order to fit the problem within the maximum allowable 2 Gbyte RAM, the VME cards had to be simplified using lumped parameter models. Performing this analysis at the card level with no components required approximately 600,000 cells and took almost 6 hours to run. When the analysis was augmented using approximate models for some of the components, it required 1.5 million cells and took 10 hours.

This analysis was repeated using embedded mesh technology. Two VME cards were detailed down to the die level (Figure 2), while the remaining cards were modeled using lumped parameters. Such a model would have required 6-7 million grid cells with a single grid. It now took only 770,000 cells, which could be solved readily on a computer with less than a gigabyte of RAM. Because the components were modeled to the die level, without approximations of compact models, the analysis was more accurate.

The second example was a telecom chassis designed for Avaya Communication. It measured 19 inches wide, 2 U (88 mm) high and 450 mm long and contained two main PC boards, three stackable cards and a power supply. The system drew about 158.5 watts and was cooled by three fans that provide 35.3 CFM (free delivery air).

The detailed thermal model included the heat sink and several PBGAs down to the die level (Figure 3). The TO263 power diodes also were fully modeled including their heat sink. This system would have required about 10 million cells using standard (non-embedded) meshes. Such mesh size would have exceeded by several fold the RAM capabilities of a workstation.

Using embedded mesh technology, the same chassis was fully modeled (including all PBGAs) with less than one million cells. The base unit, without PBGAs, takes about 650,000 cells, with each detailed component adding only between 30,000-100,000 cells.

The capabilities provided by embedded mesh technology are a significant advancement for CFD analysis. Coolit can resolve multi-scale models accurately without resorting to approximations, such as compact models. Length scales can range from almost a meter (chassis size) down to a micron, all within the same model. Most importantly, previously impossible to solve problems, can be solved now because of the reduced cell count and calculating time. More detailed analyses deliver higher accuracy, fewer “hot spot” surprises and greater confidence in the thermal design.

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