Case Study: CFD Wages War On Electronic Systems' Heat

Thermal and flow analysis software catches problems early, paring development time and dollars.

Ben Kuster, Senior Mechanical Engineer, Miltope Corporation

Electronic systems seem to follow some perverse law that dictates the smaller the package, the more power must be crammed into it. Designs end up with little space for heat sinks, fans or even air movement, leaving them prone to deadly heat buildup that can damage a system. Often, these problems don't become evident until the prototype stage. But when these heat problems are caught early—before metal is bent, components purchased and prototypes built—savings in development time and costs can be dramatic.

The trick is computational fluid dynamics (CFD) software, a thermal analysis and design tool that creates a 3D simulation of the airflow and temperature at every point within a system. The invisible world of heat and airflow suddenly becomes visible through color-coded graphics that show what is happening, even in areas physically impossible to instrument and measure. Using Coolit CFD software from Daat Research Corp, Miltope engineers have located hot spots and airflow problems, and performed "what if" design scenarios, thereby reducing the need for physical prototyping. This has pruned weeks off the development cycle and saved thousands of dollars in project costs during the development of the company's ruggedized computers and peripherals.

The Problem: Hidden Hot Spots

For years engineers couldn't deal preemptively with heat because they didn't know where the trouble spots lay until prototypes were tested. When they did test, some locations couldn't be instrumented, and if the thermocouples were placed in the wrong locations, the hot spots would be missed. Designs passed through repeated iterations of analyze-build-test-redesign before workable units evolved. It was time-consuming and costly.

Thermal engineers had to wait for circuit designers to lay out a board or system before they started. By then, the design was largely frozen and options were limited as to where components could be positioned to make room for a heat sink or fan.

Engineers could calculate only very simplified heat and airflow models, and the answers could be off by an order of magnitude or more. Many resorted to intuition to predict how cooling air might flow or where the hot spots were. But intuitive solutions worked only when new systems were just a small variation of the old, for which measurements were already available. To prevent overheating, engineers were forced into costly over-design (more fans, heat sinks and vents).

Over-design typically lowers *average* operating temperatures, but it offers no insurance against hot spots that may lurk inside even the most conservative design. It also results in unnecessary cost and weight—major negatives when the goal is to cram more and more into smaller and smaller packages—as well as greater noise and reduced reliability due to extra fans.

What is CFD?

Computational fluid dynamics solves the system of non-linear partial differential equations that model airflow and heat transfer. These models are so

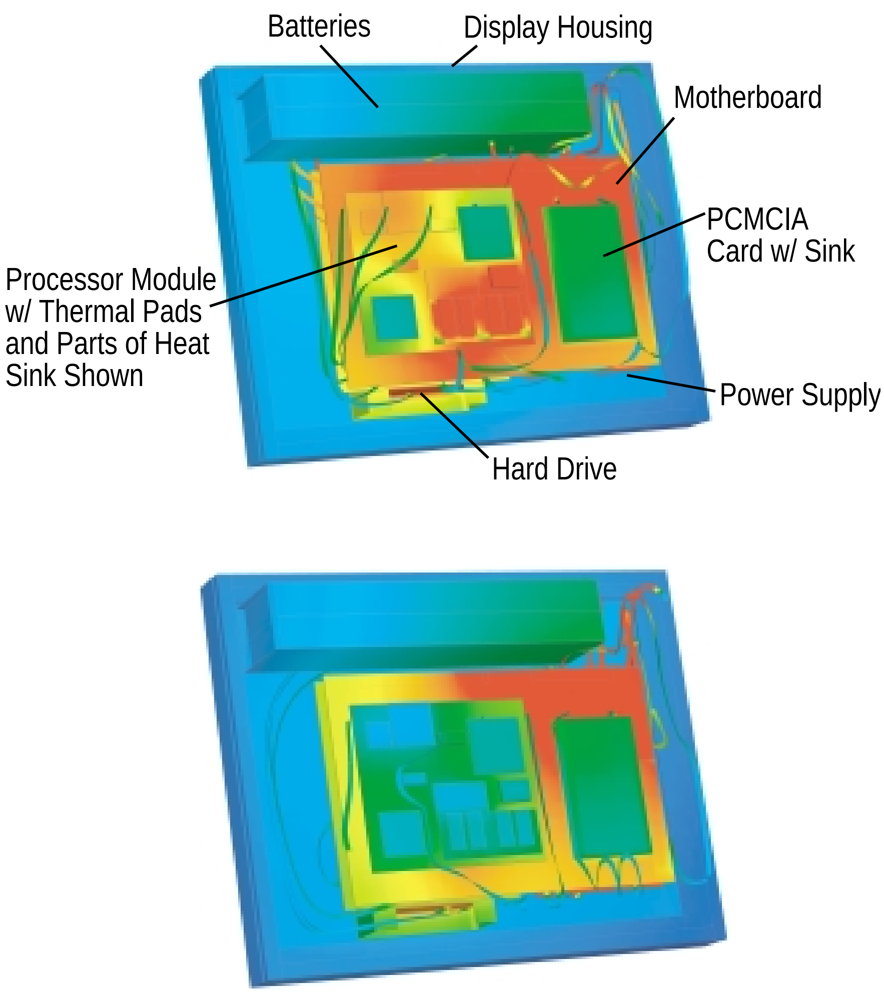

Figure 1

Color-coded Coolit simulations show the back of the VCU-1600. The original simulation (above) shows four components exceeding maximum temperatures. A custom heat sink lowered temperatures to acceptable levels, indicated by fewer red and orange colors (below).

complex that they can be solved only by computer. Early CFD software required a PhD engineer equipped with a mainframe computer. It took the evolution of powerful desktop computers and the development of intelligent software to make this tool accessible to the undergraduate level engineer.

Today's CFD software offers built-in decision making that offloads many of the error-prone problem steps, provides access to smart on-line component and materials libraries, and incorporates an intuitive GUI to step users through the modeling process. A new user can be up and running within hours of software installation without having attended a single training class.

With the software, engineers can predict temperature and airflow conditions to within a few percent. Over-design and guessing is eliminated. Physical prototyping becomes passé or is done only for final verification testing.

The thermal engineer can begin his simulations while a circuit is still in the design phase. He can advise the board designer where to place the chips and how the power supply should be shaped, rather than having to live with the layout the electronics engineer presents. When thermal problems are flagged early, the electronics engineer can participate in solving excessive heat load problems, sometimes by dividing circuit functions and locating them separately.

Building the Model

To begin the analytical process, the engineer draws the essential model geometry on his terminal or, alternatively, imports the entire design from CAD. Next, he specifies component properties, such as thermal conductivity, power dissipation, or perhaps a fan curve. The on-line library supplies most data, and this can be supplemented by keying in any special values. Parameters may be entered in any combination of units.

To solve the problem, the software splits the domain into a contiguous set of grid cells (finite volumes) and calculates its way from cell to cell. Typically, the finer the grid cells, the more accurate the solution, but finer grids take longer to calculate. The user may choose a coarser grid during the early design stages when it is more important to compare design approaches than it is to be very accurate. Finer grids are preferred as the user nears the final design. They should also be used in locations where a solution is expected to change rapidly, such as near inlets and outlets and around certain components.

The solution is a 3D color-coded display depicting temperature and airflow (Figure 1). By overlaying the temperature and airflow graphics, the user can analyze interactions between the two. A variety of additional variables can be displayed, including the heat flux vector and its components, pressure, turbulence intensity and so on. By clicking on a location, the user can identify the specific parameter values.

Air movement can be shown as streamlines, rods, ribbons, or color-coded arrows scaled to represent air velocity and direction, or it can be animated by injecting particles into the flow stream and watching them move through the enclosure at a speed that varies with air velocity. This is a particularly effective tool for discovering "dead-spots", where the air is relatively still and convective cooling is not occurring.

While surface temperatures on components may appear satisfactory, inside temperatures may be excessive.

Components/Locations	Predicted Temp w/ heatsink only on processor and video chips (°C)	Measured Temp with custom heatsink on all over-spec components (°C)	Component's Specification Max Temp (°C)
Processor	71.1	63.9	*95*
Video	70.2	61.6	*85*
Northbridge	78.9	64.8	*70*
Southbridge	77.5	62.4	*70*
Super I/O	81.8	62.8	*70*
Ethernet	77.6	61.7	*85*
Clock	77.5	62.9	*70*
External chassis-center rear	65.8	57.1	---
Ambient temperature	52.0	52.0	---

Table 1

Coolit predicted that five components would exceed their maximum recommended temperature, thus requiring a heatsink over more than just the processor and video chips.

VCU-1600 Command and Control Computer

The VCU-1600 links mortar-fire vehicles to one another and to position-and-navigational data and situation awareness information. Digitally connected through an embedded tactical modem to the Single-Channel Ground and Air Radio System (SINCGARS), the system acquires information from the Fire Direction Center and calculates an optimum fire control solution (Figure 1).

Figure 1

The ruggedized VCU-1600 Command and Control Computer developed by Miltope links mortar-fire vehicles to one another, to position-and-navigational data and situation awareness information, and then calculates an optimum fire control solution. The VCU-1600 is manufactured by Miltope Corporation under license from Phoenix Group Inc.

Developed by Miltope Corp., under contract to the U.S. Army Tank Automotive Command (TACOM), through PM Mortars at Picatinny Arsenal, New Jersey, the computer performs reliably in severe tactical environments. It will cold start at –32°C, handle operating temperatures up to 52°C, and be unaffected by dirt, dust, rain and solar radiation. The unit offers variable mounting positions, and its 12.1-inch display is readable from various angles and in direct sunlight.

The two-piece aluminum chassis is fully sealed and shock isolated. Given the severe shock and vibration requirements, fans could not be used even to equalize temperatures inside the unit. The final thermal solution involved reducing power consumption to 26 W through careful component selection and conduction cooling of the electronics through a chassis-mounted heat sink.

To develop the thermal solution, engineering employed CFD thermal analysis software to rapidly evaluate various design scenarios, eliminate prototyping and cut 3-4 weeks off the engineering schedule. The unit went from design to production in only 3 months, and received only final design testing (Figure 2). When the RAC PRISM Parts Count Reliability was calculated using the worst case operating ambient of 52°C, the total system MTBF was 7717 hours total system, more than 3x the 2000 hours requirement.

Figure 2

Command and Control Computer undergoes field trials during a "cool" 115°F day near Yuma, AZ.

The user can slice through the system for a view at any level within the system. No point or area is inaccessible.

With a click of a mouse, the user can move components, disable them temporarily from the model, change fan size, alter materials and then recalculate the results. Using these "what if" scenarios, he can optimize the placement, size and parameters of components without ever building prototypes.

Using CFD, engineers can squeeze more out of their designs. Previously when a system involved a mix of components, say some rated at 135°C and others at 70°C, the engineer might have been compelled to design for the minimum temperature rating. The result would be cooling overkill. Now the engineer can manipulate a design by isolating hot components so they can run at elevated temperatures, while lower rated units are maintained within their specs.

Designing for Desert Heat

Upfront CFD analysis was a key factor in Miltope's successful on-time delivery of the Army's VCU-1600 Heavy Mortar Commander's Interface Computer (see sidebar: VCU-1600 Command and Control Computer). The company had only three months to go from design to production on the sealed, ruggedized system. The extremely tight schedule meant there was almost no time for prototype builds or to physically measure chip temperatures.

The two-piece aluminum chassis computer drew 26 W steady-state, spiking to 67 W when two removable batteries were charging. It had to meet extremely high reliability (2000 hours MTBF while operating at 52°C) while exposed to the most stringent wheeled and tracked vehicle environments. These environments included an operating ambient temperature ranging from –32°C to +52°C with simultaneous ballistic shocks of 125 g.

Because of the severe shock and vibration conditions coupled with high-reliability requirements, fans were not an option; they couldn't handle the environment. The best cooling alternative appeared to be direct conduction cooling of the processor module components through the chassis. Initially, only the processor and video chips were designed to be conduction cooled.

But when Miltope performed CFD analysis the simulations revealed that a greater number of chips than originally thought would require sinking to maintain their temperatures within maximum specifications when exposed to 52°C ambient air (Table 1). From past benchmarking experience, the company knew that the Coolit predictions were accurate, typically within about 5%. Accuracy had also been verified by third-party benchmarking.

Color-coded simulations identify temperatures at every point within the system, while ribbons indicate internal air circulation. These views in Figure 1 are from the back with the chassis removed. The blue background is the front of unit where the LCD display is housed. The power supply and hard drive, which are nearly obscured in this view, can be examined by taking a "slice" through the unit. The original analysis (top) indicated that four components (Northbridge, Southbridge, Super I/O, Clock) exceeded their maximum operating temperatures.

Engineering evaluated approximately ten design scenarios, one of which ultimately drove operating temperatures well below design limits (Figure 1, left). The CFD software allowed Miltope to design a custom aluminum heat sink for use in the different scenarios, which included conduction cooling of chips, different thermal pads, the impact of various ambient temperatures and the impact of solar radiation. Coolit predicted that the heat sink design would maintain all components—power supply and motherboard components—within specifications and that the touch temperature of the chassis would remain within acceptable limits (no more than 15°C over ambient). It also verified that a separate PCMCIA card would be adequately cooled by conduction to the chassis through a thin stainless steel plate/thermal pad combination.

Three months after the project's start, production units sailed through formal first article environmental testing (MIL-STD-810 and MIL-STD-461), as well as recent early field trials aboard mortar-fire vehicles near Yuma, AZ, where the ambient air temperature outside the vehicles exceeded 46°C (115°F). ▮▮

Daat Research Corp.
Hanover, NH 03755-5484
(603)448-1302
[www.daat.com]