Cutting Thermal Design Costs

The design approach that pays for itself

Peggy Chalmers, Daat Research Corp.

Cost-effective thermal design demands the right tool. For electronics, that tool is CFD (computational fluid dynamics) which optimizes thermal designs, improves product reliability, shortens development cycles and cuts costs.

"Thermal simulation saved us a minimum of 6 months developing a new process control system," confirms the Honeywell project engineer, "It also eliminated hundreds of thousands of dollars in unnecessary prototyping and testing trying to zero-in on a workable solution."

With CFD, Analogic developed designs for two different CT scanners in less than a week in the process saving thousands of dollars. While at Raytheon the software eliminated a 4 month delay during the design of one of its data acquisition systems.

Engineers place their faith in CFD thermal predictions because they have been proven by over thirty years of experience and thousands of verifications by experiment. Over 70% of Daat's Coolit® predictions are within 5% and about 95% to within 10%. Such accuracy enabled Miteq to eliminate the 30% safety factor used to account for uncertainties. Similar savings resulted from eliminating overdesign in the IBM data center case study (this project was done using CoolitDC). Some independent benchmark studies assessing Coolit's accuracy can be found in Benchmarks below.

Coolit excels at calculating large problems with tens of millions of cells. It can calculate in just a few hours what a typical CFD code takes 1-2 days to compute. This speed is critical for designers, whose main purpose is to optimize - which often means multiple "what if" scenarios.

But power is not gained at the sacrifice of ease-of-use. An intuitive user interface is built into the entire Coolit software family (Coolit, CoolitPCB which focuses on printed circuit design, and CoolitDC for data center analysis). A first time user in Intel's RAID engineering agrees, "Coolit's user-friendly interface made it easy to ramp-up my modeling skills quickly."

The case histories below demonstrate how various industries have benefited from CFD thermal analysis.

Automotive

Thermoelectrics deliver hot or cold drinks for Audi drivers

Owners of Audi automobiles can keep their beverages hot or cold thanks to a thermoelectric cup holder mounted in the console. Designed by German consulting firm, AMS Technologies, the heating/cooling system faced multiple design constraints. Its

thermoelectric modules and associated fan had to squeeze into limited space, consume little power, and the fan noise had to be kept to a minimum.
The initial design drew 4 A at 12 V, and engineering anticipated it would deliver an 11 W cooling capacity to produce a beverage temperature of 9C in a 22C ambient. To verify its estimates, engineering built a detailed model using Coolit software. The model included the module geometry, number of couples and material properties (Seebeck-coefficient, resistivity and conductivity as a function of temperature).

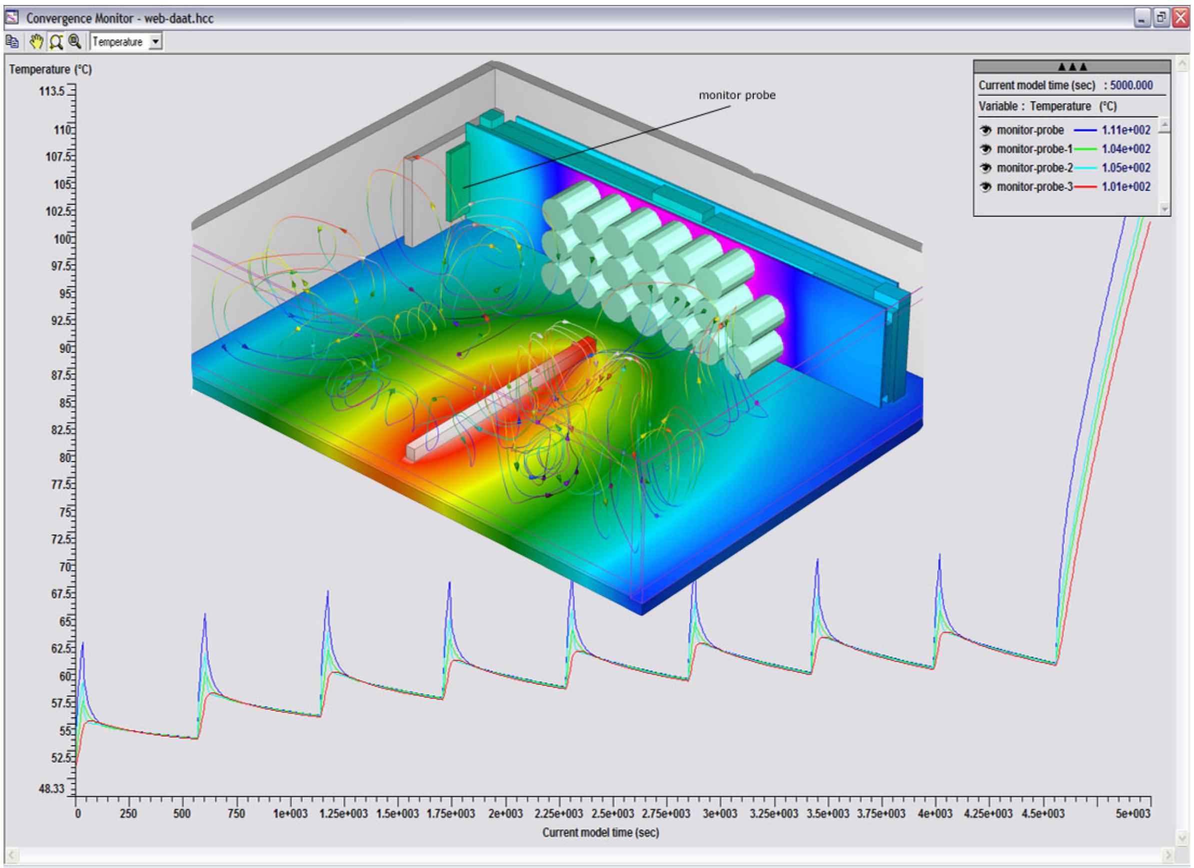
Push button sets cup holder temperature from 2C - 53C.

The analysis revealed that the initial design was inefficient. Less than 15% of the power was cooling the beverage, while the remainder was lost to ambient and as backflow to an overheated heat sink. A series of what-if scenarios were run to measure the impact of changes in insulation geometry and properties, heat sink profile, air ducts and in the selection of a lower current thermoelectric module. In the final Coolit-optimized design the cooling capacity of the thermoelectric module was reduced to 7 W, while the effective cooling capacity of the beverage increased to 3 W – almost three times more efficient than the original design. The new design could cool the beverage to 2C; while the initial design only reached 9C. At the same time, overall power consumption was reduced to 36 W from 48 W.

Military vehicle-based power supply for harsh environment

Byrd Technology Group LLC and power supply manufacturer, Granite Power Technologies, worked to develop a vehicle-based power supply headed for Iraq. The unit is mounted in a sealed cast aluminum housing along with classified electronics that the military would identify only by its size and location in the housing and the power output. To protect against sand and other elements, the housing is sealed and cooled by natural convection while operating in a 60C environment.

The power supply is constructed with encapsulated Vicor modules, 2 EMI filter modules feeding 2 DC-DC Converter modules, with integral heat plates and two pc boards. An aluminum block is sandwiched vertically between the boards and bolted to them, while the block base is bolted to the cast housing to complete the path from boards to ambient.



Coolit model of the power supply and temperature as a function of time at several monitor probe locations.

Coolit analysis predicted that the supply was within its thermal design limits. However, Granite wanted to quickly assess the accuracy of the CFD model without waiting for testing under actual conditions. So, a prototype was built in the lab and compared with Coolit predictions. The results came within 1C of the measured temperatures on the module baseplates. Interestingly, the analysis pointed out that the lead contractor's classified electronics were in thermal trouble and the contractor was notified.

Avionics

Army helicopter avionics keeps cool in harsh environment

Army workhorse helicopters are doing heavy lifting with the help of VT Miltope's Mass Memory Server 2 (MMS-2). The MMS-2, which resides in the aircraft's hot, cramped avionics bay, is a lightweight, network-attached, solid-state storage platform that is part of the helicopter's Avionics Management System. It serves as a digital map server and collects aircraft data including usage, maintenance, vibration monitoring, and engine, rotor, and balance information in order to monitor aircraft health.

MMS-2 functions as map server and monitors helicopter health. It is designed to stay cool in the helicopter's hot and cramped avionics bay.

Cooling the MMS-2, while protecting its interior electronics from contaminants (such as sand and dust, rain, humidity, and salt fog), required a separate, "dirty" conduit for air flow and heat exchange. Two rear fans pull air into the chassis from the lower front panel. The air then runs through a short, wide duct below the circuit boards before exhausting through the rear.

A baseboard with its processor module and power supply board is cooled by conduction and forced convection. Custom aluminum heat sinks mounted to these boards pull heat from the thermally significant chips, such as the processor chipset and memory. Attached to these conduction heat sinks are finned heat sinks that project downward into the air flow space of the internal duct. These heat sinks also serve as the ceiling of the cooling duct.

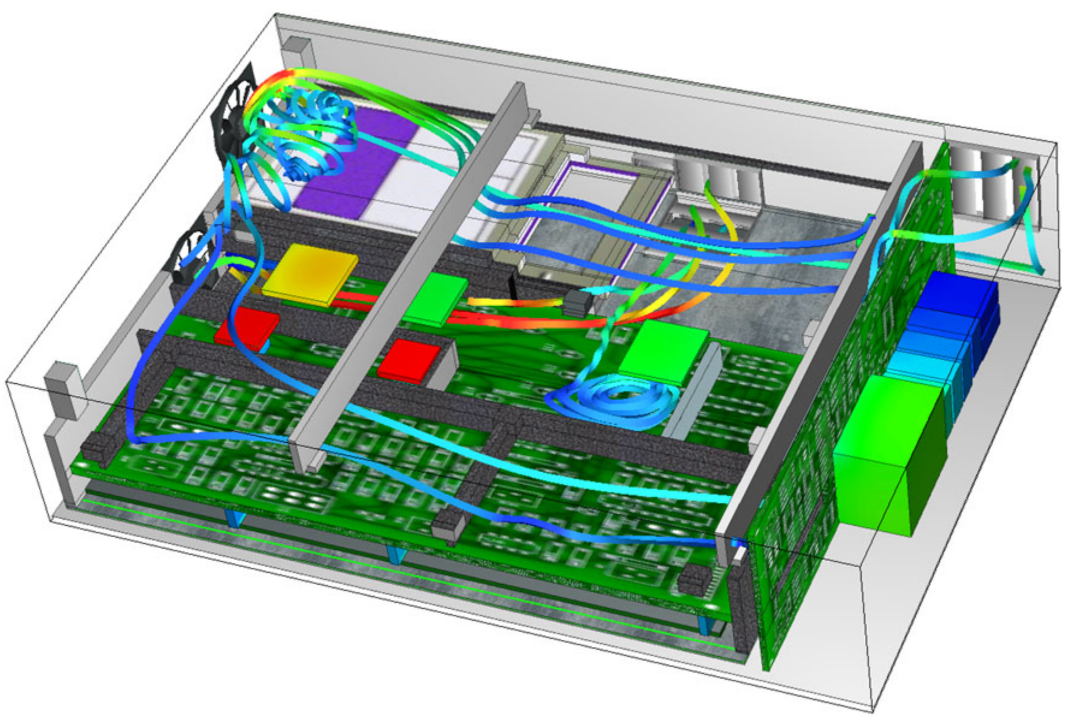
Coolit modeling ensured a reliable cooling system design across an operating temperature range of -40C to +71C. After a few tweaks to the ducting design and placement of fans to minimize chip temperatures, Coolit predicted that all major components would remain within their manufacturer's specifications with a healthy thermal margin. This modeling outcome later was verified by measurements on pre-production hardware.

Early thermal predictions indicated that the Ethernet board's components would benefit from additional cooling. So an aluminum heat spreader plate was added to lower component temperatures. Coolit further showed that a stirring fan was needed for spot cooling on a small toroid transformer on the power supply. This component could not be cooled by the same conduction heatsinking as the other power supply components, and could not be located in the air duct for environmental reasons, so spot cooling was necessary. Coolit showed that the stirring fan reduced the toroid's core temperature significantly. Finally, Coolit showed that the temperature of the four internal solid state drives remained within the manufacturer's limits.

Simulating a fan failure in Coolit was as easy as checking the box labeled Failed Fan. The MMS-2's rear fans are divided by a septum which continues the entire length of the internal duct to prevent short-circuiting of air flow in the unlikely event of a fan failure. If one fan fails, the air flow from one fan still cools half of the heat sinks for the baseboard and power supply. Coolit verified that the parallel heat exchange paths of the MMS-2 provided sufficient cooling even with a single fan operating.

Late in the design, solar radiation loading became a new requirement. Coolit easily modeled a solar load intensity of 1120 Watts per square meter, using a 45-degree solar angle and an azimuth for side loading. Predictions indicated that all component temperatures were still within acceptable limits.

Honeywell resolves EMI/thermal conflict



Coolit model of a Honeywell avionics system.

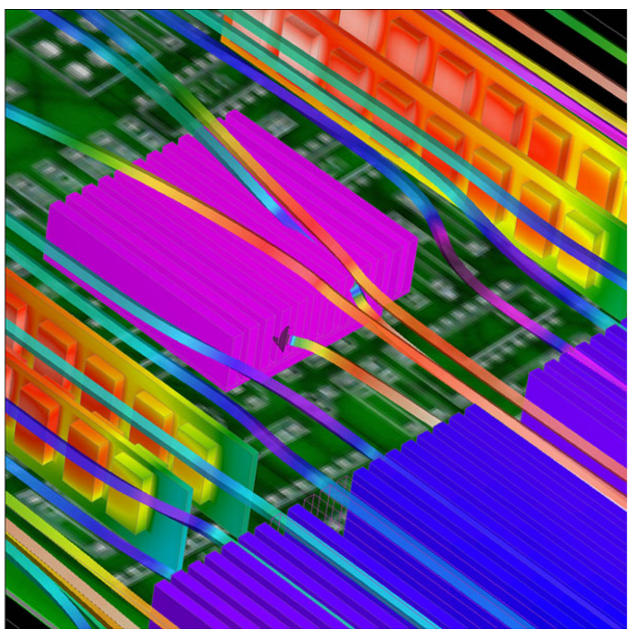
Thermal and electronics engineers are often at odds over chassis design. Thermal engineers want to maximize air exchange with the ambient, while electronics engineers seek to minimize chassis openings to improve EMI protection. Optimizing EMI design often means dividing a chassis into compartments, a feature that further restricts airflow.

A new general aviation package called for significantly higher power than its predecessor did. The cooling design for the package incorporated a fan and cooling fins. Initially, the ideal fin locations seemed intuitive. However, Coolit analysis showed that regardless of fin size or spacing, the cooling fins at these initial locations were creating thermal problems instead of fixing them. Furthermore, the analysis showed that fin height and spacing were especially critical, affecting temperatures within the enclosure by as much as 14C.

Coolit also showed that the chassis required more vents than electronics engineers had originally been willing to allow. When lab testing verified that the Coolit predictions were accurate to within a few percent, electronics engineers capitulated, and the chassis design was altered. Fortunately, Coolit identified the problems early in the design cycle, so changes could be incorporated into the first prototype. If the problem had been discovered after the prototype was built and tested, it would have delayed the entire project by months.

Computer electronics

IBM accelerates blade server design



CoolitPCB model of a blade server board with stream rods painted in velocity magnitude.

IBM's Boeblingen, Germany Development and Research Site develops very densely packed blade servers. Each server consists of a high density PCB for which optimum component placement, particularly of processor chips, power supplies and switches, is crucial to cool operation. Designs originate with the architects, who previously had to wait in queue for thermal analysis assistance from mechanical engineers. To eliminate these delays, architectural engineering began doing its own CFD analysis, using CoolitPCB.

Analyses are performed at the architect's desk. Iterations are run on his schedule without the need to shuffle information back and forth between departments. Once the board architecture and optimization is completed, the design is turned over to thermal engineering for system integration.

Typical applications have included a design with 8 DIMM sockets (dual in-line memory modules). If the sockets were placed too close together, it would inhibit airflow; if spaced too far apart, they would consume valuable real estate. CoolitPCB quickly predicted the impact of the various spacing scenarios and enabled the architect to determine the optimum spacing solution. In another application, excessive heat was being generated across the board. CoolitPCB pinpointed the source: high heat levels being transmitted from a BGA through its pins and ground planes. The predictions proved to be within 5-6% of the actual temperatures.

With CoolitPCB, Boeblingen Lab is now catching and fixing potential thermal problems earlier, reducing development time and bringing new products to market faster.

Building reliable hard drives

Seagate, a leading manufacturer of data storage equipment, prides itself on the reliability of its hard drives. One low cost, 3-1/2 inch external hard drive developed for the retail desktop market was cooled by conduction and free convection. Air had to move freely through the unit whether it was in the vertical or horizontal position, and fans were not an option for cost and noise reasons.

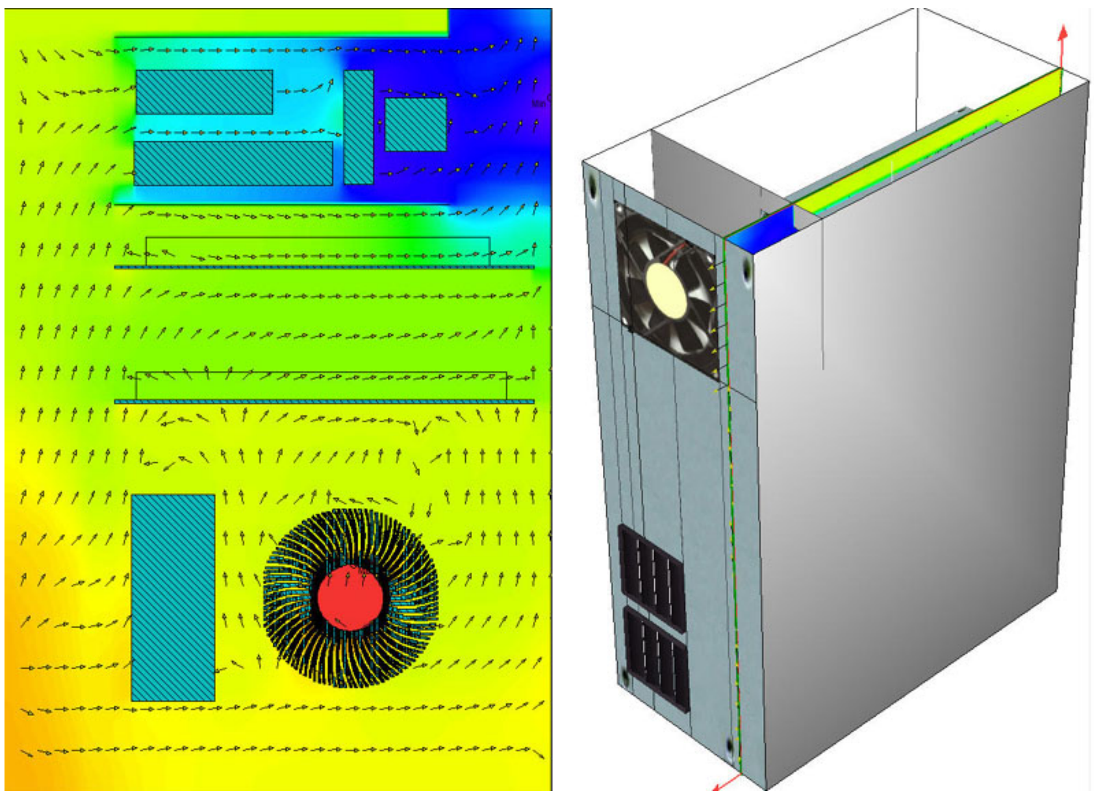
A 3.5" external hard drive

To design the unit's custom heat sink, engineers had to balance fin size, shape, and number. If the heat sink were too large, it would choke off the cooling air. If there were too many fins, air would bypass them. And the design had to be stamped in order to minimize manufacturing cost. The industrial design team had also decreed that the number of vents had to be minimized for esthetic reasons. So engineers had to identify the strategic vent locations that would allow adequate ventilation.

Normally, juggling the conflicting requirements would have demanded numerous physical prototypes tested, modified and tested again until engineering zeroed in on a workable design. The entire costly process would have taken weeks and possibly even months to complete. By enlisting Coolit, engineers completed the project in a fraction of the time. Multiple design scenarios were built and analyzed in less than a week and an optimized thermal design delivered without building prototypes.

Abbott Labs safeguards server performance

When pharmaceutical giant, Abbott Labs, developed a custom server for its specialized needs, Byrd Technology Group, LLC was asked to verify its thermal design and recommend performance enhancements. The multi-chambered system contained the usual processor, function boards, power supply and fans. But it also contained one item that made thermal modeling particularly challenging - a spiral heat sink mounted on the processor board.



Coolit easily models complex curved surfaces such as this spiral heatsink.

"Most people probably don't realize how efficiently Coolit can pull in a complex, curved surface model", notes Byrd Technology's president. "The import is very easy to use and you can adjust the amount of detail wanted." The heat sink was imported into the overall model where the consultant could observe airflow spiraling through the fins, note the effect of heat sink temperature rise on the system, and identify where the hot air exhausted and where it traveled after exiting.

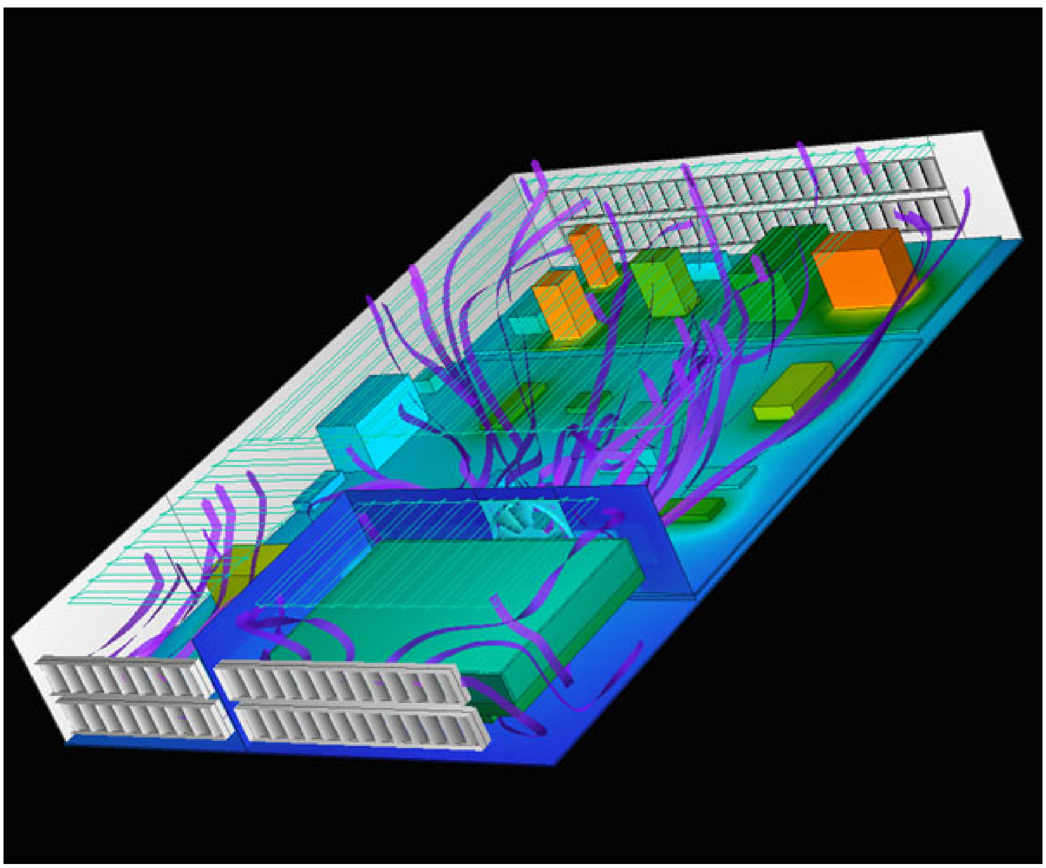
Coolit predicted that the original configuration would exceed its thermal limits and helped redesign the layout and resize the fans for an optimal configuration. "The Coolit solver is so fast," observes Byrd Technology's president. "It can run multiple iterations much faster than other thermal products. Using Coolit, we quickly delivered a thermal design that met all of Abbott's requirements."

Consumer electronics

Seagate designs optimal DVR

Millions of digital video recorders are sold each year, and getting a new design to market quickly can have a major impact on product revenue. But the number of parameter permutations often makes it impossible to optimize the thermal design using traditional methods, while still meeting the customer's project schedule.

In this project, the goal was to maximize reliability by delivering the incoming cool air to the hard drive, then directing it to the hottest components, and finally to the remaining electronics. Engineers separated the hard drive from the electronics by surrounding it with a sheet metal wall and then mounted the fan on the downstream side of the wall. This reduced noise by placing the fan inside the housing and drawing air from the hard drive section to cool the electronics.



To maximize cooling efficiency while minimizing fan noise, the DVR fan is mounted on the divider wall surrounding the hard drive. Air drawn from the drive compartment passes through the divider wall to cool the electronics.

While there were a few limitations (mostly because of cabling), the fan could be anywhere in the divider wall, the intake and exhaust vents could be located on any of the six sides of the enclosure, and the electronics and hard drive could be positioned anywhere on their respective sides of the divider wall. Engineers calculated approximately 60 Coolit models, studying the impact of component placement, the fan flow direction and rate, checking to make sure hot air from the power supply wasn't short-circuited toward the hard drive, and optimizing vent sizes and locations.

In the end, Seagate found more than one design parameter combination that met the specifications and were able to supply the customer with several designs from which to select based on manufacturing costs, aesthetics, or other criteria.

Sandisk verifies solid state drive design

Before releasing a new solid state drive (SSD) to production, SanDisk uses CFD to verify that its design will meet the thermal requirements. The SSD is a dense sandwich structure made of plastic materials and enclosed by two stainless steel covers. Inside the sandwich resides the memory and CPU PCBs separated by a thermal pad. A second thermal pad separates the memory PCB and the cover.

Staying cool even when ambient is 70C is the foundation of Sandisk's SSD superior performance and reliability

Coolit analysis quickly determined the temperature distribution, as well as case and junction temperatures of components to verify that the module did not exceed its design limits. The model also found no hot spots in the system. The design was approved for production and the new SSD drive, designed as a drop-in replacement for the hard disk drives, delivered superior durability, performance and power efficiency - keeping mobile PCs working optimally in the toughest of conditions.

Taming heat in Microsoft Kinect

The Kinect system inside Microsoft's Xbox contains motion sensing technology allowing Xbox players to use their bodies to control the movement of their on-screen characters. Developed by Tel Aviv-based PrimeSense, the design bathes the scene with encoded infra-red light patterns that are reflected and then analyzed for deformations.

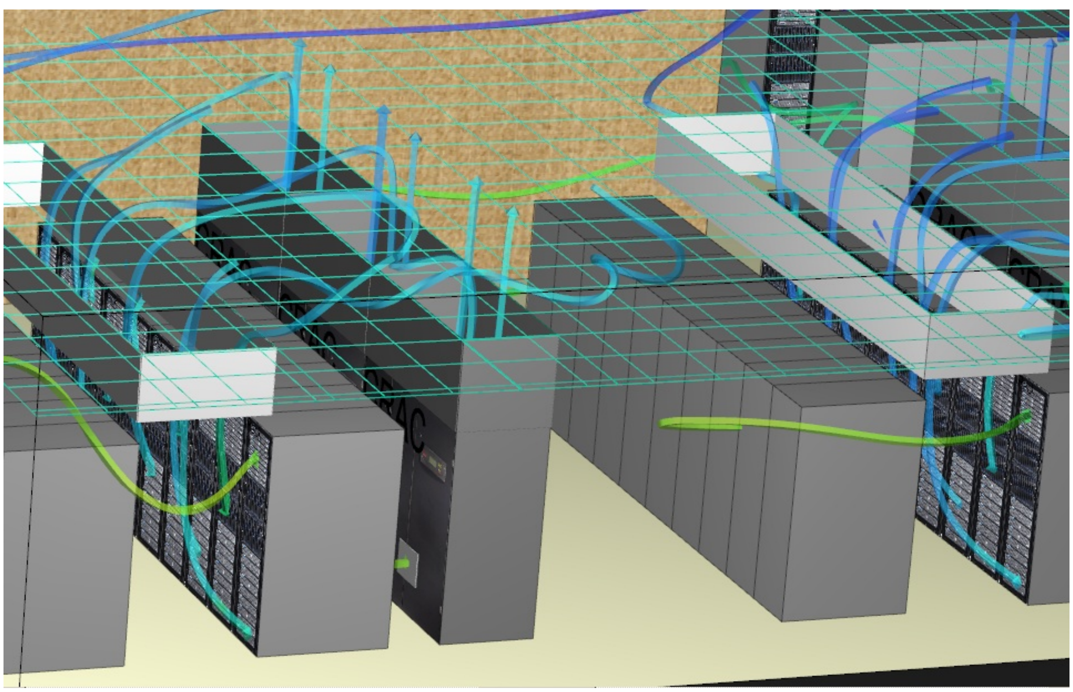
The PrimeSense design includes two cameras and a laser, with power supplied through a USB and limited to 2.5 W. The laser mast, with its temperature limit of 35C, is cooled by a thermoelectric cooler. However, the mast's compact size, significantly limits space available for the thermoelectric cooling device.

To perform the thermal analysis on its design, PrimeSense engaged thermal consulting firm, CAS Ltd. With the aid of Coolit, CAS analyzed potential configurations and developed a layout that met both the power and size constraints. The successful technology is now found in millions of homes.

Data centers

IBM optimizes an existing data center

At one IBM location, the data center occupies the entire floor of an office tower, except for the core where services, such as elevators, are located. Because it is a regular office building, there was insufficient height for both a raised floor and a suspended ceiling, so only a suspended ceiling was used. As a result, the CRACs, instead of pumping cold air down under the floor, pumped cold air up above the ceiling. Vents were built into the ceiling between facing rack rows in order to direct the cold air down. The descending cold air then was supposed to enter the racks and exit into the room and back to the CRACs for cooling.



A portion of the IBM data center shows airflow using temperature-painted streamrods.

Such designs are often problematic, since the cold air could be readily “shorted” from the racks and instead go back into the hot portion of the room before returning to the CRACs. To further complicate matters, both the racks and CRACs were near outside windows and, hence, were subject to significant solar heating. To minimize chances of short circuiting, the engineers suggested adding fans at the top of each vent to control the flow rate of the cold air. While this would ensure uniform air distribution between racks and force the cold air down closer to server inlets, the solution meant added infrastructure cost, more equipment to maintain and, therefore, more chances of breakdowns and increased energy expense.

IBM asked CAS, a leading thermal design consulting company, to analyze the design. Using CoolitDC, CAS modeled the data center in less than a day. The analyses proved that no fans, additional doors or partitions were required to maintain adequate cooling. IBM could confidently use the significantly less costly, but the more reliable and more energy efficient design. Furthermore, the upfront analysis cost far less than the proposed design changes and it completely eliminated any concerns about short-circuited air.

Mobile data center for defense applications

At the Israel Defense Forces data centers, exceptionally high reliability is an absolute must. The critical and often mobile nature of the applications demand that the data centers run cool even under harsh conditions, and often it is impossible to incorporate spare capacity for backup. A typical site consisted of a 16 x 12 m room containing 8 rows of racks cooled by 4 CRACs. This configuration did not provide uniform cooling, and the tops of some racks were exceeding allowable temperatures.

Mobile data center.

Thermal consulting firm CAS used CoolitDC to build a model of the data center and then calibrated the model against actual flows and temperatures. Typically actual and calculated measurements matched within a few percent.

Once the model was calibrated, the firm investigated the impact of a mix of cold and hot aisles, reducing the air leakage and replacing missing blanking panels which were affecting the cold aisle efficiency.   Many scenarios were evaluated in a brief time span.

All this required computing dozens of different cases in order to arrive at the optimal solution. Speed of modeling, both in making model changes and in actual computing of cases was of the essence.

A solution developed for one IDF data center required completely sealed cold aisles which eliminated all hot spots without any additional cooling equipment. In fact, the simulation showed that CRAC supply temperatures could be increased from 12C to 15C, while still keeping rack inlet temperatures under 25C. The design change resulted in over 12% energy savings, which more than paid for the consulting effort.

Defense electronics

Ruggedized mortar fire control system

VT Miltope had only 3 months to go from design to production on its mortar fire-control computer system for the Army. The tight schedule meant almost no time for building physical prototypes to measure temperatures as a check on heat buildup. The sealed, ruggedized system operated under ambient temperatures from -25F to +125F, while exposed to ballistic shocks of 125 g.

Battle-ready laptop can take the heat.

Severe shock and vibration coupled with very high reliability requirements meant fans were not a cooling option; they wouldn't withstand the environment. So Miltope enlisted Coolit to develop a rugged, passive cooling design, while eliminating physical prototyping, thereby shaving 25% off the development cycle.

The best cooling approach appeared to be conduction cooling of the processor module components through the chassis. Initially, only the processor and video chips were targeted for conduction cooling. But Coolit simulations revealed that a greater number of chips would require heat sinking to maintain their temperatures within specifications.

Using Coolit, Miltope designed a custom heat sink and analyzed numerous scenarios, including conduction sinking of different chips, benefits of thermal pads with different thicknesses and conductivities, and the impact of various ambient conditions. When actual component temperatures were later measured on pre-production hardware, the thermal model predictions proved to be accurate to within 5%.

Air defense radar systems

A typical radar system consists of numerous parts that require thermal analysis. In one design, there were two isolated cooling subsystems: an open loop system that cooled the antenna and a closed loop system that was sealed to protect the power and control electronics. The latter used baffles to direct the airflow across the components and over the cabinet cooler where heat was released into ambient.

The best mechanical locations for two fans in the closed loop system intuitively seemed likely to result in air recirculation near one of the power supplies. But other possible locations potentially would increase the pressure drop and result in insufficient airflow through the system. Using Coolit to analyze different scenarios, engineers discovered that despite recirculation at the preferred location, there would still be adequate cooling.

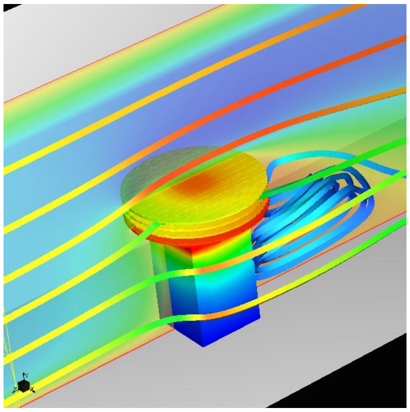
Since adopting Coolit, ITT Gilfillan has begun simulating even small, inexpensive components it previously could not economically justify analyzing. For example, a plug-in power supply might contain 30-50 parts, but it can be modeled quickly and efficiently in Coolit. This new information has resulted in more reliable and high-performance designs. Coolit has proven to be a valuable virtual prototyping tool that permitted the company to reduce its reliance on physical prototypes with an accompanying reduction of product development time and costs.

Heat sinks

Custom heat sink

When a computer chip company developed a thermal solution for its new server chip, the company only expected the vendor to fabricate the design. The company was pleasantly surprised when Calgreg Electronics told them it could create a custom heat sink that would be better and less expensive than the in-house design.

Using Coolit, Calgreg analyzed the impact of fin direction, surface area, base thickness, fin thickness, fin height, spacing, etc. The resulting optimized design was impressive. Calgreg reduced costs by 22%, which in this high volume application meant huge savings to the customer. Perhaps even more importantly, Calgreg slashed the heat sink footprint by 40%. Freeing up board real estate was golden for PCB designers because there was more room to layout traces and less need to route around components.



Coolit simulation on a Calgreg radial heat sink.

When the final design tests were run by the customer, Coolit predictions proved to within 4-5%.

Optimizing microgroove heat sink

The new heat sink design by ATEC combines a microgroove-surfaced heat sink with fluid manifold cooling. A series of manifolds direct fluid in and out of a section of the microgrooves, causing the fluid to vaporize and pass onto the condenser before being recirculated.

Researchers use Coolit to study how variations in microgroove design impact its thermal-hydraulic performance, and how the various designs stand up against the performance of a conventional heat sink of identical volume. Further simulations seek to determine how design can be optimized for performance.

Simulations are run to obtain overall heat transfer coefficients as a function of inlet air flow rate. The manifold microgroove heat sink is very demanding on CFD software. The geometry contains a great number of air channels and even at high flow rates, the Reynolds number within the narrow micro-grooves is low.

When comparing designs, researchers found Coolit saved them lots of time. It is fast and accurate, and unlike other CFD software, Coolit results can be quickly exported into a spreadsheet for comparison. Accessing previously run files is also a snap - a fraction of a minute compared to other software which could take up to 20 minutes.

LED lighting

LED light for plant and animal growth

At a world renown German research institute, LED-lighting is used to simulate the sun during experiments on plant and animal growth. The lighting systems are mounted inside large dark rooms and emulate the sun's day/night cycle. During their experiments, researchers use a special wavelength to accelerate plant growth.

LED arrays will replace these existing neon fixtures in greenhouse experiments.

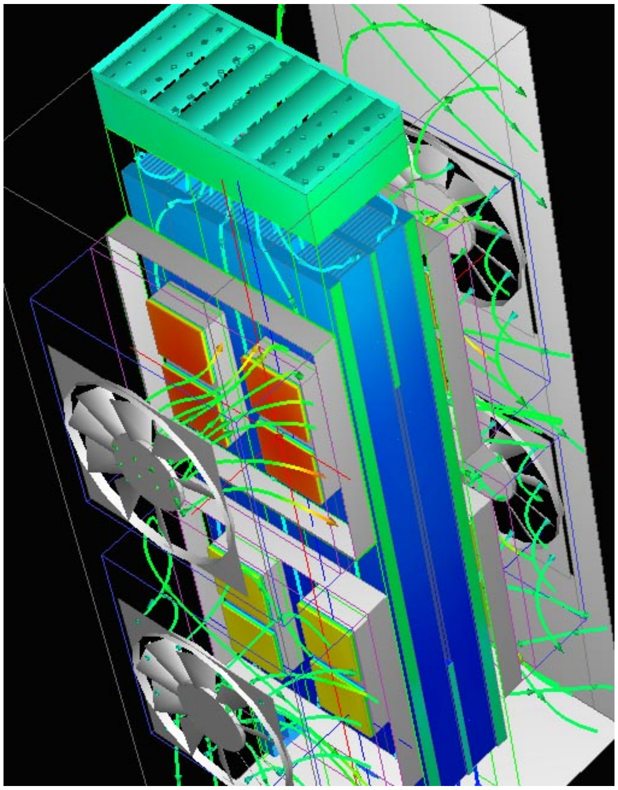
Significant heat is generated by each lighting system and must be dissipated by a 7 ft x 2 ft cold plate attached to it. Because temperature influences the wavelength emitted by the LEDs, each cold plate has to ensure a uniform temperature distribution across its surface. To design the cold plates, the lighting controls manufacturer, a global leader in LED lighting and power solutions, contracted with thermal consulting expert, AMS in Munich.

Forced water cooling was selected as a simple and cost-effective approach with the coolant tubing looped back and forth along the length of the cold plate. Using Coolit, AMS analyzed the impact of various design parameters, such as the number of tubing loops, pitch, flow velocity, and interface material used between the PCBs and the cold plate. When the Coolit optimized design was tested, it verified the prediction accuracy and satisfied all the cooling requirements.

Medical equipment

Surgical cooling blankets with TECs

A leading global provider of patient temperature management products uses thermoelectric coolers to produce cold air for its surgical cooling blanket during brain surgery. The blanket is wrapped around the patient to lower body temperature and increase the chances of surgical success. The initial cooling design performed well thermally, but it proved too noisy for the operating room. Its two 100 CFM fans mounted on external heat sinks generated 55 db and doctors were complaining.



Coolit model of TEC-cooler for surgical blankets.

Using Coolit analysis, UK firm CE Technologies determined that there was poor airflow around the heat sink due to an inadequate fan and heat sink. Quieter, lower flow fans simply would not work with the existing heat sink, and there was not enough room to mount a larger heat sink.

Within three days CE Technologies developed a number of design options, allowing the manufacturer to choose the best combination for production. The winning design optimized spacing between fans and heat sink to improve airflow, included a new heat sink and two 70 CFM fans that significantly reduced noise.

The analysis and new design cut 3 months from the project schedule and came in at only 25% of the estimated cost. When the final Coolit design was tested, the analysis proved accurate to within 5%.

CT scan equipment

Analogic Corp, whose data acquisition systems are found in majority of the world's CT scanners, used Coolit to select and size the appropriate forced air device and design baffles to optimally distribute airflow across multiple data acquisition boards.

A typical CT unit

The 200 W data acquisition system consisted of 17 boards riding on the CT scan's rotating gantry. With the gantry rotating at 90 rpm, there was sufficient centrifugal load to adversely affect the cooling fan bearings. To maximize bearings life, the fan was mounted in the direction of board travel with the air funneled back onto the boards by baffles.

Initially the thermal engineer felt multiple blowers would outperform fans in this application, but Coolit models proved the reverse was true and that only one fan was sufficient. The CFD-designed system of vents and baffles provided optimal airflow for each board. Analogic developed designs for two different CT scanners in less than a week at large savings.

Power supplies and rectifiers

Power supplies for Apache helicopters

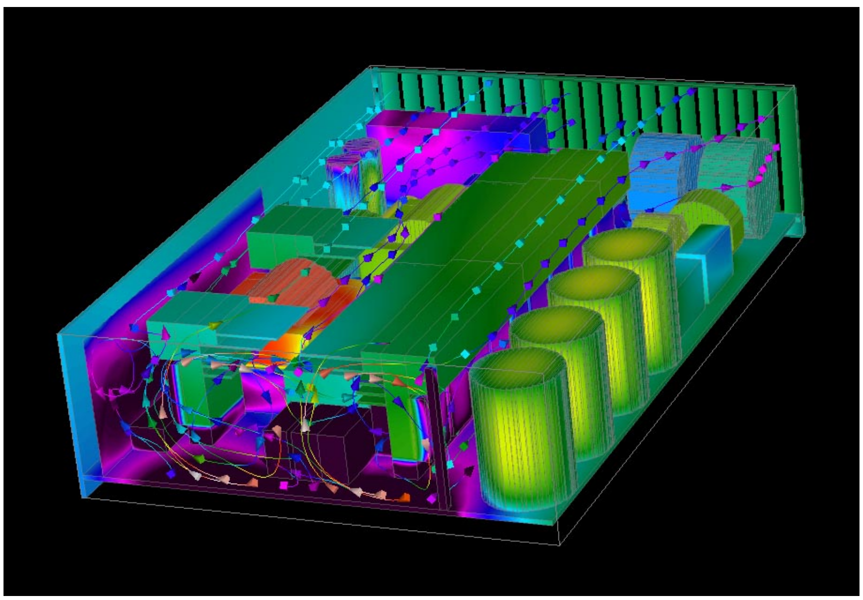
Under a contract to Lockheed-Martin, Coolit helped Varo LLC develop a digital power supply for the Apache helicopter's night vision and target acquisition system. The very small power supply modules provided highly precise power conversion.

The design consisted primarily of a heat sink with two high-density printed circuit boards mounted on each side. In this unit, both the overall heat of each board and the heat generated by several components presented thermal challenges. With Coolit, Varo was able find a fin design that would remove heat from the boards. Coolit simulations also pinpointed the problem chips: the FET drivers and SOs with high, 40C/W, junction to case resistance.. Once they were identified, the electrical engineers solved many problems by re-design, splitting a thermal load so that part of it would go to a remotely located resistor instead of having the driver chip handle it all.

Eaton shrinks rectifier 60%

Eaton Powerware, a leading provider of power quality and backup power management solutions, faced stiff design restrictions in producing a new rectifier module. The 3 kW unit would dissipate 300 W, and in order to achieve balanced three-phase currents, units had to be mounted in multiples of three per 19-inch wide shelf. This meant the rectifier envelope had to shrink by at least 50% over the existing model.

Geometry allowed little leeway in manipulating the electronics to enhance cooling. Components had to be positioned in a predefined sequence and this limited the possible locations for heat sinks, vents and fans. To scope the problem, Powerware engineers enlisted Coolit to identify hot spots and explore "what if" scenarios without expensive and time-consuming physical prototypes. While at it, Coolit helped design a tiny, but highly effective heat sink with optimized fin spacing and pinpointed preferred fan and vent locations.



Coolit model of a rectifier unit.

Throughout the design process Coolit's ease-of-use proved crucial. The electronics engineers who undertook the thermal design had no CFD training. But Coolit's intuitive interface helped the designers get up to speed.

Once the Coolit-suggested changes were implemented, the resulting design exceeded the dimensional goals. The new unit shrunk to roughly 60% of the original size, enabling multiple units to fit within a 19-inch shelf. Plus, the rectifier's power density achieved a record - making it the most power dense 3kW rectifier available.

Process control

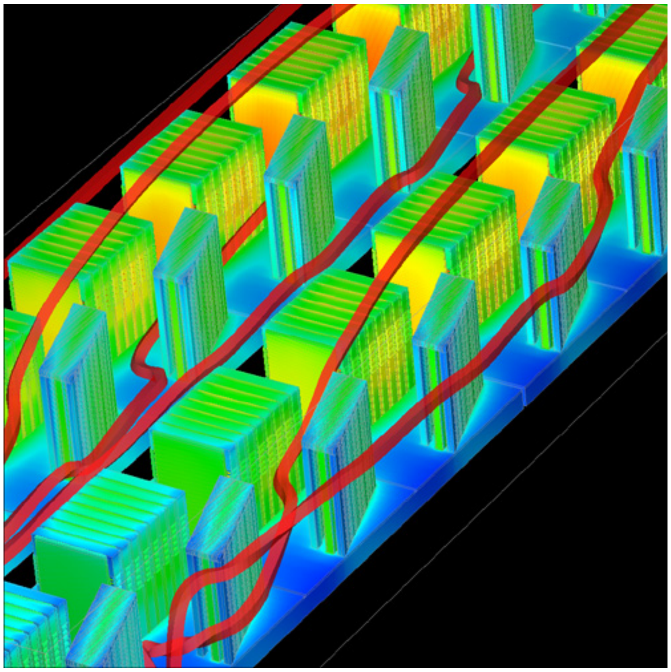
Optimizing Honeywell's process control system

To maximize module count while minimizing footprint, Honeywell engineers, developing the Experion process control system, vertically stacked the I/O and controller modules. But vertical stacking caused overheating. Cool air entering the bottom of the cabinet would grow warmer from one module to the next. By the time it reached the upper portion of the stack, the air would be so hot that it caused modules to overheat.

The system contains 36 modules stacked into three columns of 12 modules each. To keep components from overheating, more fans and/or vents would be required, but this was not an option because fans reduce reliability, add noise, and pull in contaminants, while additional venting on the sides was not possible because the equipment is often joined side by side.

With the obvious fixes off-limits, it was reasoned that if each module were tilted, unheated air could enter at the bottom right side of the module, flow across it and exit at the top left side. Each module, regardless of its vertical position in the stack, would be cooled by cool air entering from the bottom.

Since there was no time to build a physical prototype to prove the concept, engineers used Coolit. The analysis predicted that if the modules were slanted 18 deg and stacked close together in the vertical direction, cool air would reach each of the 36 modules without co-mingling of hot and cool air from one column to the next. Verifying the design through physical prototyping would have taken a minimum of 2-3 months. Time-to-market was critical and Coolit delivered.



Coolit analysis shows that the tilted module design will deliver cool air to each module.

Tilting the modules solved the airflow problem, but there was still one more thermal challenge. One I/O module dissipated almost twice as much heat as the others. The problem module contained 16 high-heat-dissipating Field Effect Transistors (FETs) and heat from the FETs was being transported via the copper traces across the length of the board to other devices. Engineers tried to fix the problem by spreading the FETs evenly over the board surface, but Coolit predicted that some devices would still overheat.

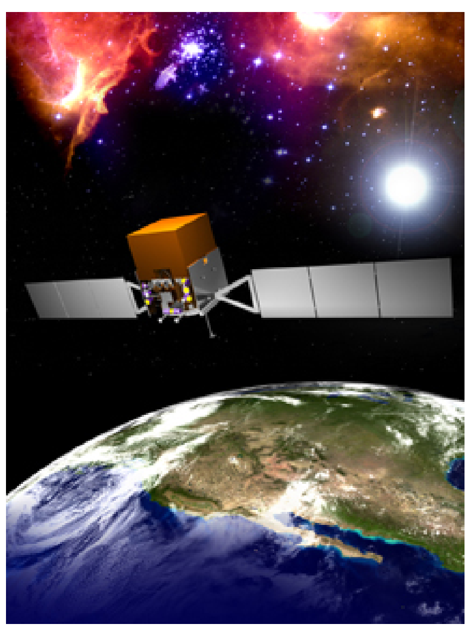
The next proposal was to thermally isolate, the high-heat-producing devices from the rest of the board. A design was developed in which all FETs on the board were separated from the other devices by a thermal barrier. The concept worked. Heat passing from the FETs to the opposite end of the board was dramatically reduced, and Coolit verified that components on both sides of the barrier remained within their operating limits.

Developing this design using modeling saved Honeywell a minimum 6 months and considerable money. “Without a good simulation tool, we’d have had to throw away hundreds of PC boards as we cycled through fabrication, assembly and testing trying to zero in on a workable design,” explains the project engineer. Estimated savings using Coolit - hundreds of thousands of dollars.

Satellite communications

Designing a data acquistion system for NASA and SLAC

Stanford Linear Accelerator Center (SLAC) and NASA built the satellite that transported to outer space the 'grand observatory' for mapping gamma-ray bursts. This telescope known as GLAST, Gamma-ray Large Area Space Telescope, delivers 50x the resolution of the EGRET project and probes the mechanisms of particle acceleration, investigates dark matter and the early Universe, and advances science's knowledge of black holes.



Spectrum Astro rendering of the GLAST spacecraft in orbit above the Earth.

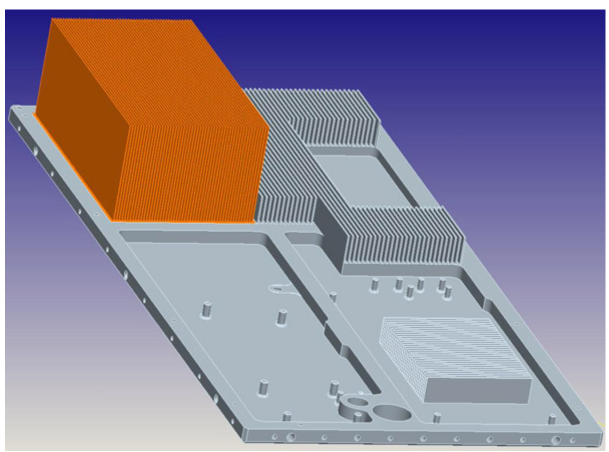
The telescope collects incoming gamma-ray signals from outer space and feeds them into a 850,000 channel data acquisition system. The system sifts through the data, determining what looks promising and what should be discarded. When an interesting signal is detected, the system orients the telescope to face the source.

The 300-watt data acquisition system is cooled by heat pipes controlled by shutoff valves that automatically thermally stabilize the electronics at approximately 15C. The heat pipes transfer heat from the electronics to solar panel radiators for dissipation into space. The goal is to hold system temperature constant to within +/- 1C, because larger thermal gradients can cause bending and warping of the detectors. But designers also must prepare for the worst. If one of the 8 square meter solar arrays fails to open, or if a heat pipe fails, temperatures could vary anywhere from -40C to 55C.

To verify the system's thermal design across the full temperature spectrum, Coolit simulations were constructed based on imported geometry and searched for hot spots in each of the system's 12 electronic modules. The Coolit analyses proved that the GLAST could handle even the worst-case conditions.

Optimizing electronics for satellites

MCL designs high power RF amplifiers that serve as uplinks in satellite communications systems. Typically the units operate outdoors attached to truck-mounted satellite dishes and must handle wide temperature variations and be environmentally sealed against contaminants, such as dust, rain, and snow. Because the dishes are gimbaled, the heat sinks must be as small and light as possible.



Removing least effective fins reduced heat sink weight.

A recent amplifier, designed for increased power, generated 1500 W from the main module and 400 W from an accessory module. To reduce size and weight, the heat sink was designed to form part of the sealed amplifier enclosure. Heat conducted to ambient is expelled by an external waterproof fan.

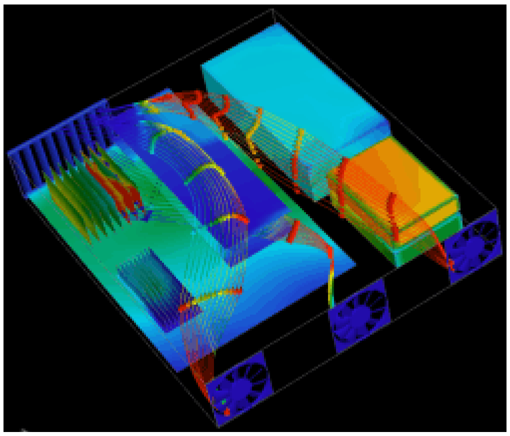
Thermal performance versus weight became a real challenge during heat sink development. Higher thermal performance designs were too heavy, while the lighter designs did not adequately cool the components. Coolit modeling pointed to the solution

- a combination of materials. As the design evolved, a detailed model was created that included wiring, individual resistors, capacitors and other components. Coolit analysis then determined the optimal fin shape, size and spacing. It minimized heat sink size and quantified air flow requirements. Coolit also identified which fins were least effective. These fins were removed, further reducing weight, while still keeping the heat sink structurally strong and satisfying the cooling requirements.

Telecommunications and networking

Thermal management of rack mounted telecommunication equipment

The military electronics leader Raytheon is detecting potential thermal problems early in the development cycle when engineers have maximum flexibility in packaging design and component placement. In one project, Raytheon upgraded an 18 x 9 x 7 inch, rack-mounted communications package containing two power supplies drawing 600 W. When the proposed air-cooled design was analyzed using conventional thermal techniques, the analysis indicated that component junction temperatures would remain at 146C, comfortably below 150C upper limit.



Redirecting more airflow towards the heat sink side of the assembly improved cooling.

When this design was subjected to Coolit scrutiny , a different scenario emerged. Coolit predicted that the junction temperature would reach an unhealthy 176C. Specifically, Coolit indicated that the power supply heat sink could not adequately dissipate the heat unless the heat sink is redesigned. Coolit also helped improve air flow. Initially, air was diverted so that it would brush both the component and heat sink sides of the power supplies. CFD analysis showed that by redirecting more flow to the heat sink side of the assembly, the heat dissipation could be dramatically improved.

Reducing design risk of networking equipment

At QLogic, Coolit acts as an up-front tool enabling engineering to select the appropriate components and optimize air flow before committing designs to fabrication. In one project, adequate airflow was available, but high power density at the chip level demanded a custom thermal solution, because air flow impedance requirements made it impossible to use an off-the-shelf heat sink. By running simulations on various heat sink combinations, Qlogic was able to zero-in on a very low airflow impedance design that adequately cooled the chips.

"Thermal analysis is a risk reducer for us and our customers," notes QLogic's engineering manager. "It allows us to comply with customer requirements and have an early view into the performance. Compared to other thermal software, Coolit models are very easy to build, and processing is fast and very efficient. And the use of local grids reduces my solution time and enables me to build larger models."

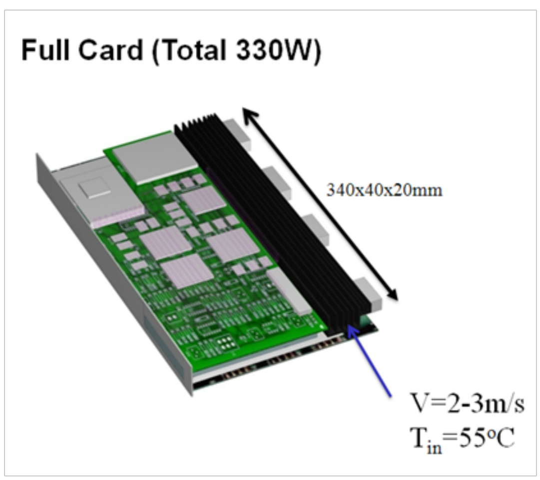
He adds, "Without Coolit, complex systems would require lots of testing and modifications to get where you need to be. With the software, development time is shorter, test time and modification time is limited, and there are fewer design iterations."

Qlogic always compares the thermal predictions to actual test results. While accuracy will vary somewhat with system complexity, even very complex models prove accurate to within 10%.

Heat pipe saves ECI telecom design

ECI engineers initially design chassis and select fans based on the expected power dissipation of components. They then use Coolit to optimize heat sinks, determine component placement, predict junction temperatures, and assess the operating performance of fans.

Such a generally effective approach proved inadequate for one mother-daughter board combination. The high powered combo was housed in a small enclosure that made it difficult to dissipate the heat adequately. In addition, the design contained large vendor modules that blocked air flow across the cards. No amount of fan tweaking or component selection and placement optimization could compensate for the expected 300 W thermal load, and the unit was exceeding its temperature design limits.



Heat pipe transfers heat from front of card to heat sink on the back.

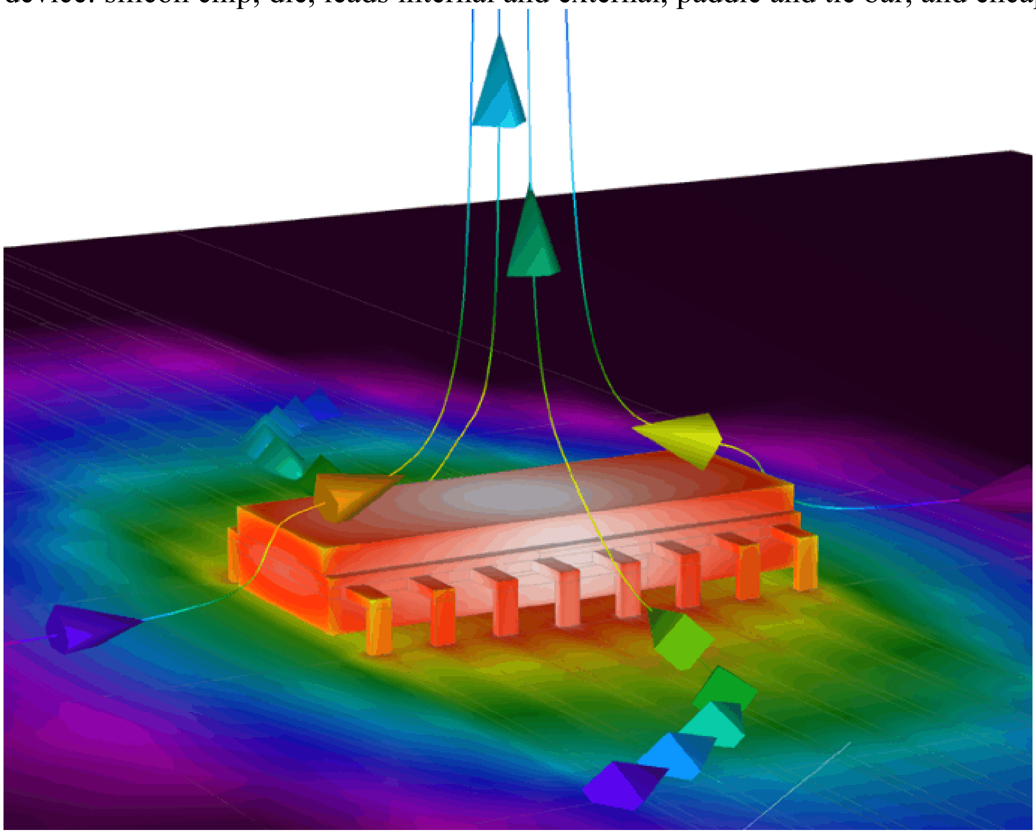
A new approach was suggested with a heat pipe to draw heat from the components on top of the main card. The heat is then transferred to main card's backplane connector area where there is adequate real estate to mount a heat sink. Using Coolit, ECI optimized the component placement on the mother-daughter board and determined the optimum spacing between the boards. The Coolit analysis predicted the new design would achieve the desired results. The design was independently confirmed by the vendor who built the heat sink and embedded heat pipe system.

Benchmark Cases

Free convection: Single component PCB

Nokia AB has developed a series of benchmark tests for CFD codes. The test shown here, involved a board mounted SO16 device.

The device was placed horizontally in the test chamber and it was cooled by natural convection and radiation. The model included the detailed internal architecture of the device: silicon chip, die, leads internal and external, paddle and tie bar, and encapsulant.



Coolit model of the Nokia board with SO16 device

The lab test was done for two SO16 devices to see the variability in the measurements. The Coolit test was run independently of the experiment and without the knowledge of experimental results (blind). Only after the computed results were delivered, were the measured data communicated to the engineers doing the Coolit analysis.

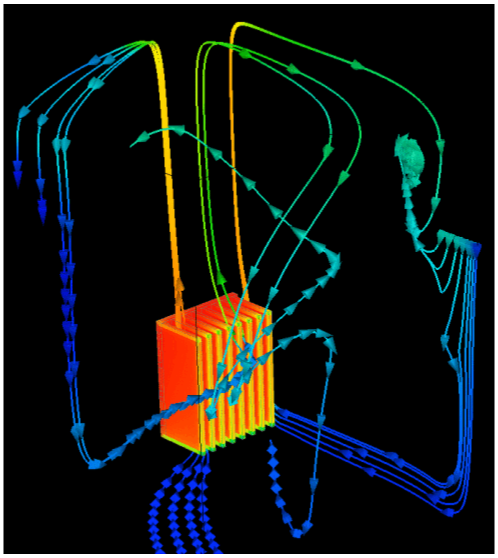
The results were as follows:

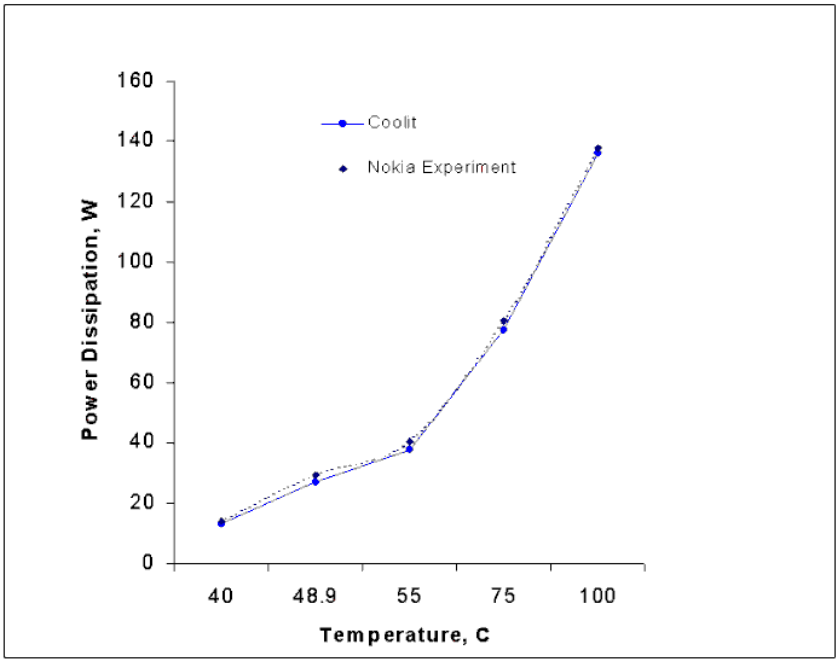
Coolit prediction: $T_{junction}$ = 76.85C

Nokia experiment: $T_{junction}$ = 76.85C and 79.45C (corresponding to two experiments)

Free convection: Plate fin heat sink

This experiment, carried out at Nokia Research Center, was designed to provide a well-defined model for CFD simulations, thereby eliminating potential uncertainties. The fin array was isothermally powered to within 1C by electrical cartridge heaters.





Flow pattern and predicted vs experiment power dissipation.

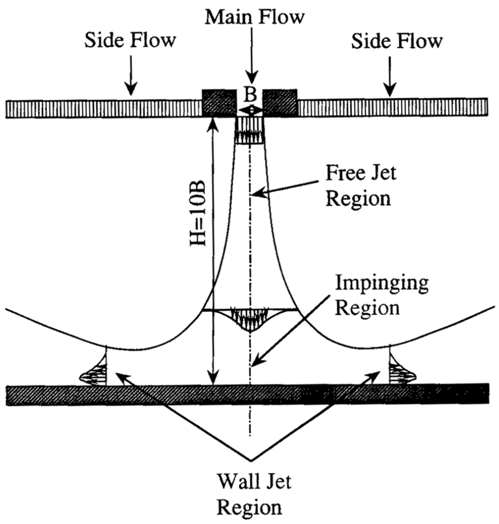
Temperature was monitored by a combination of PT 100 platinum resistance sensors (DIN IEC 751) embedded in the cartridge heaters and thermocouples attached to the baseplate. Temperature and power dissipation were measured to within 0.2 C and 1%, respectively. To facilitate heat transfer rate calculations, a double-sided symmetry design was employed. The enclosure walls were water cooled to ensure isothermal surfaces and permit definition of fin array adiabatic wall temperature. Fluid velocity and temperature profiles were measured at the upper and lower opening of a central U-channel passage using hot wire anemometry, and salient features of enclosure fluid flow were observed using smoke flow visualization. Coolit simulation was run blind, i.e. without the knowledge of experimental data.

Forced convection: Turbulent impinging jets

Impingement cooling in which a surface is cooled by an impinging jet (air or liquid) is an important and highly efficient method for cooling electronics. The high efficiency is the result of thin boundary layers formed at the point of impact that produce very high heat transfer rates. The jet's boundary layer does not follow the log-law of the wall and cannot be computed using conventional CFD turbulence models with wall functions.

In this project a prediction by Coolit for a jet impinging on a flat surface was compared with experimental results by Tsubokura et al published in the Monthly Journal of Institute of Industrial Sciences at the University of Tokyo, 1997, vol 49, No. 1. Coolit's eddy viscosity model without wall functions was used. The Reynolds number based on the inlet velocity and the jet width was 6100, which is commensurate with Re in electronics cooling application.

Figure 1 shows a schematic of the experiment. Figures 2 and 3 show the x-velocity profile two and four jet-widths away from the jet axis, respectively. Figure 4 shows the y-velocity distribution for several locations.



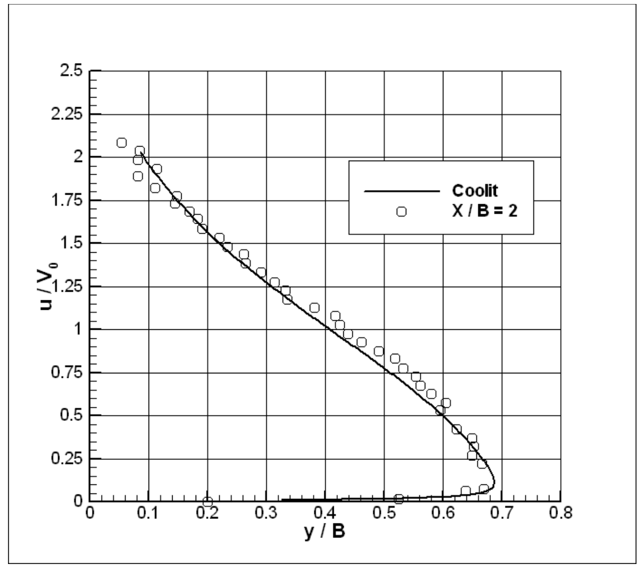
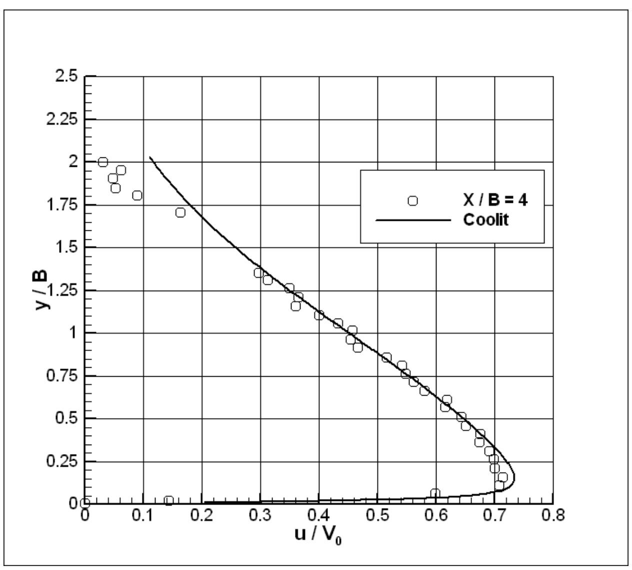


Fig. 1 (left) shows schematic of the experiment and Fig 2 shows velocity profile two jet-widths from axis.



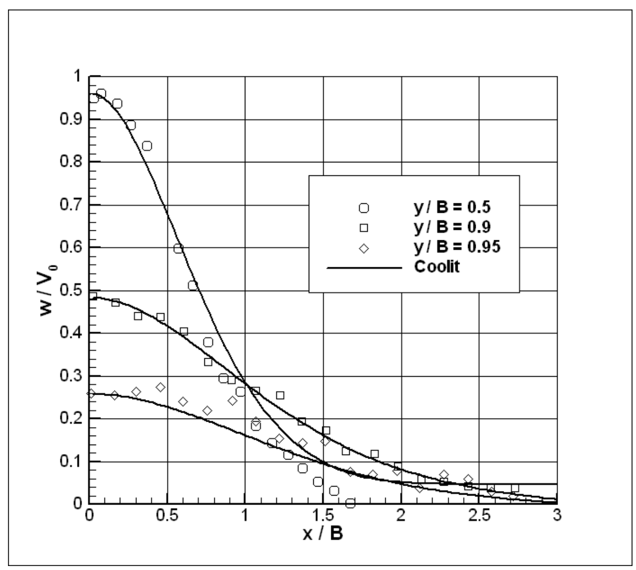


Fig 3. Velocity profile four jet-width from axis (left) and Fig. 4 shows y-velocity at several locations.

Forced convection: Laminar and turbulent impinging jets

A schematic of the problem is shown in Fig.1. A planar jet is impinging against a plate of length 2L and kept at the constant temperature Tw. The jet is emitted from a rectangular nozzle with the width 2d = 1.29e-3 m and length L=7.62e-2 m. The nozzle's outlet is located h = 6.35e-3 m above the plate. At the inlet of the nozzle, a uniform velocity profile, U_0 and constant temperature, T_0, are specified. Considering the symmetry of the problem the computational domain shown in Fig.1 includes only a half of the physical domain. For turbulent jets, the Coolit eddy viscosity turbulence model without wall functions was used. The computed results were compared with impinging jets experiment by Gardon and Akfirat (J. of Heat Transfer, ASME, Series C, vol. 86, pp. 101-108, 1966).

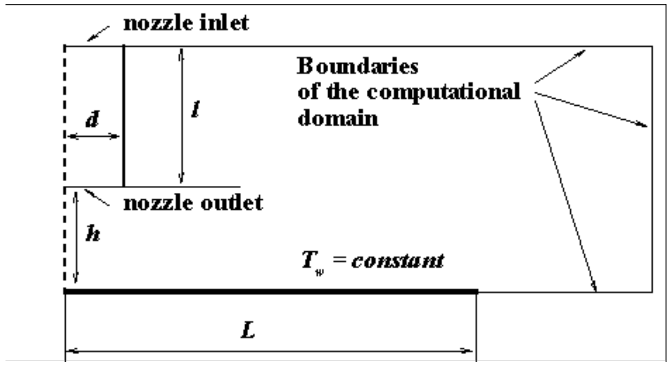
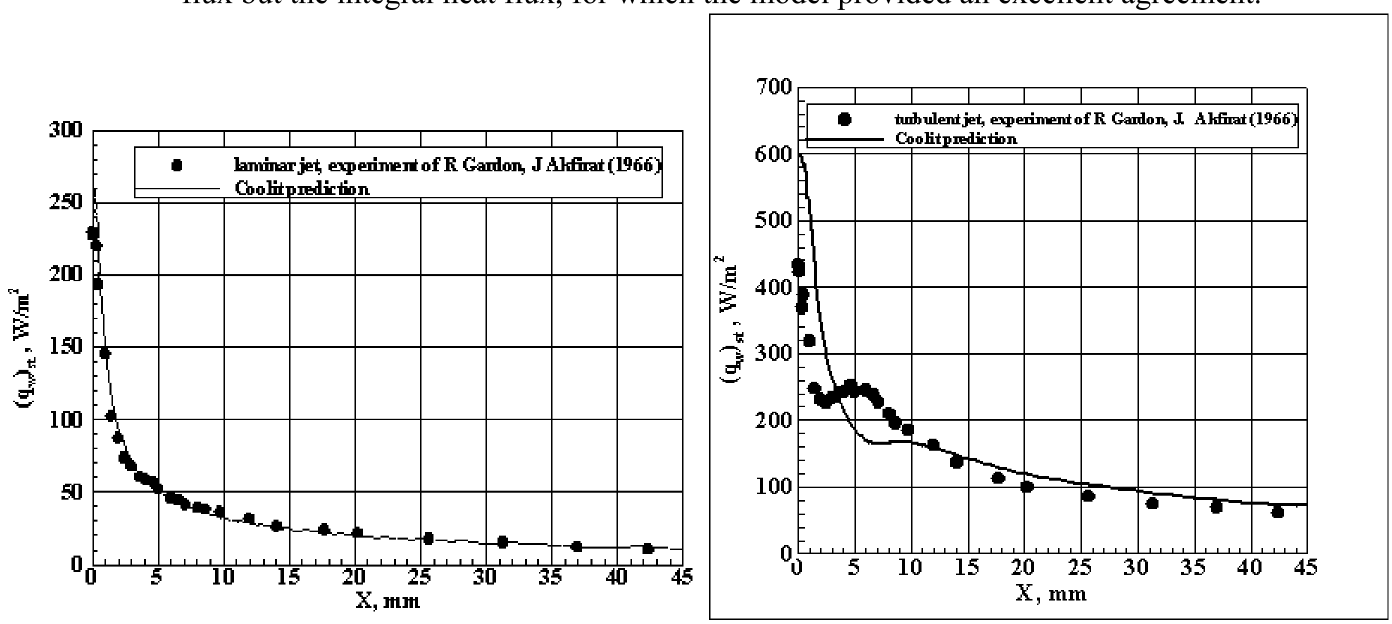


Fig. 1. Computational domain

A comparison of computed and experimentally measured heat flux along the plate at two values of Reynolds numbers was carried out. The Reynolds number was defined by the velocity at the nozzle inlet and nozzle width. In the laminar flow regime, Re=450, the agreement of the predicted and measured heat flux values is virtually ideal. For the turbulent flow, Re=2750, there is a local discrepancy in the vicinity of the region where the transition to turbulence most likely occurred. The exact transition point cannot be predicted by any of the existing turbulence models and such behavior is expected. The key parameters in practical simulations, however, is not the point distribution of the heat flux but the integral heat flux, for which the model provided an excellent agreement.



Left: Heat flux along the plate at Re=450. Right: Heat flux along the plate at Re= 2750.

Mass memory server

VT Miltope's Mass Memory Server 2 (MMS-2), which resides in the aircraft's avionics bay, is a lightweight, networked, solid-state storage platform that is part of the helicopter's Avionics Management System. It serves as a digital map server and collects aircraft data including usage, maintenance, vibration monitoring, and engine, rotor, and balance information in order to monitor aircraft health.

Cooling the MMS-2, while protecting its interior electronics from sand, dust, rain, and salt fog, required a separate, "dirty" conduit for air flow and heat exchange. Two rear fans pull air into the chassis from the lower front panel. The air then runs through a short, wide duct below the circuit boards before exhausting through the rear. A baseboard with its processor module and power supply board is cooled using custom aluminum heat spreaders, which pull heat from the processor chipset and memory. Attached to heat spreaders are finned heat sinks that project downward into the cooling air flow of the internal duct.

The modeling was done from -40C to +71C. After a few tweaks to the design, Coolit predicted that all major components would stay within their manufacturer's specifications. This was verified by measurements on pre-production hardware.

	Ambient T = 60C		
	Predicted	Measured	Difference
CPU die	71.8	70.6	-1.2
PCH die	72.0	71.8	-0.2
T1 transformer	75.6	74.4	-1.2

	Ambient T = 71C		
	Predicted	Measured	Difference
CPU die	82.8	79.2	-3.6
PCH die	83.0	83.4	0.4
T1 transformer	86.1	85.8	-0.3

Heat exchanger for F-16 aircraft

The 250 W computer was housed in an aluminum chassis measuring 265 x 200 x 365 mm. The chassis exterior was cooled by natural convection and radiation. The chassis interior held 12 cards that were fastened to a heat exchanger by wedge-locks. The plate-fin heat exchanger consisted of 31 horizontal fins mounted on each side of the chassis. The heat exchanger was cooled by forced airflow from the fan.

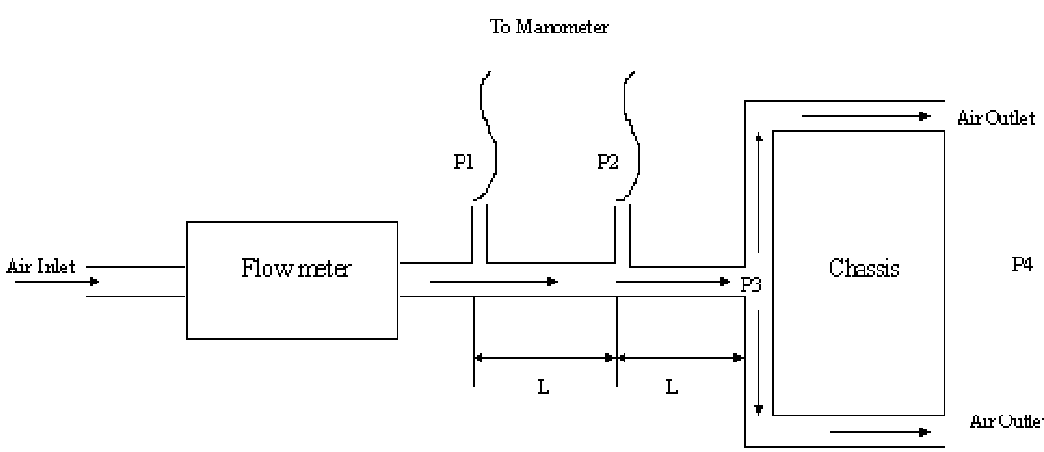
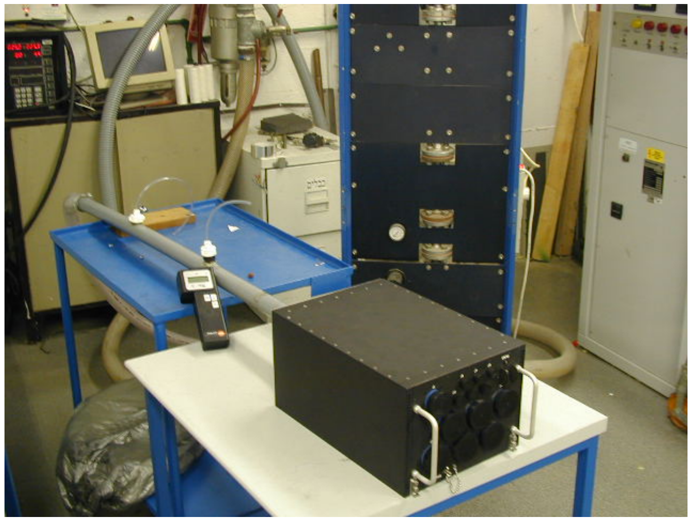


Fig. 1. Schematic of the experiment

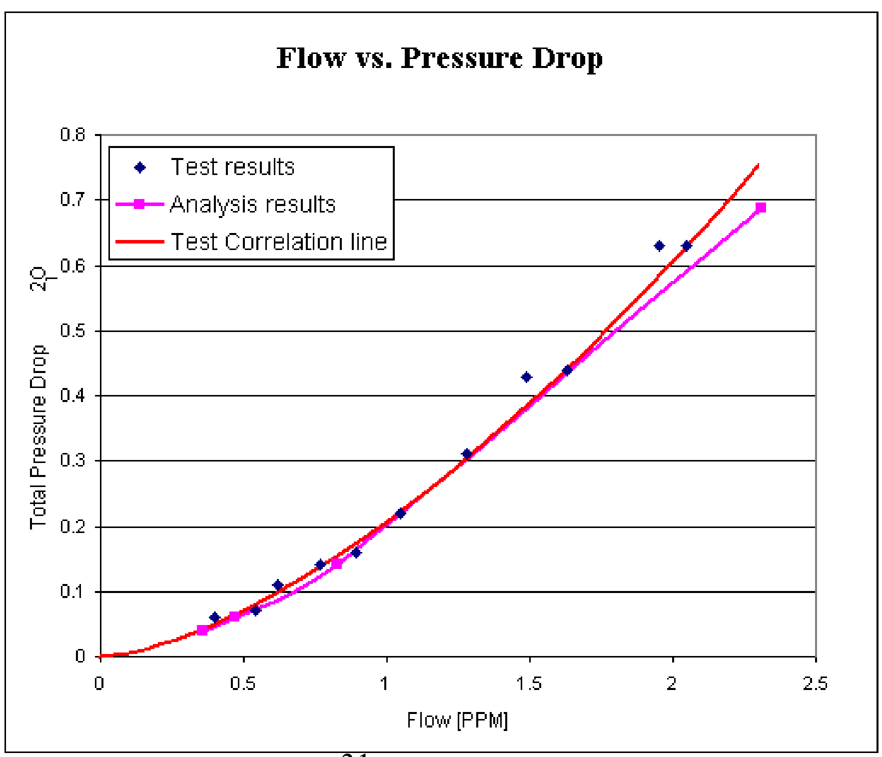


Photograph of the test set up

Before building a prototype, the system was designed using Coolit by CAS Ltd. To meet the manufacturer's requirements, four analyses were performed using different mass flow rates corresponding to different flight conditions. The pressure drop across the heat exchanger predicted by Coolit was recorded as a function of the mass flow rate through the system.

Pressure Predictions

Once the system prototype was designed and built, an experiment was conducted to determine the pressure drop across the chassis prototype, DP34 = P4 - P3, see Figure 1. Eleven experiments were run with different mass airflow rates as shown below (black dots). The corresponding pressure readings were recorded on a manometer. The test data



were plotted as a best fit curve (red solid line) and the results were compared with the Coolit predictions (magenta line). Excellent agreement was observed throughout the entire pressure-flow range.

Temperature Predictions

To verify the temperature predictions, a test was performed at one of the design mass flow rates. The temperature distribution across the "cold plate" was recorded at steady state. The "cold plate" temperature should not exceed 78 C. The conditions measured at the heater are shown in Table 1.

Table 1

Location	Test (deg. C)	Prediction (deg.C)
Inlet	24.4	24.5
Slot 1	59.1	57.7
Slot 2	62	60
Slot 3	64.2	63.1
Slot 4	66.9	64.4
Slot 5	68.8	65.3
Slot 6	70.2	67.3
Slot 7	72.1	68.8
Slot 8	72.4	70.3
Slot 9	73.6	71.4
Slot 10	74	72.9
Slot 11	75.2	73.2
Slot 12	76.8	77.3
Outlet	67.5	67

Table 2 and the accompanying plot, compare the predicted and actual temperatures for the different locations based on the above boundary conditions. The Coolit predictions were all within 5% of measurements.

Predicted vs measured temperatures at different slots.

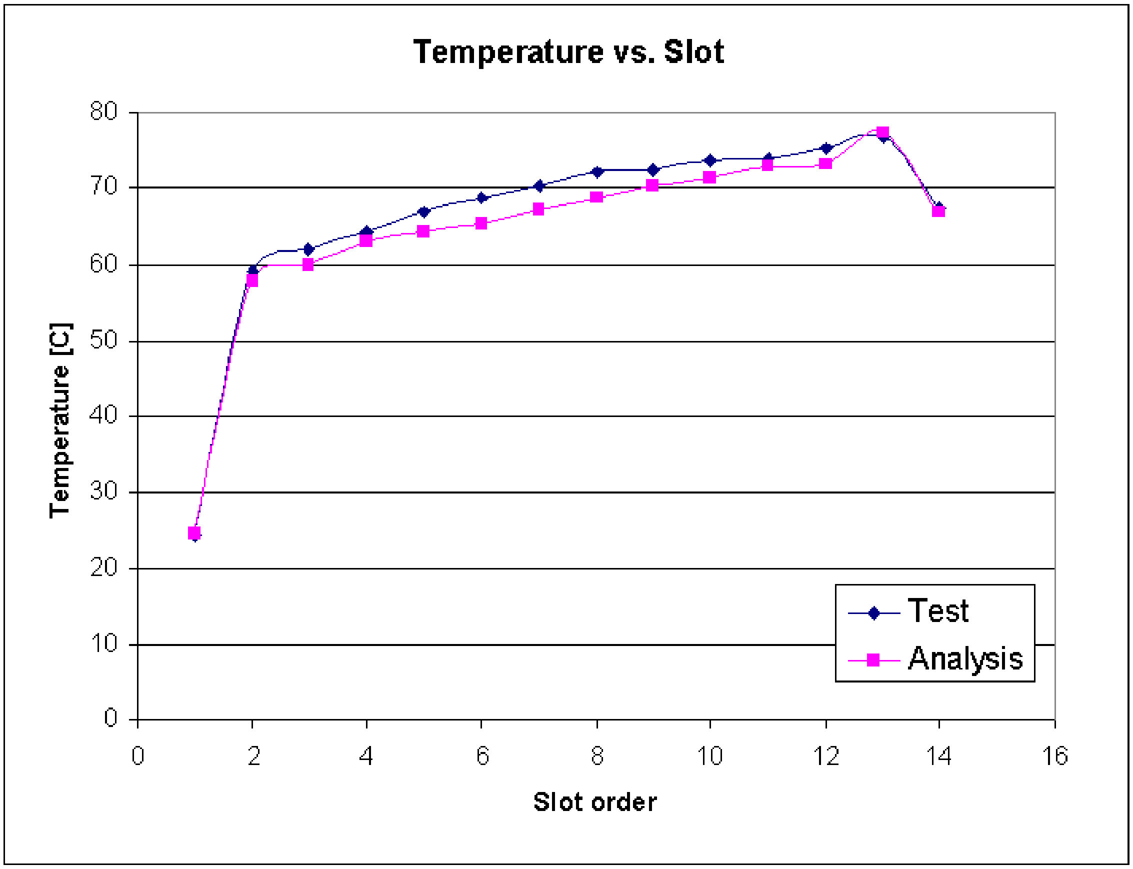


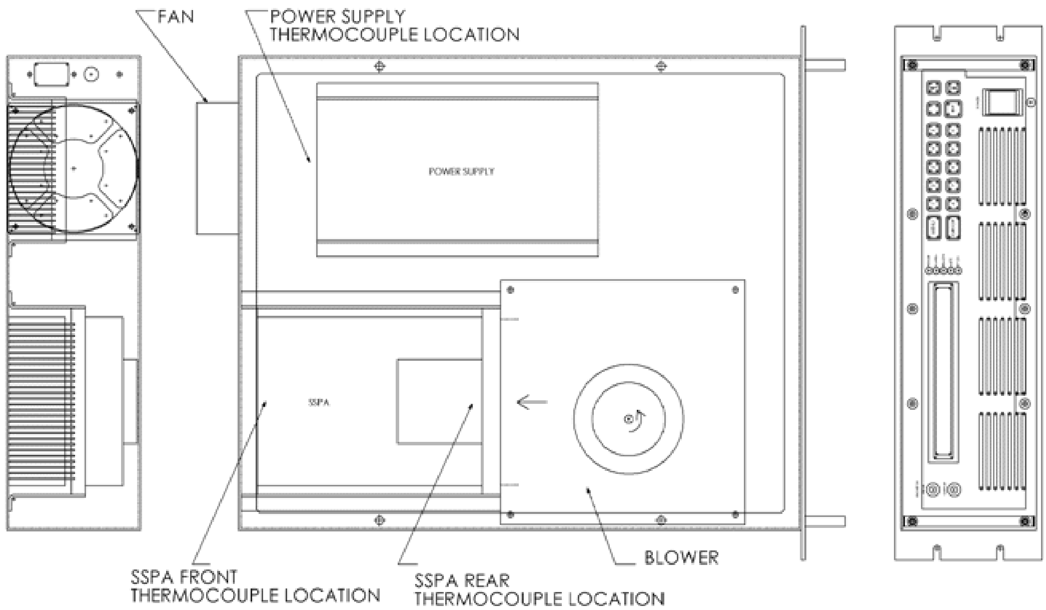
Table 2

Air Temperature	**71 deg.C**
Atmospheric Pressure	**1008 mbar**
Inlet temperature	**24.5 deg.C**
Inlet air mass flow	**0.86 PPM**

Power amplifier

To assess the accuracy of the Coolit predictions, Miteq Corp. benchmarked a 3 RU rack-mounted Solid State Power Amplifier (SSPA) whose main components are a 3-stage power amplifier and power supply. A bonded-fin heatsink is mounted beneath each main component, and the assembly is cooled by a side-by-side blower and axial fan arrangement that pulls cooling air into the enclosure and forces it through the SSPA and power supply heat sink fins before exhausting it out the rear vents.

Since the subsystem was still in the design stage, a mockup was required. An aluminum housing was machined to match the 'form factor' and thermal mass of the final SSPA housing, and the actual 100 W power supply was mounted inside the 3RU enclosure. To simulate the FET amplifiers, engineering used resistors, bolted inside the machined housing and driven by the power supply, that delivered equivalent power dissipation.



Schematic of the experiment

Thermocouples were mounted in 3 locations: at the lowest powered FET amplifier (SSPA rear), at the highest powered FET (SSPA front), and in the exhaust air stream exiting the power supply heat sink. After power-up, the subsystem reached steady-state temperature in 30 minutes. Temperature measurements were taken once every 60 seconds for 4 hours. The results are shown in the table below; the Coolit predictions matched test temperatures within 3%.

	SSPA Rear	SSPA Front	Power Supply
Coolit prediction (deg. C)	38.5	49.4	26.9
Actual (deg. C)	37.9	48.8	26.3