A STEP CHANGE IN ELECTRONICS THERMAL DESIGN: INCORPORATING EDA AND MDA DESIGN FLOWS

MECHANICAL ANALYSIS

WHITEPAPER

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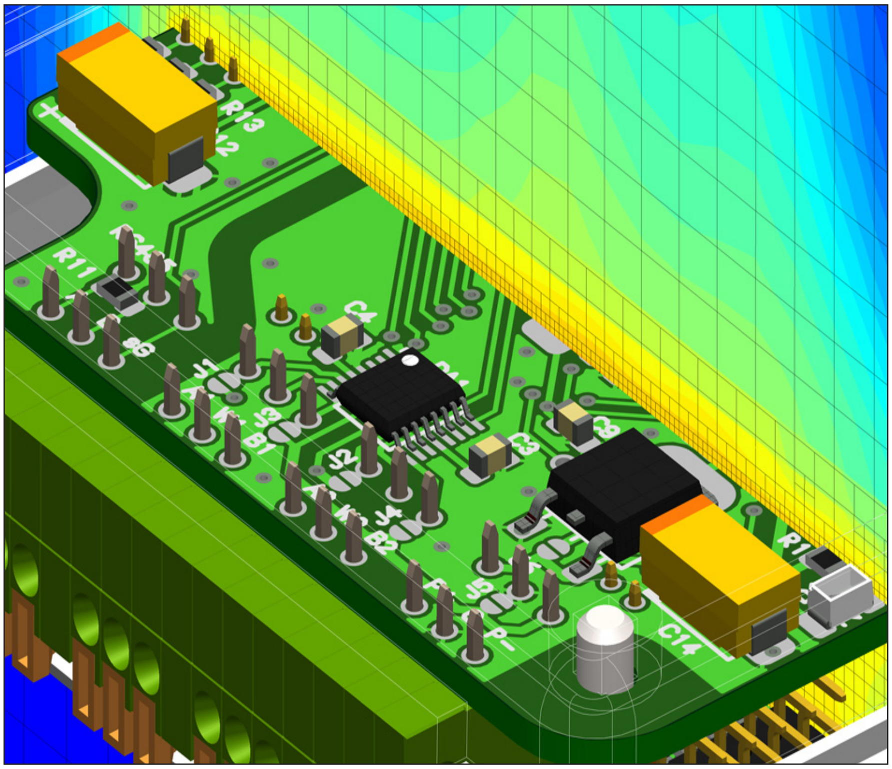
The main source of heat in electronic equipment is their semiconductor chips, and the temperature sensitivities of these chips presents a challenge in designing cooling mechanisms. Overheating causes the chips to prematurely fail—and failure of only one chip can disable the entire equipment, the higher the chip temperature, the earlier and more certain the failure. As functionality has increased, the associated heat dissipation has escalated to the extent that it is recognized as a potential limitation on the pace of electronics development. Appropriate cooling strategies are needed to prevent overheating, and failure, of critical components.



In electronics, the complete design cycle from concept to first customer ship is much shorter than in traditional manufacturing industries—in some sectors, now as short as nine months—and delays in product release of even a few weeks can severely affect profit. Electronics cooling design and simulation applications have to be quick, reliable, and integrated into a fast-moving, complex design process. The people responsible are not experts in CFD or fluid dynamics, and they do not want to spend a lot of time learning detailed CFD concepts, or running potentially time-consuming operations such as sophisticated grid generation.

Mechanical engineers are responsible for all aspects of the physical design of the equipment, that is, everything beyond the electronics design, which typically culminates in the printed circuit board (PCB) layout. They are responsible for the enclosure, appropriate location of the PCBs and other components, and for ensuring structural integrity as well as safe, reliable operation of the equipment. Cooling and thermal design is only one of the issues they are concerned with, although often it is a crucial issue.

Mechanical engineers have to collaborate with electronic designers using electronic design automation (EDA) software and with other mechanical designers using mechanical design automation (MDA) software. Thermal design software is expected to contribute at all stages of the design process, from concept, through design exploration and optimization, to final verification. These diverse needs have major implications for software development, especially with regard to interface, data management, and integration.

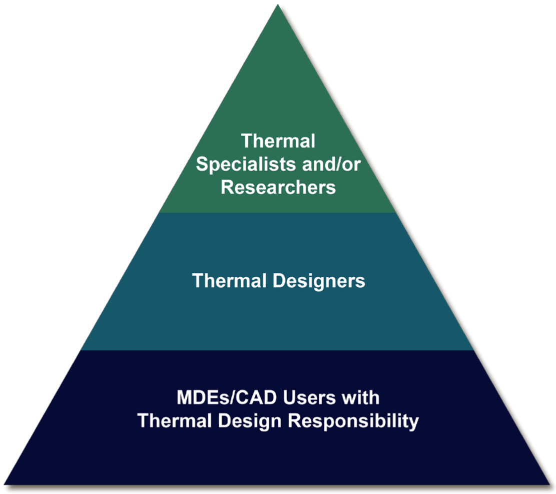


Figure 1: *The variety of engineers involved in electronics thermal design.*

Traditionally, CFD-based thermal design software has targeted engineering analysts with specialized knowledge of thermal design and the use of CFD techniques. These engineers still form a core group in electronics companies today; however, CFD-based thermal design has broadened to include electrical engineers, general mechanical design engineers, industrial designers, and marketing engineers (Figure 1).

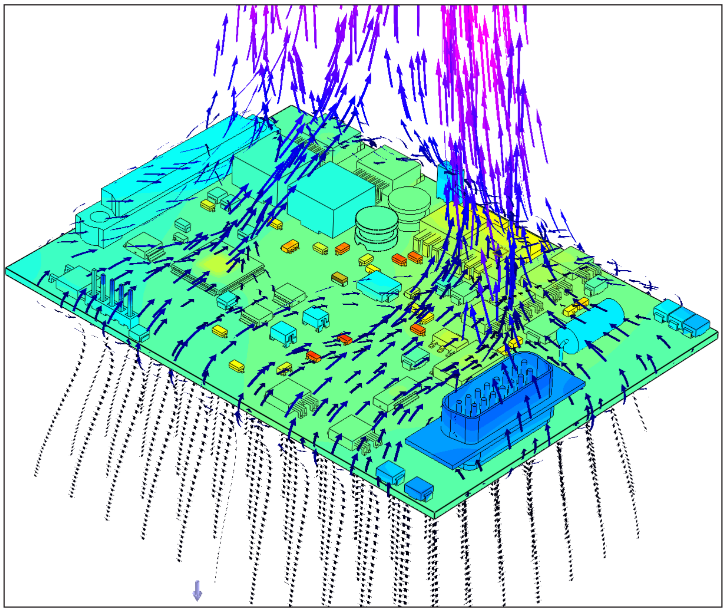
As a result, the requirements for designing a software solution have become more challenging in terms of user interface (UI) design, geometry and attribute pre-processing, interoperability with other mechanical computer-aided design (MCAD), CAE, and EDA software, obfuscation of CFD terminology and functionality, post-processing results, and meshing/solver performance.

General-purpose CFD software is far from ideal in satisfying these requirements, which is why special-purpose software, such as Mentor Graphics FloTHERM XT, optimized for electronics thermal applications, with industry-specific input and control, was developed.

THERMAL DESIGN ISSUES FROM CONCEPTUAL DESIGN TO FINAL PRODUCT

Inside electronics equipment is a complex assembly of many solid objects (such as PCBs, electronics packages and devices, cabling, fans, and heatsinks). Air flow is confined within narrow regions between these solid objects. As well as convective transport within the air, conduction within the solid objects (which can have extremely complex internal structures), is critical. Analyses involve large numbers of such objects (sometimes thousands), as well as extreme disparities in scale (from meters to micron scale).

Because of this complexity, electronics products pose a unique set of challenges for thermal simulation, including geometry capture, scale disparity, uncertainty over missing data (component thermal data, power dissipation, material properties, layer thicknesses, interface resistances), transitional flow regime, mesh generation, hardware environment, and the need for increased accuracy.



GEOMETRY CAPTURE

During detailed design, the geometry comes from both the EDA and MDA design flows. One particular challenge is that EDA systems deal with 2D representations of the electronics because both IC and PCB design are done using schematics. PCB design tools require only the component layout and often do not contain even the most basic geometric information about the components such as component height. Detailed information about the internal geometry of the chip packages is typically unavailable.

SCALE DISPARITY

Miniaturization resulting from Moore's Law has caused an increasing disparity of length scales, between the size of the physical product and the size of the internal components and circuitry. Typically meter to micron scale geometry has to be accommodated within the same model. The presence of small gaps, in the casing for example, can also have a profound effect on the cooling of the electronics.

As a result, scale disparity continues to increase over time—this results in the requirement for behavioral models when the geometry cannot be represented directly within the simulation, as is usually the case with PCB traces on multilayer PCBs, and compact thermal models (CTMs) for IC packages to avoid having to model the internal geometry, which is often unknown.

MISSING DATA

This leads to another challenge unique to electronics cooling applications—missing data. Material property data is absent from MCAD systems, so CFD simulations in general suffer from this problem. In the case of electronics cooling applications, systems are essentially constructed from many components from many different suppliers, the thermal characteristics of which are typically not well understood. These include IC packages, PCBs, heat pipes, fans, Peltier devices, etc.

The geometry comes in part from the EDA system, which often does not include any information on the materials being used. This adds complications during electronic systems assembly where thermal interface materials (TIMs) and gap pads are used to maximize the thermal contact between different parts of the system to implement an effective cooling solution.

Also operational power information is needed for the active components to predict system temperatures under operational conditions, which vary as a function of the product's usage. Design for steady-state operation at maximum power, which leads to significant over-design, is no longer tolerable [1, 2]. Increasingly, transient simulations are needed to ensure reliable operation and minimize overdesign.

FLOW REGIME

In highly cluttered electronic systems, air is forced through channels that contain all manner of protuberances that induce low Reynolds Number transitional flow. However, this wall-induced turbulence is not self-sustaining, and the flow would be laminar if the channel were smooth. Turbulence modeling is, therefore, a particular challenge. Within a fast-paced design environment, providing a sufficiently fine mesh to perform large eddy simulation (LES) is completely impractical because of the large number of flow channels, objects, etc. combined with a large system residence time.

Until recently, the practicality of using standard two-equation Reynolds Averaged Navier-Stokes (RANS) models has been questionable. Zero-equation "effective viscosity" models have been favored to impose an estimated turbulent viscosity because the low mesh densities often used would cause one and two-equations models to predict less realistic turbulent viscosity values than can be estimated based on empirical data and knowledge of the bulk flow velocity.

A key issue with one- and two-equation models is the need to refine the mesh near to the surface when used with standard, generalized, and scalable wall function treatments (log law, van Driest, 1/7th Power Law, etc.), to provide a y^+ value of ~30 for the near wall cell, with a low mesh size inflation rate out to the core flow. In electronics applications, boundary layers start at the leading edge of components, PCBs, heatsink fins, etc. resulting in a large number of very thin boundary layers to resolve within the system, so the standard advice on y^+ simply cannot be followed. Consequently, LVEL [3] remains the model of choice. However, the recent application of immersed boundary treatments to electronics cooling applications overcomes this drawback.

MESH GENERATION

Although generic to CFD, mesh generation for electronics cooling applications presents a challenge because of the sheer number of solid–fluid and solid–solid surfaces that need to be captured. As a consequence of the need for fully automated optimization including geometry changes, the meshing also must be fully automated with no manual intervention beyond predefining the required mesh sizes before meshing is started.

A fortuitous outcome of using EDA systems to design components and PCBs in 2D, with no aesthetic requirements for the unpackaged electronics, is that electronics tend to contain large numbers of Cartesian-aligned objects, so Cartesian-based grid systems are the natural choice for this application. However, size constraints are forcing electronics designers to angle components on boards, insert DIMMs at an angle, and design heatsinks with non-Cartesian profiles.

Use of simple Cartesian meshes with grid lines that “bleed” out from an object to the edges of the solution domain are inadequate because they quickly lead to unacceptable mesh counts when increasing geometric detail is added to the model. As a result, the use of locally refined Cartesian overset grids to refine the mesh within and around objects has become prevalent, allowing either porosity or voxelization treatments to approximate non-Cartesian and non-aligned Cartesian objects with acceptable accuracy in many cases.

As the amount of non-Cartesian geometry present within electronics systems has increased, so has the need for more sophisticated meshing strategies. Over recent years, Octree meshes with MCAD-embedded CFD in early product design increasingly have been used across a range of industries and applications where the product design process is built on a company’s MCAD system.

In electronics, design processes vary considerably from company to company. Embedding CFD within the MCAD system may not facilitate its use because often much of the early design work will be done outside the MCAD environment, and the design process may be centered on the company’s EDA flow. Thus, the simulation approach used in MCAD-embedded CFD needs to be available within a stand-alone product.

HARDWARE ENVIRONMENT

Traditionally, thermal design has been done alongside electronic design. The use of high performance computing (HPC) infrastructure for CFD has been far less than in other industry sectors; for example, in automotive, HPC has facilitated the use of LES to undertake “high fidelity” CFD to address difficult aspects of the product design, such as aero-acoustics. But in electronics cooling applications, increased simulation precision does not translate into improved product quality. The quality of the simulation model is limited by far greater uncertainty in the input data.

To date, good scalar performance with reasonable scaling up to 8–16 cores has matched market requirements. Good scaling for a limited number of shared memory nodes is likely to remain the target for hardware performance. The hardware environment may change away from desktop to cloud-based computing, which will greatly facilitate design space exploration by the use of numerical design of experiment techniques.

INCREASED ACCURACY

As a consequence of design margins shrinking, the need for simulation accuracy is increasing. This however, does not translate directly into a need for higher fidelity CFD. Indeed, since the early 2000s, clock speeds have not increased, capping die-level power density, and power increases have occurred at higher levels of packaging, such as the PCB.

What has this to do with accuracy? The allowable temperature rise from ambient to junction is not increasing, but as power densities increase within the package, PCB, etc., the proportion of the temperature rise that occurs in the air is diminishing. Put another way, the importance of modeling the conduction within the solid structures is increasing. This explains the emphasis placed on MCAD integration (e.g., for heatsink design), and perhaps more importantly EDA integration, to accurately capture the copper content and distribution on PCBs, effects such as Joule heating in traces, and power and ground planes, and to accurately measure the thermal conductivity of TIM materials, particularly the softer Type I and Type II materials that are not well-suited to being measured in ASTM D5470–based equipment.

SOLVING THE THERMAL DESIGN CHALLENGES FOR ELECTRONIC PRODUCTS

The electronics-cooling CFD software, FloTHERM XT, has been created to address these challenges. FloTHERM XT provides easier modeling of more complex devices and enclosures, connected with SmartPart technology where required, particularly for LED lighting, consumer electronics, aerospace/defense, and automotive design engineers.

Meshing can take up a significant amount of time and energy in some general-purpose CFD codes and can be a cause of frustration when it goes wrong. Most general mechanical engineers would like to simply have the software do the job for them wherever possible, but with the ability to switch to more manual definition should the need arise, and this has reinforced the need for more sophisticated meshing strategies. The advanced code in FloTHERM XT provides semi-automatic, object-based algorithms, with options to adjust the mesh manually where necessary or to allow the freedom and control that is required by the more experienced, and CFD-aware, thermal engineers.

FloTHERM XT uses highly stable numerical schemes and solution controls that operate semi-automatically to control the convergence of the solution with only the minimum of intervention ever being required.

For electronics cooling applications, issues relating to turbulence modeling are rarely, if ever, the largest source of error in the results. It is more likely to be uncertainties in power dissipation, materials, flow rates, or interface resistances. However, turbulence can be a source of concern for some more specialized designs. The FloTHERM XT CFD solution provides the best possible model for the application area of interest and only provides alternatives if there is a clear reason to do so. The software provides options for laminar, transitional, and turbulent flows, but limits the turbulence models that are available to avoid confusion. FloTHERM XT makes use of a general two-equation model combined with a proprietary immersed boundary treatment for near-wall effects that smoothly transitions between the different flow regimes, resulting in excellent benchmark results appropriate for electronics applications.

USER INTERFACE VERSATILITY

FloTHERM XT is tailored for rapid model building in electronics cooling applications to support the needs of MCAD engineers, as well as thermal experts. FloTHERM XT was built with attention to personal requirements of the type of engineer who will be using the tool. It includes a best-in-class CAD interface toolkit and geometry engine, with a simple option to either run the software in “full” or “reduced” mode. Reduced mode is a control switch that obfuscates many of the less-common features and toolbars, thus reducing feature bloat and encouraging use of the software by those not trained in CAD.

DESIGN PROCESS CENTRICITY

FloTHERM XT provides a rapid design environment, in which geometry can be changed and the simulation results rapidly regenerated. It is designed to fit into the complex mechanical design environments and associated processes that exist in today’s electronics companies. In FloTHERM XT, imported CAD and internally generated geometry function seamlessly together, thus enabling supply-chain integration and offering an opportunity for the product to fit anywhere in the mechanical design flow, from early conceptual design to final product verification (Figure 2).

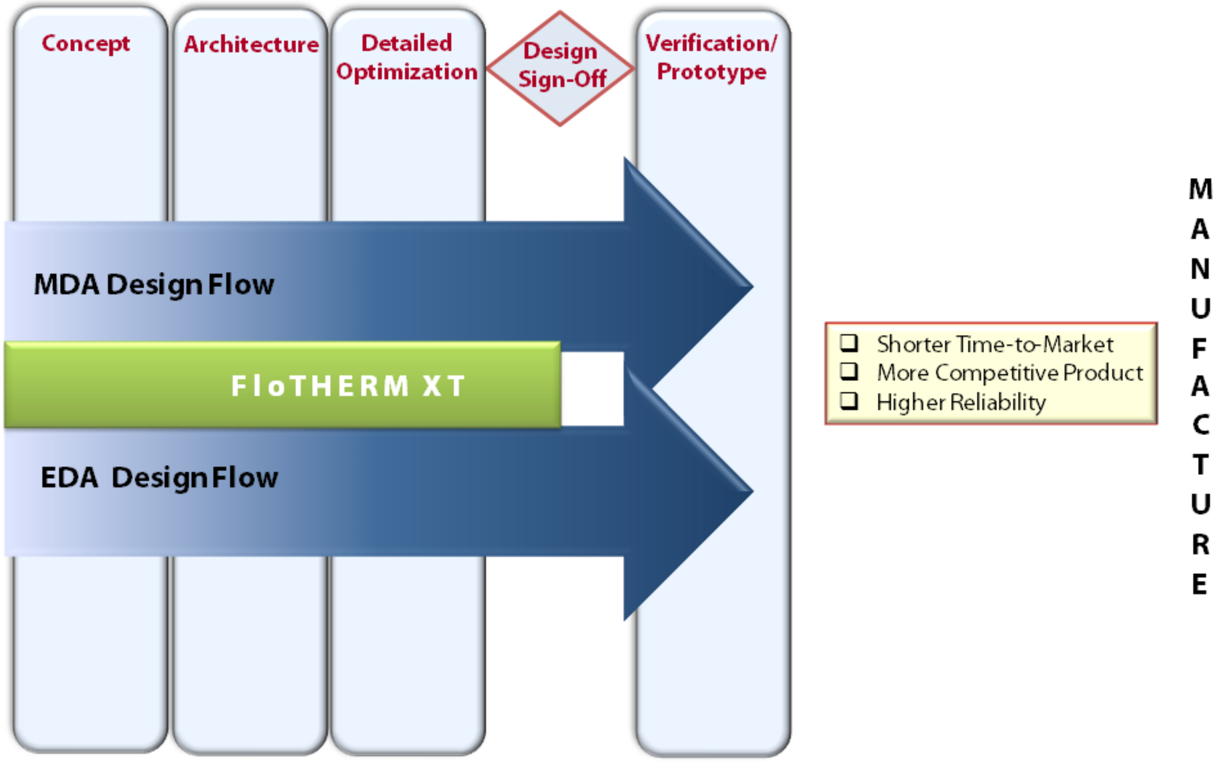


Figure 2: *MDA and EDA design flows interconnect via FloTHERM XT.*

The software fits into this optimum design flow and minimizes the risks associated with the thermal aspects of the design as early as possible. By incorporating a solid modeling engine and native links to the most common EDA design suites, FloTHERM XT can help companies bring the mechanical and electrical design disciplines closer together through the creation of a 3D model of the product that can be very simple or as detailed as necessary, in sync with the design in the MDA and EDA systems. FloTHERM XT can help companies further compress design times, reduce cost, and project risk.

Its unique set of EDA-interfacing capabilities (FloEDA Bridge), including update functionality, makes it easy to remain concurrent with the latest EDA design changes (Figure 3).

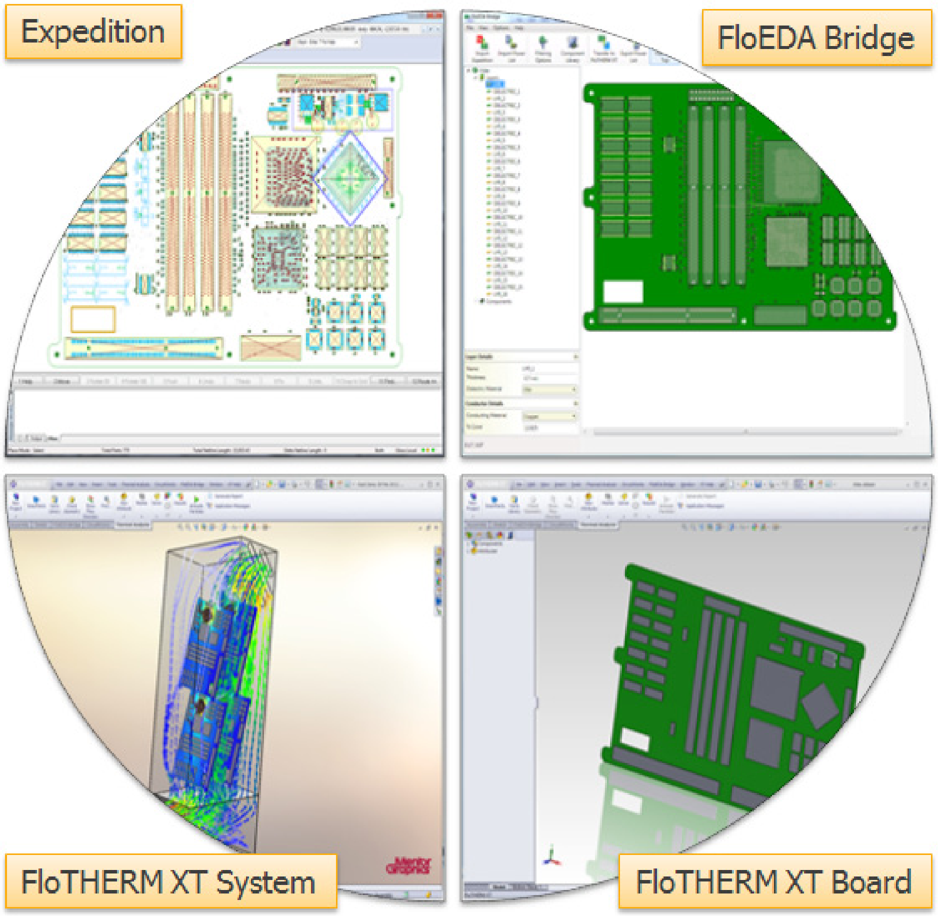


Figure 3: *FloTHERM XT interfaces easily with EDA tools.*

With FloTHERM XT, simulations can be started at the conceptual stage and continue through to implementation. Fewer iterations are needed to correct late-in-process design errors, and continual forward progress can be made, reducing time to market.

This unique software is useable by design engineers as well as thermal experts; thus, experimental changes can be quickly validated or eliminated, and there is more opportunity for "what-ifs," which results in a more competitive product. It reduces dependency on over-burdened thermal experts and bridges the gap between EDA and MDA design domains.

With direct integration from PCB design tools, there is no error-prone and time-consuming translation. Filtered PCB data (e.g., for non-heat dissipating components) reduces computation times, and the filter settings are remembered. FloTHERM XT allows companies to leverage Mentor Graphics leadership in PCB systems design tools.

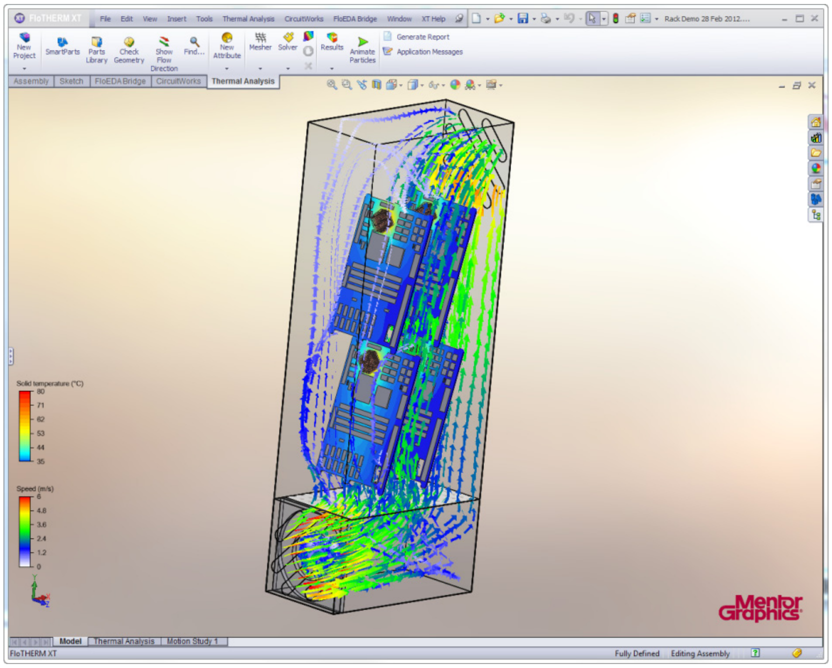


Figure 4: *FloTHERM XT has an easy-to-use, customizable interface.*

FloTHERM XT provides automatic meshing, convergence, friendly GUI, model build, and efficient simulation of most complex systems, delivering significant reduction in the total time spent on thermal simulation (Figure 4) vs. general-purpose based CFD solutions.

CASE STUDY

The scenario for this case study in FloTHERM XT is the concept-to-prototype design of a new wall-mounted Internet box, requiring a new arrangement of vents, a stylized shape as dictated by industrial marketing colleagues, and a main circuit board dissipating 30% more power than earlier designs.

The first stage concept design involves the creation of a box model with simple representations for the PCB and components, and an initial assessment made of overall cooling strategy and temperatures of the critical components (Figure 5).

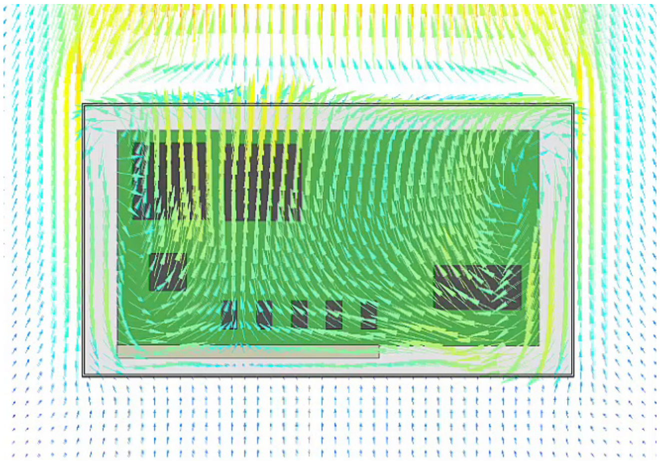


Figure 5: *Concept design for the wall-mounted Internet box.*

The design then evolves in stages toward a model of the complete system with an MCAD-based mechanical design for the enclosure and any required heatsinks. Interface resistances are added, and the full board layout is imported from EDA via Expedition (Figure 6).

The component modeling also evolves as more information is defined. Thermal models may be changed from block-style, simple component models upwards in complexity to 2-Resistor [4], DELPHI [5], or fully detailed models, taking advantage of the advanced library swapping and filtering support within the software (Figure 7).

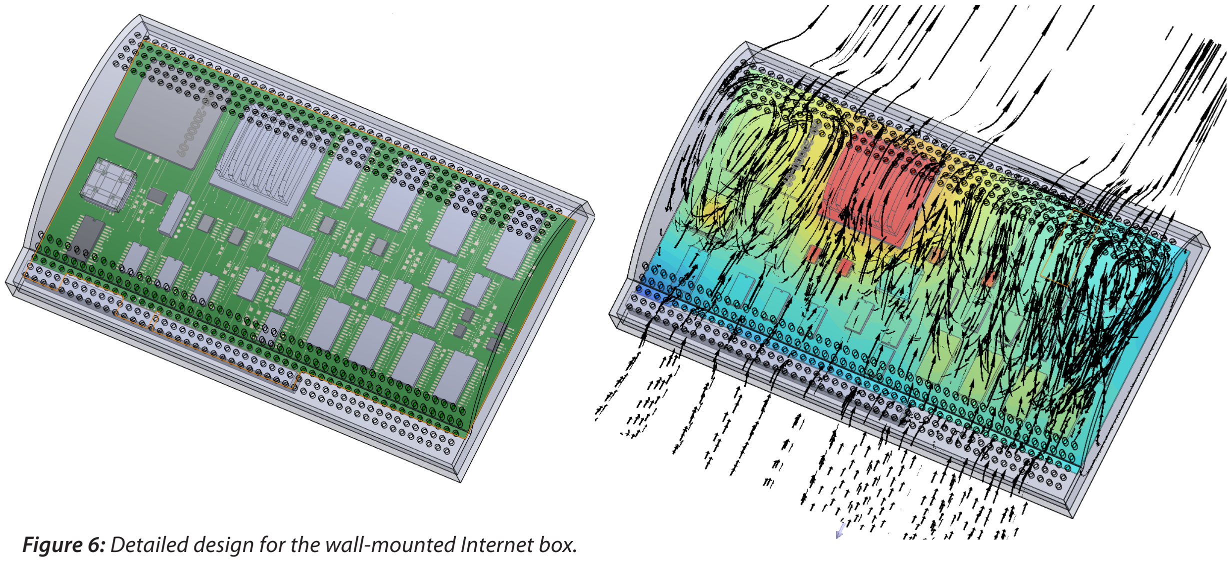


Figure 6: *Detailed design for the wall-mounted Internet box.*

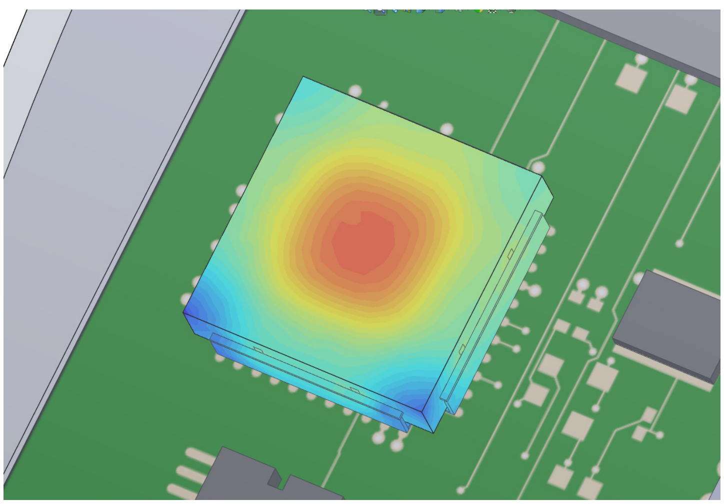


Figure 7: *Detailed component modeling for the wall-mounted Internet box.*

At all times, there is complete history and traceability of both the MCAD and EDA data as the overall system design proceeds towards prototyping and ultimately manufacture, depicted in Figure 8.

FloTHERM XT has an in-built reporting function allowing Microsoft Word, PDF, and HTML files to be created that contain project data, results information, and screenshots. The reporting is fully configurable, so component temperatures that are acceptable, marginal, or exceed allowable limits can be colored differently, as shown in Figure 9. This reporting functionality minimizes the time taken for result feedback to the mechanical and electrical design teams and facilitates rapid decisionmaking.

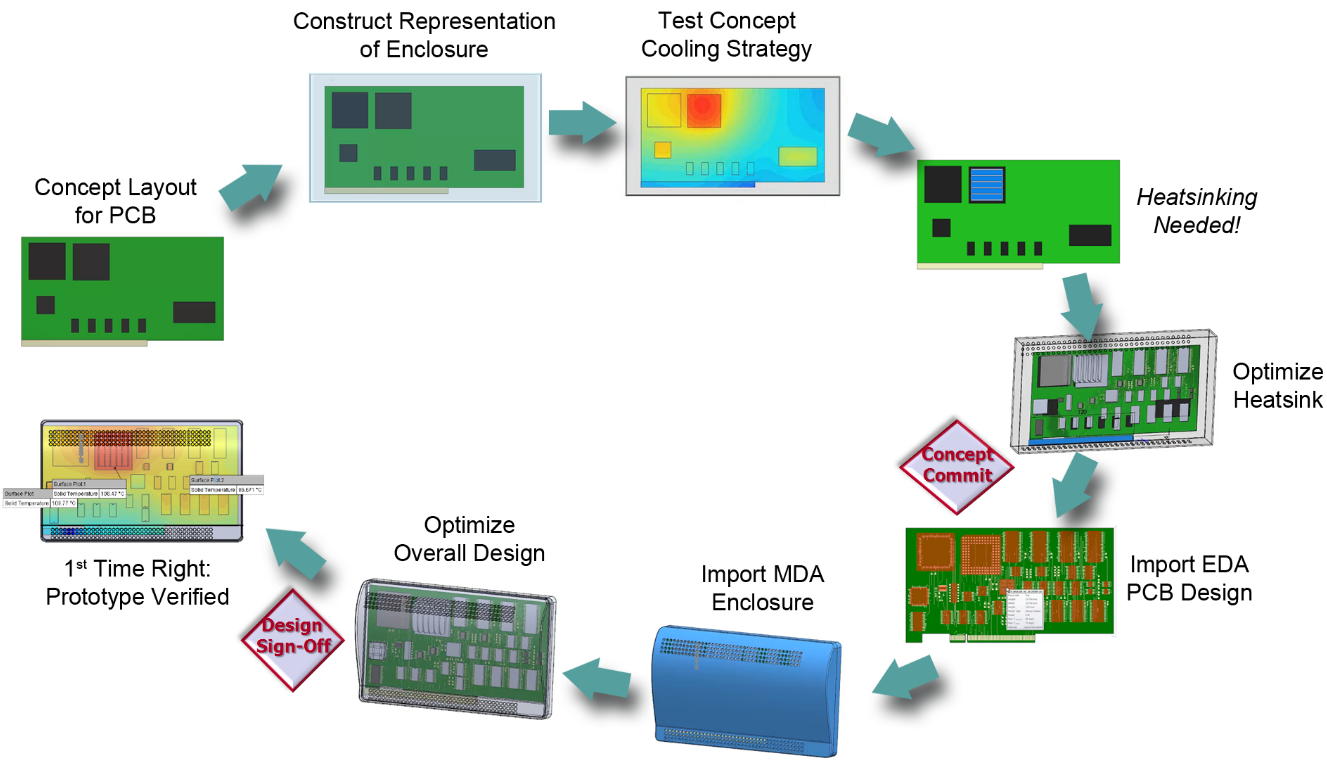
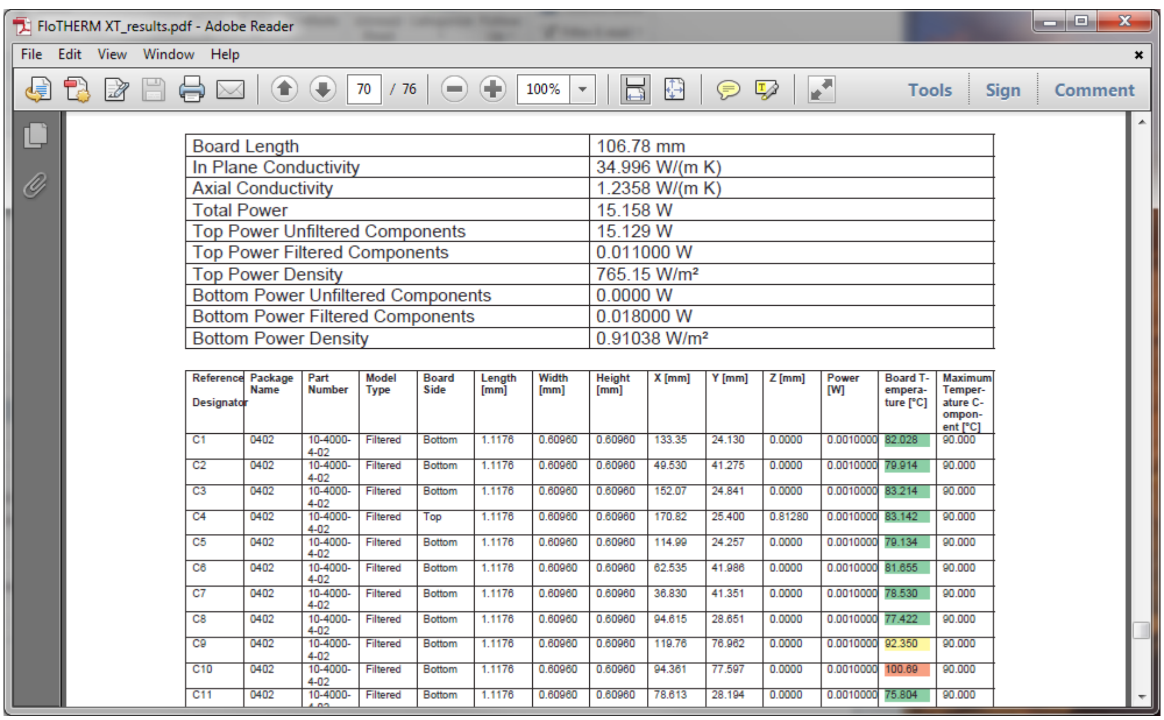


Figure 8: *FloTHERM XT covers the entire thermal design flow for electronic products.*



Board Length	106.78 mm
In Plane Conductivity	34.996 W/(m K)
Axial Conductivity	1.2358 W/(m K)
Total Power	15.158 W
Top Power Unfiltered Components	15.129 W
Top Power Filtered Components	0.011000 W
Top Power Density	765.15 W/m²
Bottom Power Unfiltered Components	0.0000 W
Bottom Power Filtered Components	0.018000 W
Bottom Power Density	0.91038 W/m²

Reference Designator	Package Name	Part Number	Model Type	Board Side	Length [mm]	Width [mm]	Height [mm]	X [mm]	Y [mm]	Z [mm]	Power [W]	Board T-empera-ture [°C]	Maximum Temper-ature C-ompon-ent [°C]
C1	0402	10-4000-4-02	Filtered	Bottom	1.1176	0.60960	0.60960	133.35	24.130	0.0000	0.0010000	82.028	90.000
C2	0402	10-4000-4-02	Filtered	Bottom	1.1176	0.60960	0.60960	49.530	41.275	0.0000	0.0010000	79.914	90.000
C3	0402	10-4000-4-02	Filtered	Bottom	1.1176	0.60960	0.60960	152.07	24.841	0.0000	0.0010000	83.214	90.000
C4	0402	10-4000-4-02	Filtered	Top	1.1176	0.60960	0.60960	170.82	25.400	0.81280	0.0010000	83.142	90.000
C5	0402	10-4000-4-02	Filtered	Bottom	1.1176	0.60960	0.60960	114.99	24.257	0.0000	0.0010000	79.134	90.000
C6	0402	10-4000-4-02	Filtered	Bottom	1.1176	0.60960	0.60960	62.535	41.986	0.0000	0.0010000	81.655	90.000
C7	0402	10-4000-4-02	Filtered	Bottom	1.1176	0.60960	0.60960	36.830	41.351	0.0000	0.0010000	78.530	90.000
C8	0402	10-4000-4-02	Filtered	Bottom	1.1176	0.60960	0.60960	94.615	28.651	0.0000	0.0010000	77.422	90.000
C9	0402	10-4000-4-02	Filtered	Bottom	1.1176	0.60960	0.60960	119.76	76.962	0.0000	0.0010000	92.350	90.000
C10	0402	10-4000-4-02	Filtered	Bottom	1.1176	0.60960	0.60960	94.361	77.597	0.0000	0.0010000	100.69	90.000
C11	0402	10-4000-	Filtered	Bottom	1.1176	0.60960	0.60960	78.613	28.194	0.0000	0.0010000	75.804	90.000

Figure 9: *FloTHERM XT report showing component temperatures. Items highlighted in red have failed.*

SUMMARY

Since the launch of FloTHERM, the challenges facing thermal designers have changed. Power dissipations increased, and products have become smaller and more tightly packed than ever before. Design complexity is driving the EDA and MDA design flows closer together, with pressure on thermal designers to use native geometry from these systems without simplification to keep the simulation model up to date, minimize the time taken to analyze design variants, and increase accuracy of results. These changes have affected the demographics and skill sets of engineers, which has implications for software usability, geometry handling, and the underlying CFD technology. FloTHERM XT has been written to support different types of design engineers and levels of expertise, to be as usable in early design as it is in late design verification, with the ability to evolve the model as the design is elaborated and provide an environment that delivers the best possible collaboration between the main mechanical and electrical design flows.

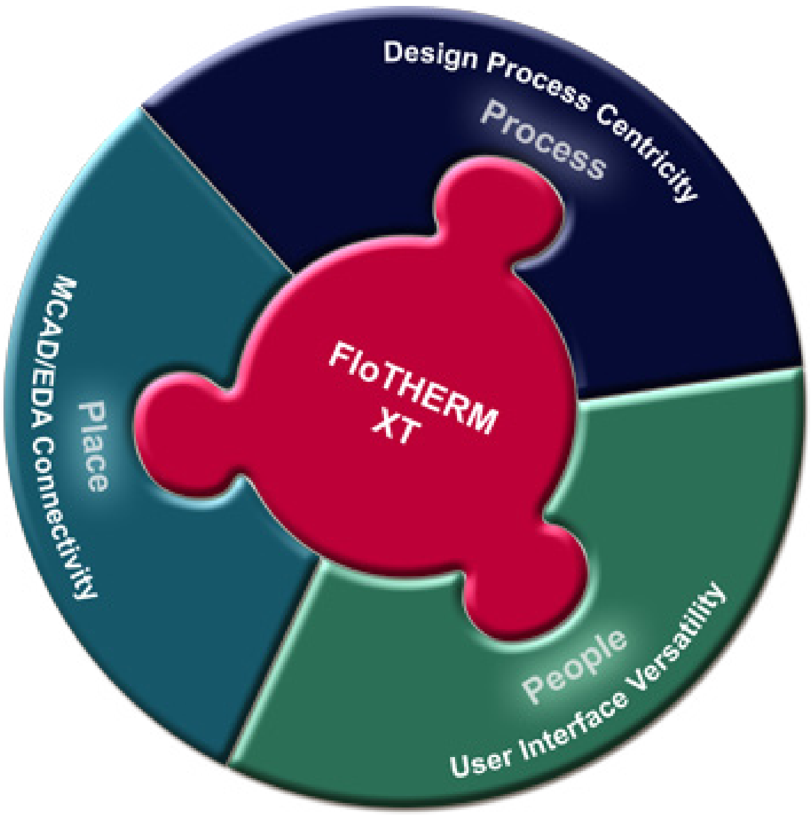


Figure 10: *FloTHERM XT is designed to connect the diversity of people, places, and processes involved in today's thermal design flows for electronic products.*

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Corporate Headquarters
Mentor Graphics Corporation
8005 S.W. Boeckman Road
Wilsonville, Oregon 97070-7777
Phone: +1 503 685 7000
Fax: +1 503 685 1204

Sales and Product Information
Phone: +1 800 547 3000
sales_info@mentor.com

Mechanical Analysis Division
(formerly Flomerics)
81 Bridge Road
Hampton Court
Surrey, UK KT8 9HH
Phone: +44 (0)20 8487 3000
Fax: +44 (0)20 8487 3001

Flowmaster Limited
(a Mentor Graphics Company)
The Maltings, Pury Hill Business Park,
Alderton Road, Towcester
Northants, UK NN12 7TB
Phone: +44 (0) 1327 306000
Fax: +44 (0) 1327 306020

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