Thermal Challenges in Avionics

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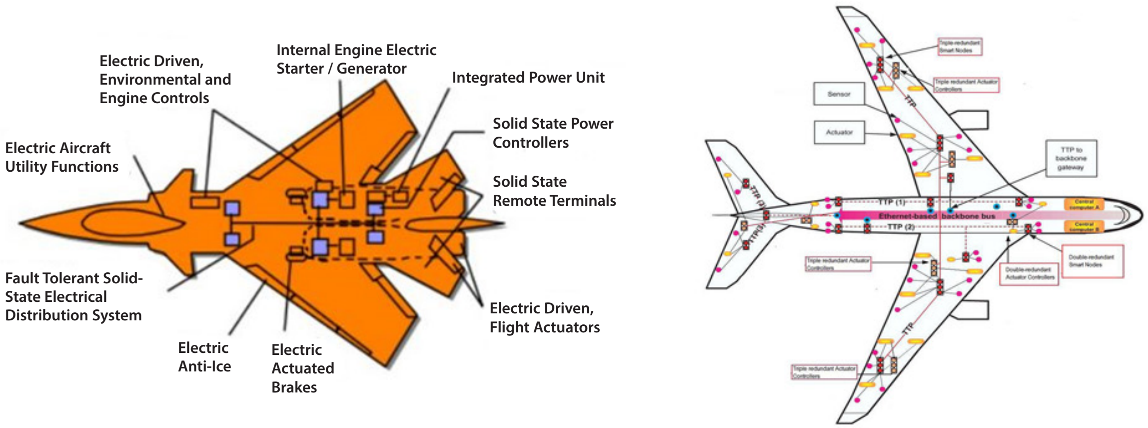

Figure 1. Example of Aircraft Actuation System for Military and Civilian Aircraft. Source: SAE International: Electrical actuation systems for flight and engine control applications mature and GlobalAerospace.com: THE FUTURE OF AIRCRAFT ACTUATORS: Hydraulic or Electric Power?

Introduction

The satisfactory performance of any modern aircraft depends to a very great degree on the continuing reliability of electrical systems and subsystems. This is becoming even more crucial with the development of More Electric Aircraft (MEA) such as the Boeing 787. MEAs use electrical power to drive components that have historically been driven by bleed air from the engines. This includes hydraulics for control surfaces and landing gear, deicing, cabin temperature and pressure, plus many other smaller operations. Besides the introduction of MEAs there is also an increasing consumer demand for power on commercial aircraft such as In-Flight Entertainment Systems, and In-Seat power and WiFi. These have all increased the burden on the electrical system of the aircraft, making it critical to manage power consumption. One of the largest consumers of the electrical power are the avionics systems.

Avionics are the electronic systems used on aircraft, artificial satellites, and spacecraft for communications, navigation, the display and management of multiple systems, and the hundreds of systems that are fitted to aircraft to perform individual functions. The increased use of such systems brings with it an increased need for compact and efficient power generation, conversion, and thermal management systems. Thermal management is key to design the most high performance and lightweight systems that exceed the required reliability standards.

Thermal Challenges in Avionics

Increased electrification leads to thermal challenges, and despite electrical systems being highly efficient, the sheer magnitude of on-board power demand of nearly 1 MW of power requires that as much as 50kW of heat be removed to ensure the system operates properly and not cause damage to the components due to overheating. The thermal challenge is to remove the total capacity of waste heat with minimal increase in temperature and at minimal weight and volume.

Adding to the challenge is the fact that while the components of the avionics systems continue to get smaller they are still very power hungry and generate as much or more heat than older generation components. This smaller packaging of the system makes it harder to have the space for heat sinks and other cooling devices to aid in the dissipation of heat. This is further compounded by the trend to put more electronics in the same space resulting in multiple electronic systems in the same space as a single system of the past, each generating the same or more heat as the older system resulting in a significant increase in the power density of the overall system.

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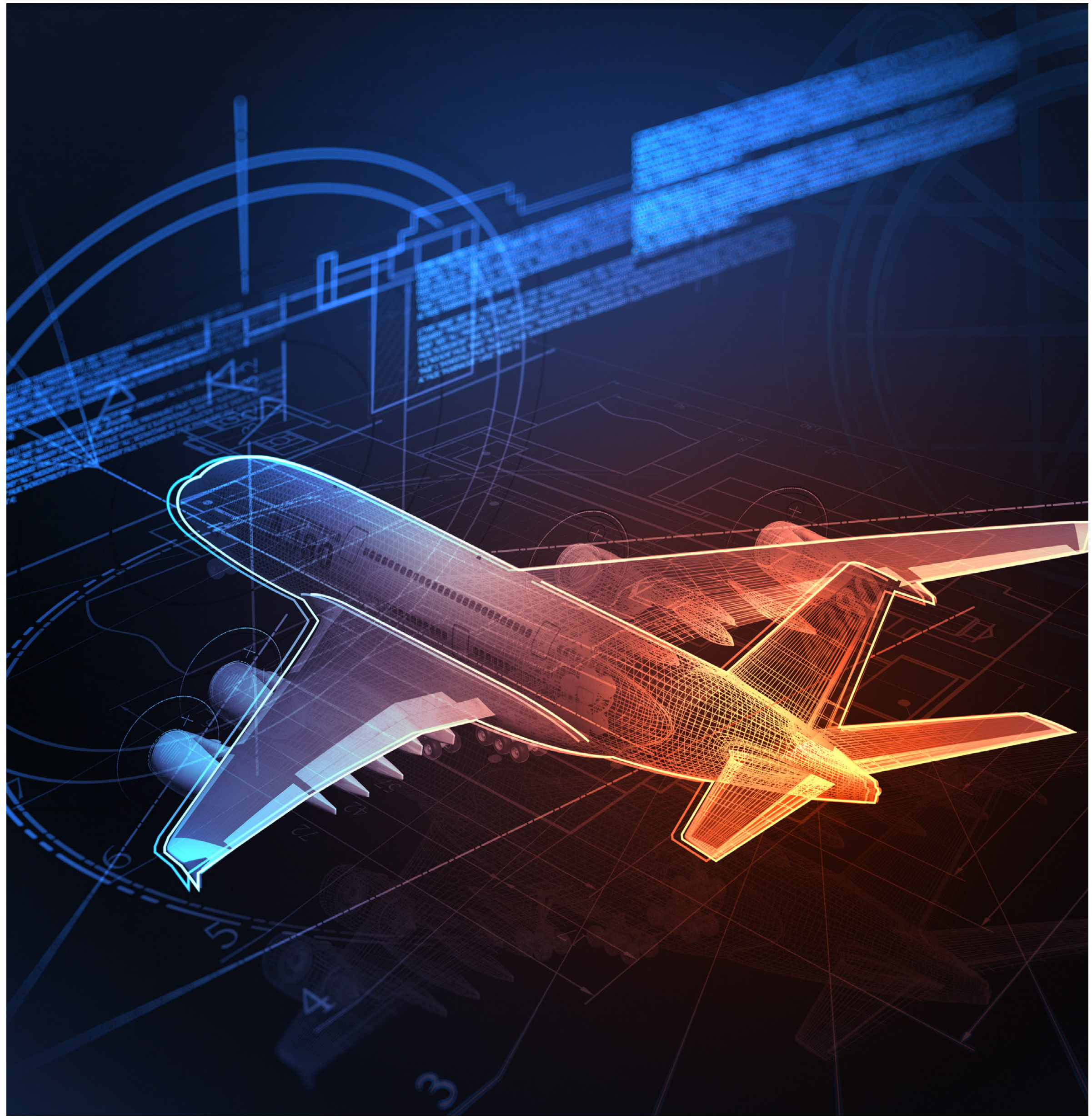

A Lesson Learned

Rockwell Collins Improve simulation processes for Commercial Aircraft Avionics

By Mike Croegaert, Industry Vertical Manager, Mentor Graphics

Rockwell Collins is a leading manufacturer of aircraft avionics systems for both commercial and military markets. They have a staff of highly experienced thermal analysts that utilize FloTHERM® Electronics Thermal Analysis Software for upfront simulation to predict the thermal performance of these products early in the design process and make design decisions around thermal management.

Some of the analysts have over 20 years' experience using FloTHERM, so when for a particular product, the results of thermal testing were significantly different than the results of their analysis, there was a great deal of surprise. Even after updating the FloTHERM model to better match the final design, the results still did not correlate in a non-conservative way to the test data to one key test scenario. This caused them to kick off a lessons learned exercise to better understand what was causing the discrepancies.

The product in question is the data processing element of a cockpit display system for a new, large commercial aircraft. The product is forced-air cooled; designed to meet Aeronautical Radio, Incorporated (ARINC) Standard number 600. It comprises a top-level chassis or Line Replaceable Unit (LRU,) that dissipates approximately 100W with several subsidiary LRUs or modules inserted into it. The system had a requirement to operate for 180 minutes after the loss of the aircraft supplied cooling air; termed a Loss of Cooling or LoC scenario. It was this scenario where the CFD analysis failed to correlate to test.

In this particular case, the preliminary thermal analysis included an up-front Computational Fluid Dynamics (CFD) analysis using preliminary mechanical and electrical design information to model the thermal situation inside the unit using FloTHERM. The results of this analysis were utilized to establish an initial thermal design strategy for the chassis, which included heatsink design and airflow management. The thermal design plan included a subsequent thermal survey on a fully instrumented early engineering unit, developed to account for the results of this initial thermal modeling. Both the thermal modeling efforts and the thermal survey testing addressed three operating environments: Normal Flight Operating (NFO), Normal Ground Operating (NGO), and Loss of Cooling (LoC). The Loss of Cooling environment required stabilization under Normal Flight conditions followed by operation with no forced-air cooling for 180 minutes. This environment largely drove the design of the system as the COTS components were very near to their upper engineering temperature limits. The custom heatsinks implemented in the unit were optimized for best performance across the various environments using the CFD tool.

During the LoC test portion of the thermal survey, the unit suffered functional failures and many of the temperature predictions were as much as 20°C below the corresponding test data. These discrepancies between analysis and testing gave rise to late design modifications. A quick review of the thermal model indicated that the model was constructed fairly well and seemed to be reasonably representative of the final configuration of the product. There were some areas where the model fell short, such as where component parameters weren't available, as the part had not yet been fully designed, so their power was spread over the Printed Wiring Board's (PWB's) surface. In general, the model was built to the usual standards. Correcting the obvious few small shortcomings did not completely rectify the errors that were seen in the result.

In order to maximize the efficiency and knowledge benefit of the exercise, the original team of engineers that performed the thermal analysis and heatsink optimization was pulled together. The investigation was run as a small engineering project. The goals defined for the study were to try to understand where the initial modeling effort had fallen short, find, and then document the requisite changes in modelling approach to improve the prediction accuracy of future modeling efforts for a chassis of this type.

The first task undertaken in the review was to revisit the initial thermal model used to evaluate the thermal situation which drove the heatsink and airflow metering strategy for the chassis. The model was updated to match the geometry and component thermal details as they were tested in the thermal survey without significant changes to the modeling assumptions used in its construction. Two specific sets of test data were chosen to pursue correlation that then drove, by necessity, two separate CFD models. The two tests chosen were identified as the most representative of the chassis final configuration with only small, known exceptions that could be modeled separately for each (e.g. presence or absence of heatsinks added in the given test.). The goal for this effort was not so much to accurately model the final configuration of the chassis as it exited the testing but, rather, to get to a correlated model that made engineering sense and that matched each set of thermal test results for each of the two operational configurations.

This chain of events was fortuitous because, as the correlation effort progressed, it became clear that the effort would require two quite dissimilar models in order to get correlated results for each operational situation. The LoC model ended up being different from the NFO model in ways that exceeded just the differences in unit configuration between the two test scenarios.

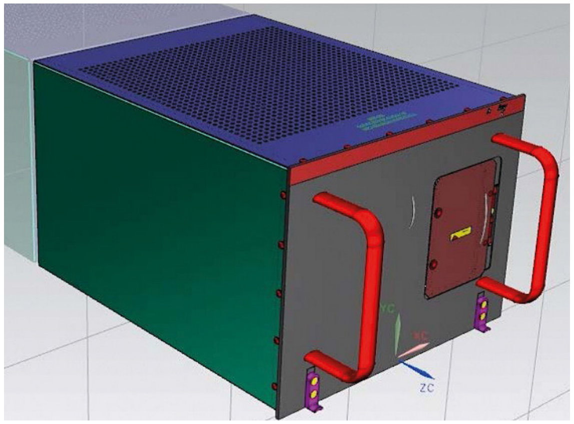

Figure 1. Chassis Model Mechanical Overview

From these tests several Lessons Learned were obtained. The two models that came out of this effort uncovered a number of nuances to the modeling of this type of chassis and environment that the team was not aware of at the outset. The lessons learned will facilitate modeling efforts on future programs with similar chassis designs. Here are some of the more significant findings:

- Both scenarios required refinements of the modeling approach to the inlet conditions for the chassis:

1. For the NFO case, the original model had utilized correctly sized openings with perforated sheet components with percentage open parameters set to agree with the expected metering plate design. A fixed flow was then imposed on the openings that would provide the required mass flow per the system design. This resulted in a nearly pure vertical flow through the chassis. During the follow-up investigation, the temperatures could not be made to correlate across the entire chassis with this configuration. Two modeling changes were required to fix this issue. The first was to add a detailed model of the plenum used in the test setup. This accurately modeled the airflow within the plenum and introduced lateral and fore to aft flow variations that allowed the model to correlate better. Also for the NFO case, the rows of metering plate holes were modeled as long thin perforated sheet strips, which allowed faster model convergence, but the percentage open had to be adjusted downward to account for the interaction between the inner and outer chassis perforations. See Figure 2.

2. For the LoC case, the inlet plenum also had to be modeled in detail. Further, getting the mass flow drawn into the chassis by natural convection required that it be monitored and controlled in the simulation. A fixed resistance simulating the test chamber inlet ducting was added and adjusted to match the very low inlet mass flow measured during the LoC tests. While using long thin, perforated sheet strips for the inlet worked well under force air conditions, for the LoC case, this approach did not allow for accurate correlation of the two models. In this case, each metering plate inlet orifice had to be modelled individually, as the velocity profiles across the rows of orifices were not uniform. See Figure 3 and Figure 4.

- The exhaust configuration for both chassis was modeled initially using perforated plate components in FloTHERM. This was found to also not accurately model the exhaust conditions for the LoC case. Ultimately for LoC, the best results were achieved when the chassis top was also modeled as a grid of small orifices below the previous perforated sheet component.

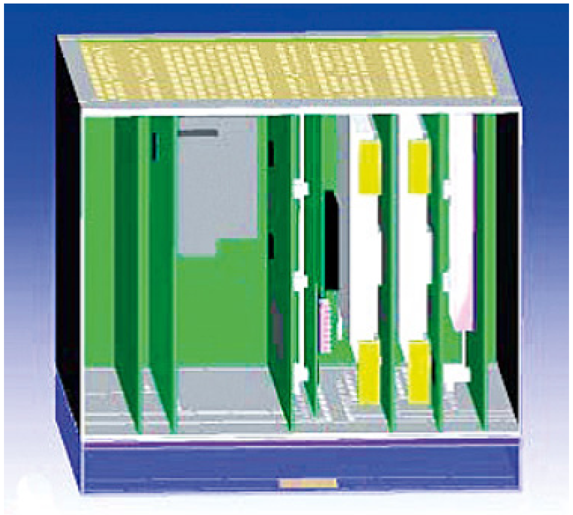

Figure 2. Final NFO CFD Model

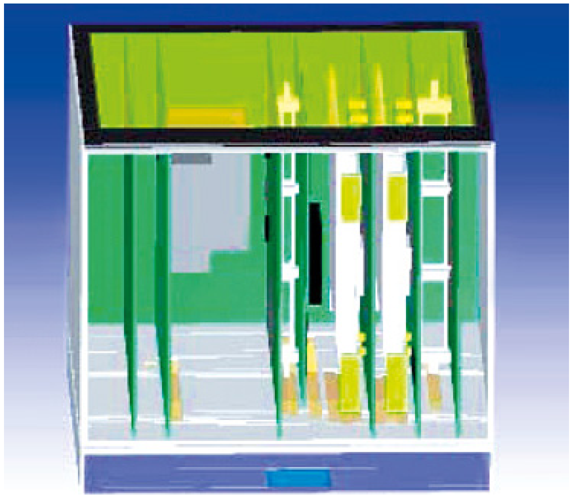

Figure 3. Final LoC CFD Model

- The LoC model is a steady state model, thus, it produces the temperatures at infinite time. The temperatures used to correlate the model had to be adjusted upward from those measured in the 180 minute LoC test. This was possible to do analytically as the test data was exponential in the last several minutes of the test and a high confidence prediction of the temperatures at infinite time was easy to make. This was a small detail but the error associated with not making this adjustment was greater than the desired 2°C error for predicted temperatures on the hottest components.

- On average, a general component's power dissipation was overestimated under NFO conditions by 20 to 40%. The NFO model, thus, generally overestimated component temperature rises.

- The non-linear thermal behavior versus temperature of several components resulted in their correlated power dissipations being significantly higher than those found in the correlated NFO model. This demonstrated that having a correlated NFO model, which is then run without airflow to simulate the LoC case, would severely underestimate component temperature rises of all these components.

- In general, the initial power dissipation estimates used to construct the original CFD model ended up matching the correlated power out of the LoC test data. It was found, however, that the final correlated power supply component power dissipations averaged approximately 50% higher than the original estimates. This was attributed to the increased system power required to drive the components that were exhibiting non-linear power increases with temperature.

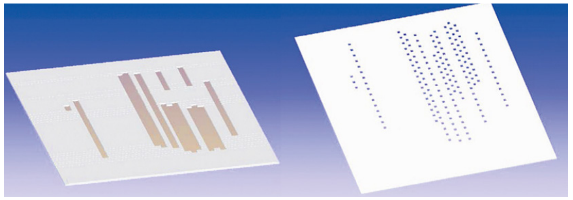

Figure 4. Final NFO (top) and LoC (bottom) Metering Plates Comparison

- The initial model was missing several components because the data for them was not available and some turned out to be key to the heat generation. Some of these components ended up driving specific thermal decisions later, during the appraisal tests. Key point here is to have as many components modeled as early as possible in the process.

- This Lessons-Learned project uncovered a number of facets of the original analysis work that go beyond a simply flawed analysis approach. Several of the usual assumptions for this type of CFD modeling proved to be inadequate and/or incorrect. As a side benefit of this effort, a procedure for quickly and reliably correlating a large complex thermal model to measured thermal data was developed and refined. The results presented here are applied on and will improve the results of all follow up development projects.

Tackling the Thermal Design Challenges of Smaller, Lighter, and More Efficient Avionics

Introduction

With every Kelvin increase in temperature, the risk of avionic component failure increases. For civil and military applications, the thermal characteristics of avionic components directly influence overall thermal management. They dictate the size, weight, and power (SWaP) of the cooling and therefore the overall system and can decide between function and failure. Commercial off-the-shelf components for avionic systems may cost less, but the lower price has to be weighed against SWaP and reliability to ensure the whole cooling system is viable.

This article demonstrates how thermal transient testing combined with computational fluid dynamics (CFD) can help find this balance and ensure that safety critical devices work within their prescribed temperature limits. The process starts with selecting and measuring the thermal characteristics of electronics components, along with accelerated ageing tests, to determine the most suitable components. This is followed by the thermal simulation of the avionics equipment (for example, navigation and combat or in-flight entertainment systems) and the associated cooling system using CFD software. Some industry examples illustrate how this process is helping companies create higher quality products and develop faster, more efficient, and cost-effective avionics systems.

Industry Trends

Electronic systems are a key component for high reliability and safety in modern airplanes. Systems for collision avoidance, navigation and control of the airplane are enabling pilots to ensure passenger safety and mission fulfillment with every flight. With the advances in technology, new processors and other electronic components become smaller, faster and therefore more powerful in their performance. With these advances the power density increases and thermal management becomes a vital role in ensuring the reliability of these components. A failure of such components in mid-air is simply not an option which is why modern aircrafts (rotary and fixed wing) are equipped with redundant systems for all critical avionic systems, to ensure the safety of the crew and passengers.

In military aircraft, the electronic systems have become more dominant in design and operation because they not only support the maneuverability and situation awareness of the pilot but also provide essential image and sensor processing, data recording, and broadcasting and communication between home base and wingman. The newest generation of aircraft cannot be flown by a human pilot without avionics. The earlier an enemy or threat is detected, the better are the chances for a positive outcome.

The Problem

The ratio and tradeoff of size, weight, and power (SWaP) is a crucial system design consideration. As these aircraft are fitted with an increasing amount of electronics and with more components, they become heavier—and more weight can mean less time in the target zone. Weight has become almost a dimensionless coefficient such as Reynolds and Mach number. Electronics in an aircraft must be lighter, smaller, and more efficient to allow the aircraft to carry more systems, payload, or fuel. Less weight results not only in longer mission duration but also higher maneuverability.

A good design of power components can reduce energy consumption and save fuel as well as reduce the power that is dissipated as heat. Another important factor for system design is cost. System developers are looking into using commercial-off-the-shelf (COTS) components to reduce costs, not only because such components cost less than custom-designed ones but also because maintenance and replacement of such products is often much easier. But many COTS products are not designed for rough environments and special measures in the design must be made to compensate for this factor.

Even with SWaP considerations and using COTS products, the systems still have to be smaller, lighter, and use less power without losing too much performance—this leads us into thermal issues that have to be managed to maintain high reliability of these systems in their defined environment.

Analysis of Semiconductor Components

A good understanding of semiconductor components' thermal behavior is important because it is crucial to the optimum thermal design for a low SWaP ratio. Insufficient understanding of a component can lead not only to an oversized cooling system but also to a bad choice of the selected components that are to be used for the lifetime of the system.

Thermal Characterization

The Mentor Graphics T3Ster® thermal transient tester uses a "smart" implementation of the static test version of the Joint Electron Devices Engineering Council (JEDEC) JESD51-1 electrical test method [1] that allows for continuous measurement during a heating or cooling transient. This measurement methodology for the junction-to-case thermal resistance of power semiconductor devices makes it possible to thermally characterize a component with high accuracy and repeatability. The result is far richer data that is measured from much earlier in the junction temperature transient than possible with other techniques.

The automatically generated dynamic compact thermal model of the component can then be applied directly in computational fluid dynamics (CFD) simulation software (FloTHERM®).

The T3Ster Master post-processing software fully supports the JESD51-14 standard for junction-to-case thermal resistance measurement [2], allowing the temperature versus time curve obtained directly from the measurement to be re-cast as “structure functions” (described in JESD51-14 Annex A), and then easily find the value of the junction-to-case thermal resistance.

The characterization method uses the temperature sensitivity of the semiconductor component. This sensitivity has to be measured before the actual characterization can begin, and it should be done according to the JESD51-1 standard to record the cooling curve of the component.

Once the measured temperature sensitivity parameters (TSP) are obtained, you can characterize the component by powering up the device (heating it) with P_H [Watt] until a steady state is reached. Once the junction temperature T_J is constant, the heating current is switched off to a lower measuring currentthat creates a low measuring power P_M [Watt]. The measuring current is negligible compare to the heating current. This sharp power step introduces the cooling process and is recorded until a steady state is reached.

From the temperature sensitivity of the component and the lower steady state temperature, ideally realized with a cold plate, the transient cooling curve is created as shown in Figure 1. The temperature difference ΔT [Kelvin] is derived by the temperature sensitivity of the component; and the thermal resistance of the component can be calculated as shown in the equation: $R_{th} = \Delta T/(P_H - P_M)$.

From the recorded cooling curve, a structure function can be derived as shown in Figure 2. This structure function shows thermal resistance and capacitance of the single layers from junction to environment. The vertical sections of the curve show thermal capacitance C_{th} [W/(s · K)] and low thermal resistance R_{th} [K/W] materials such as metallic layers in the component structure; whereas horizontal lines show higher thermal resistance layers such as die attach, glue, grease, and other thermal interface materials (TIM) and PCB layers, etc.

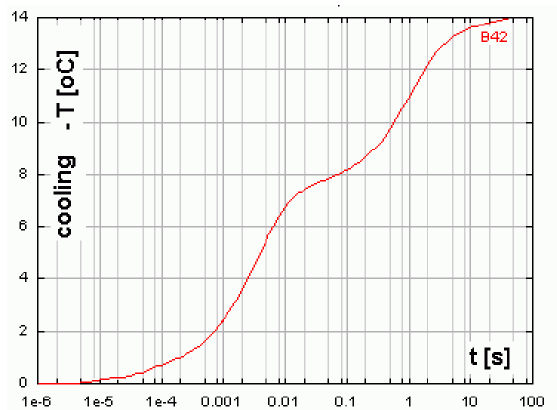

Figure 1: Cooling curve of a sample component.

Each step of the structure function can then be described as a resistor and capacitor in a Cauer ladder as shown in Figure 3. By specifying the final node “case” of the component in the curve, a compact thermal model can be derived and used for accurate component representation in a simulation for the thermal resistance from junction to case.

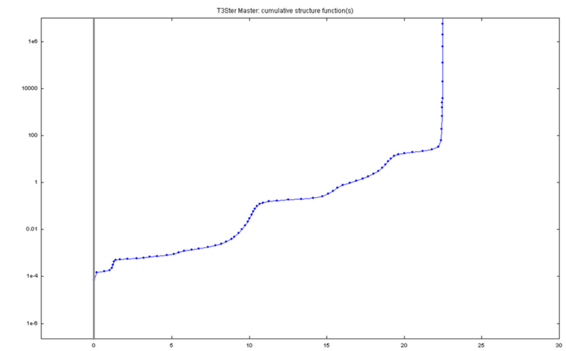

Figure 2: Structure function of a sample component showing vertically thermal capacitance and horizontally thermal resistance.

This thermal characterization method was also used for TIM1 and TIM2 type material measurement in the NANOPACK project [4].

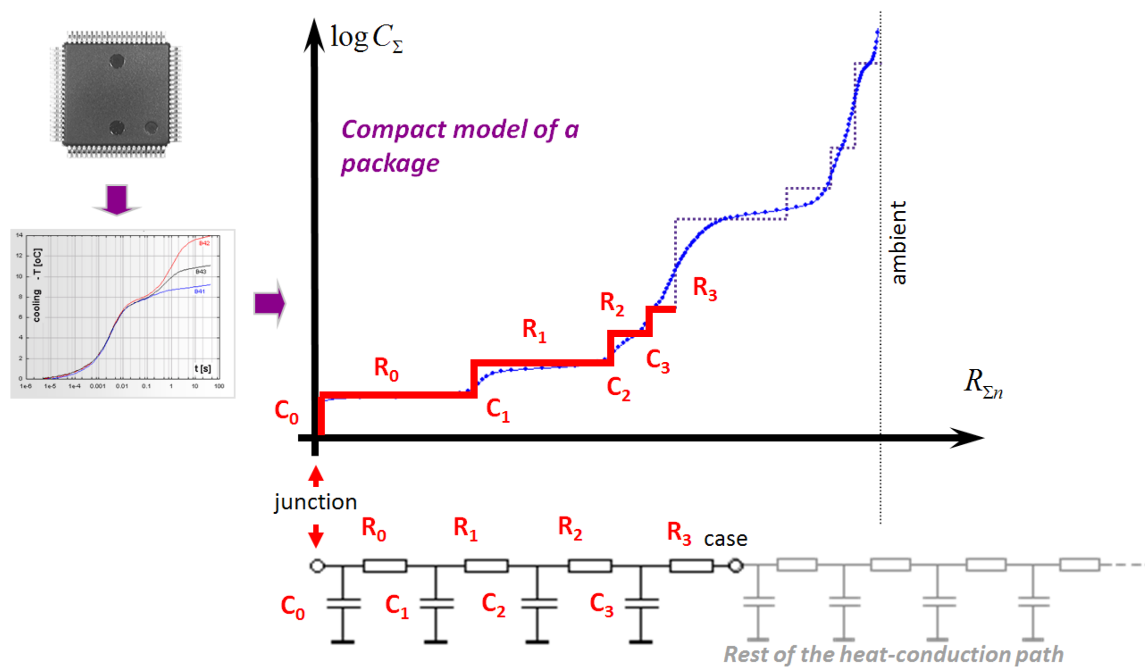

Figure 3: Step by step from component to Cauer ladder.

Lifetime Testing and Failure Characterization

Component characterization is important to be able to judge the quality of components, not only for the component manufacturer during production by taking samples to determine if the production process is running without errors, but also for system integrators because naturally component properties can vary from vendor to vendor and also be different than listed in the datasheet.

With the necessity of high reliability for safety critical components, it's important to ensure perfect functioning of the system over its lifetime. A system's lifetime can be several thousand hours under constantly changing environment conditions such as temperature variations and shocks, pressure variations, humidity, etc. These conditions increase the aging process and can result in component or material failures. Material degrades over time because of these fluctuations and can result in TIM degradation, die delamination, etc.

The components are usually exposed to harsh environments that are even worse than the actual environments to accelerate the aging process and identify degradation. This is called highly accelerated life testing (HALT) and can shorten the original testing time by some order of magnitudes.

Thermal characterization is a nondestructive measurement and can reveal failures caused by this process inside the component. If for example the die attach is degrading and the die delaminating, it will result in an increased thermal resistance. Such an increase of the thermal resistance increases the junction temperature of the component because the heat cannot be dissipated as quickly as with a healthy component. As a result, the component is likely to fail sooner than a healthy component because long excessive temperature increases the aging process even more. The thermal management system that is designed for the system is not efficient and powerful enough to cope with basically a "different" component than the original designed component. If in addition the system has to function in a worse-case scenario of a failing cooling system, the situation becomes even worse.

The following examples show cases of tests done with different failures in the component in general or over the ageing of the component, to show the difference in the measured structure function. The structure function clearly shows in these cases increased thermal resistance of the component for these failures (Figures 4 and 5).

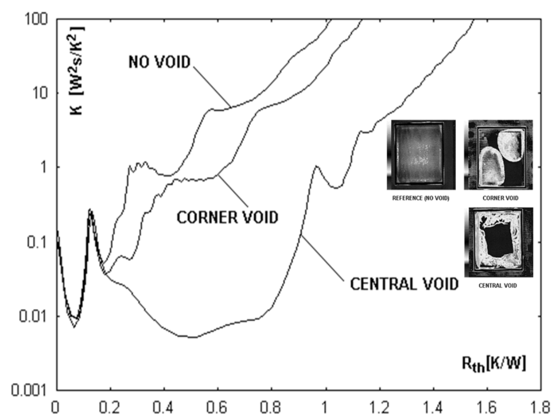

Figure 4: Die-attach voids shown in the derivative of the structure function [5].

As illustrated in the examples, the failure in the package structure and in the heat path outside the package structure can be measured up to the environment. The rest of the structure function, depending on the magnitude of the failure, is often just shifted horizontally or vertically, indicating that the rest of the heat path has kept its properties and the failure only exists in the responsible layer of the package or assembly.

This test, where different LEDs were compared over a lifetime of up to 6,000 hours, showed that a set of "NONAME" LEDs failed after around 3,000 hours compared to some LEDs from "EU" and "US" vendors which reached 6,000 hours without substantial degrading of the components [6].

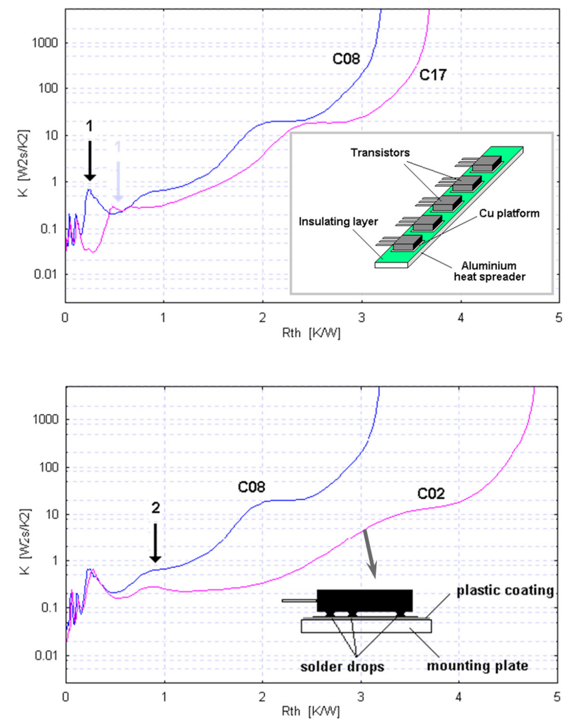

Figure 5: Test set with two failures show in the derivative of the structure function: die-attach delamination in the package (top), imperfect package soldering (bottom).

The LEDs of the European vendor degraded just slightly. This degradation is possibly caused by a delamination of the LED package from the printed circuit board (PCB), and something similar seemed to have happened for the "NONAME" vendor between 500 and 2,000 hours. But the "NONAME" vendor LEDs had an even more significant degradation of the TIM between 0 and 500 hours.

Because the LEDs are delivered already attached to the metal-core PCB (MCPCB), the TIM material is defined by the vendor; thus, the purchased package of the "NONAME" vendor in general is not a good choice for the system in which it would be used.

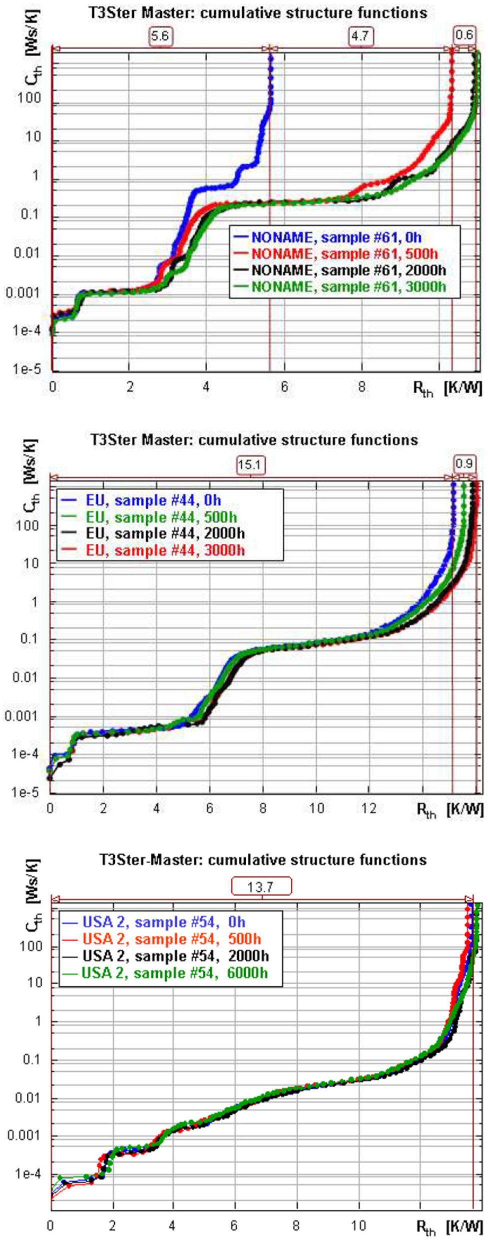

Figure 6: Comparison of LED package degradation over aging: LEDs of a "NONAME" vendor (top), LEDs of an "EU" vendor (middle), and LEDs of a "US" vendor (bottom). (Courtesy of Budapest University of Technology and Economics, Department of Electron Devices.)

Characterizing Componenets in a System

As described, the thermal characterization of components soldered onto PCBs can be measured in a quick way if a cold plate is used for a better fixed "environment" temperature. For measurements in a complete system, the measurement itself can take longer because it is often hard or impossible to fix the temperature to a certain value and achieve a faster convergence to the cold steady state of the measurement. If proper cooling can be applied to the system, it can accelerate the measurement. In addition to the overall system, other components, larger PCB, etc. will also influence the measuring time—the heat has to reach the hot and then cold steady state and all components influence this process with their own heat capacity.

In general, a complete system can be measured and thus possible maintenance work on the aircraft's system is possible. Such an in-situ measurement of a system is shown in Figure 7, which is an example of a memory chip on a dynamic random access memory (DRAM) module on a PC motherboard in a JEDEC standard still-air chamber.

Simulating Avionics Thermal Design

Thermal and fluid flow simulation with CFD software is essential for efficient development of avionics products. Such simulations can minimize physical prototypes and enable designers to test different design variations and boundary conditions of the system without a single prototype. This helps to optimize designs to better match the thermal challenges.

A wide range of CFD software is available on the market: commercial and open source. Each has its advantages and disadvantages in capability, suitability, and performance for different applications. For electronics cooling, where most geometries are basically square-shaped, it makes sense to use the highly robust and fast meshing approach of a Cartesian mesh. Other mesh types take a long time, especially with a high-quality mesh, or tend to instability. Because of its nature, the Cartesian mesh is generally best suited for a CFD solver because the 3D Navier-Stokes equations are defined in the basic coordinate directions and there are no secondary fluxes at skewed faces.

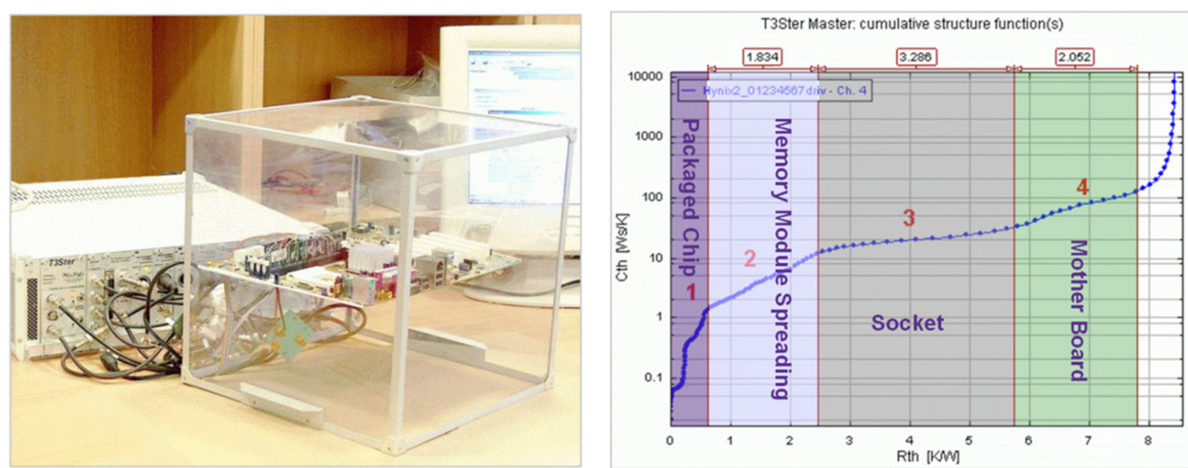

Figure 7: In situ thermal characterization of a DRAM chip on the module and motherboard of a PC in a JEDEC still-air chamber.

For more complex shaped geometries, different approaches can be used. Some are based on Cartesian mesh which switches to a tetrahedron mesh toward the surface to more accurately represent the surface of the geometry, but again they have the secondary fluxes caused by skewness of the cells. Another approach is to cut the geometry stepwise with the intersecting cells on the surface; this works perfectly for square-shaped geometries as usually used in electronics cooling applications but is not suitable for complex geometry. A third approach is to use a special cell technology, the partial cells which are basically cut by the geometry into a solid and fluid section of the cell but can also be solid-solid in case of different materials in contact with each other. There are also more sections within a cell possible, which for example can apply for thin features such as heatsink fins that would cause a cell sectioning into fluid-solid-fluid [7]. Some of these meshing methods are shown in Figure 8.

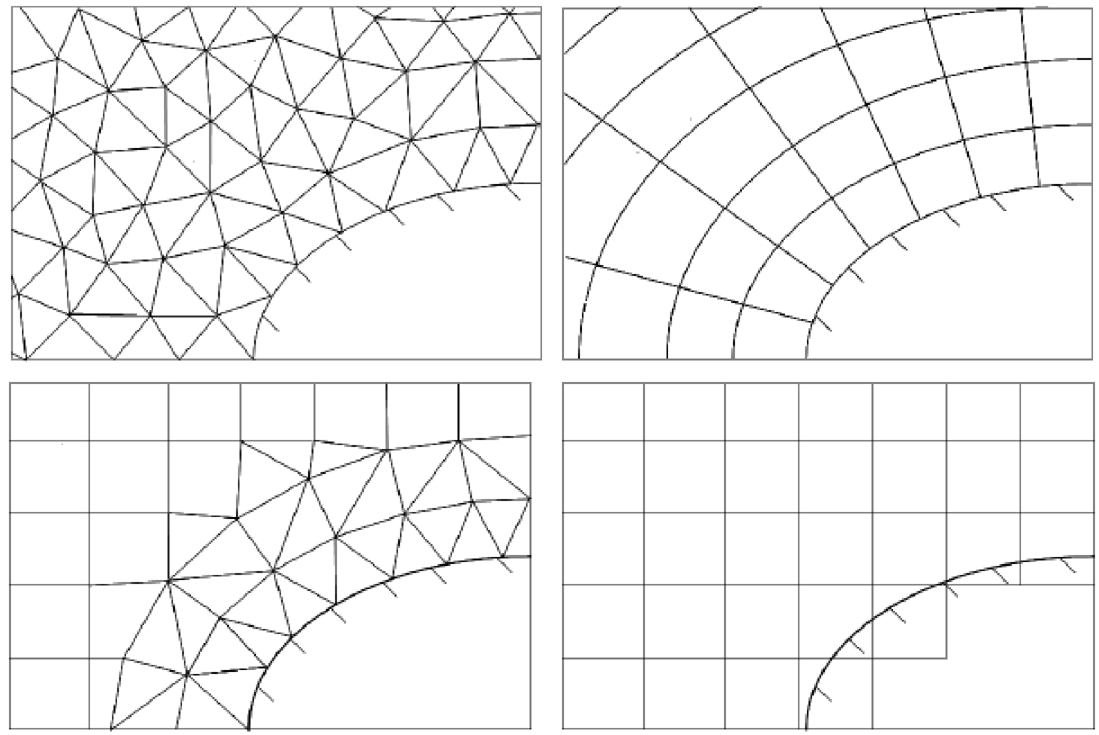

Figure 8: Example of various mesh types used in CFD calculations.

The capability of the solver is determined by the physics needed to calculate the problem. For electronics cooling applications, the basic capabilities are usually heat conduction and fluid flow, including convec- tion (natural and forced) as well as radiation. For some more detailed analysis, joule heating and handling of some engineering models such as thermoelectric cooler (TEC), 2-resistor, or even a more detailed compact thermal model (CTM) representation of the electronic components are necessary. Such engineering models enable the engineer to consider more complex structures, processes, and phenomena in a simplified but yet accurate form often based on simplified equations or certain assumptions.

Such a CTM for example can be used from the thermal characterization measurements of the component, simplifying the complex structure of it, which would cost several thousand more cells and calculation time to solve, and yet create a highly accurate resolution and results of the component.

With additional post-processing capabilities, it is possible to enable the engineer to have a deeper inside look into the problem. Standard capabilities such as cut-plots of certain parameters including temperature, velocity, or pressure, or flow trajectories and surface plots help to show the distribution of the parameters in space and time. The final decision on how and where to change the geometry is left to the engineer in such a case. He or she will be shown the hot and cold spots of the geometry and their values, but how to get the heat out of the hot regions into colder areas is left to his engineering knowledge completely.

Two new and patented parameters can reduce the search for a better solution by directly pointing toward the critical areas and areas that bare possibilities. These parameters are called bottleneck and shortcut number, B_n and S_c, respectively. The B_n is showing directly where the bottleneck (as the name suggests) is in the design; for example, a badly conducting PCB below a hot component at which vias could provide a better thermal dissipation into the PCB to better spread the heat through all layers of the PCB or contact it through to a heatsink or the enclosure on the other side of the PCB. The S_c enables the engineer to see areas where there is cooling potential caused by cool airflow or a colder component close by such as a heatsink. That way the engineer is directly confronted with possible areas of improvement instead of finding them himself with the standard set of parameters usually provided in CFD tools.

Simulation can be done from the component level up to the system level, including the environment it is built in. A detailed model of a component can help to understand the heat flow through the 3D geometry in more detail and provide a good thermal model similar to the thermal characterized component that was measured (Figure 9). There is a good correlation between simulation of a detailed component and the measured component.

Of course, for PCB designers, such a detailed simulation of a component is not as important as long as a good CTM exists because the simulation results will be very accurate with such an engineering model. A PCB with many detailed modeled components would not be ideal to simulate because the mesh size would increase drastically and result in extensive calculation times. For a relatively rough analysis of a system, a 2-resistor model is accurate enough, and for a highly accurate simulation a DELPHI compact model would be a better choice [8].

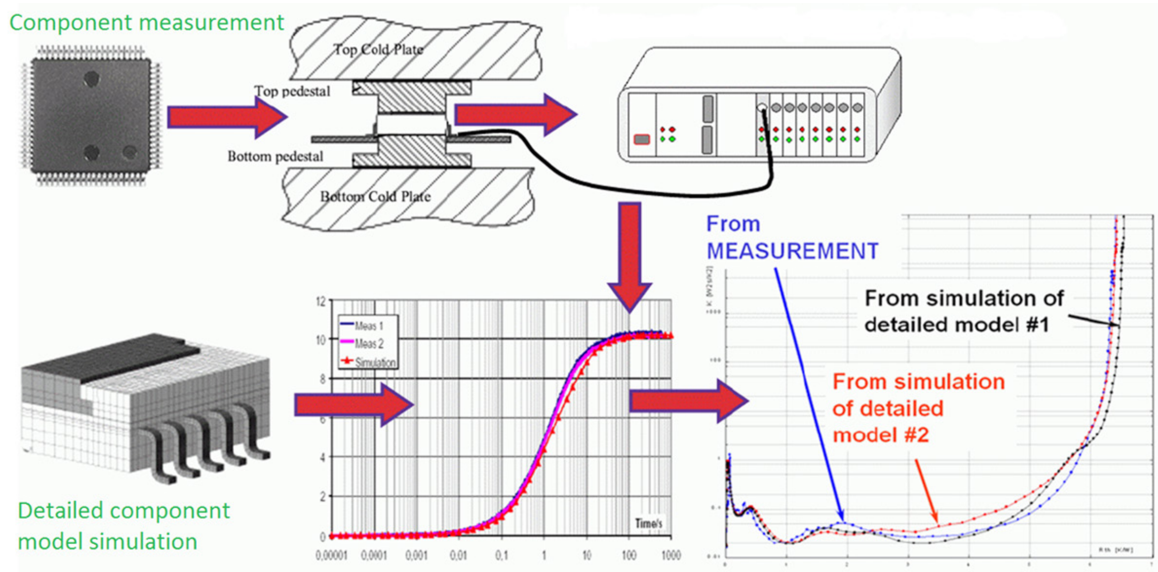

Figure 9: Correlation between measured component and detailed component simulation.

Conclusion

Datasheets of components can be vague or not detailed enough for highly accurate simulation results, and often vendors do not provide more information for their components to ensure an accurate simulation. Thermal characterization can provide the detailed information necessary for simulation, component failure analysis and prediction, and help in the decision of the component selection.

For a complete system measurement as a part of the aircraft maintenance, further research with avionics systems supplier should be done to identify the potentials and needs for such an early detection of possible component failures. A result of such an implementation into the maintenance process would be increased reliability in the installed system and safety to the mission and passengers of the aircraft.

Computer simulation has been a widely used method for a long time and is constantly increasing in accuracy. With detailed compact thermal models of the components, the accuracy of the thermal design can be increased and oversized cooling systems improved, which helps in all areas of the SWaP factor.

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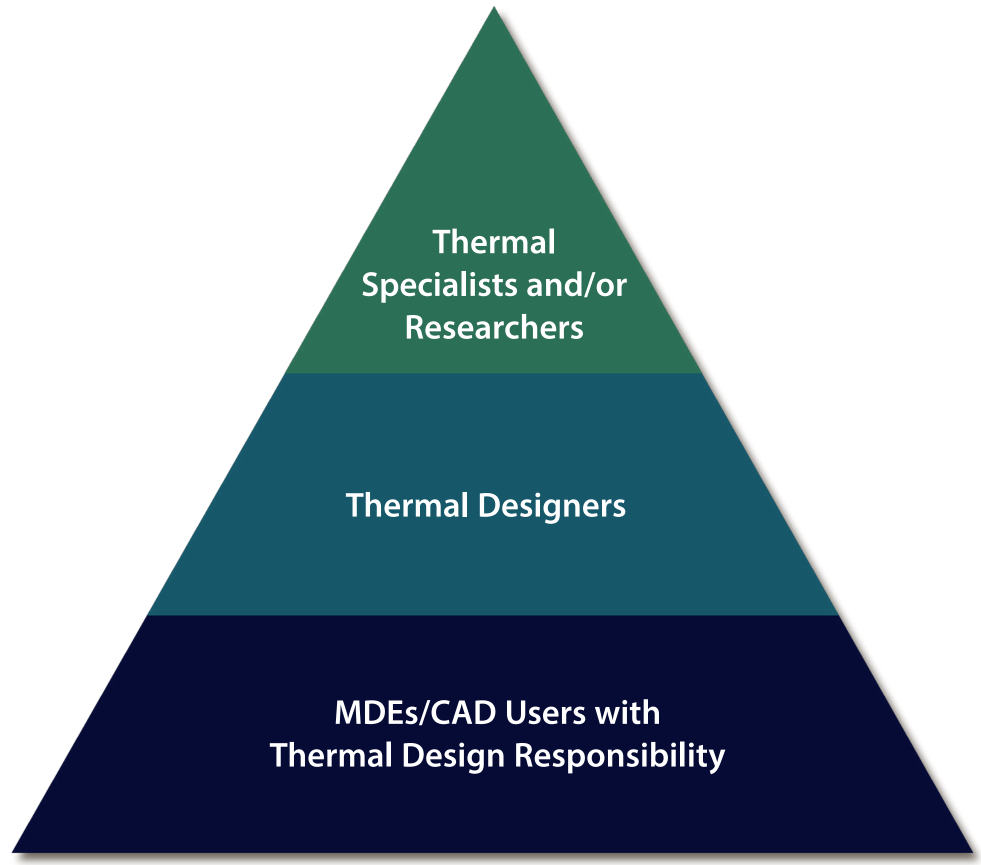
Reliability in Avionics Systems

The main source of heat in electronic equipment is their semiconductor chips, and the temperature sensitivities of these chips present 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.

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.

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, mechanical design engineers, and reliability engineers.



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, complication 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. For a more in-depth analysis of the role CFD plays in thermal management of avionics systems download the whitepaper: Reliability in Avionics Systems – Managing Excessive Heat

Getting Heat Out

By Darryl McKenney, VP, Engineering Services, Mercury Systems, Inc.

Mercury Systems is a publicly listed company based in Chelmsford, MA, USA and is a leading supplier of commercially developed, open sensor and Big Data processing systems for critical commercial, defense and intelligence applications. We design and build end-to-end, open-sensor processing subsystems. Our product set spans the entire ISR (Intelligence, Surveillance, and Reconnaissance) sensor processing chain, from acquisition to dissemination, helping customers address a broad range of sensor processing. Mercury Systems have worked on over 300 programs, including Aegis, Patriot, SEWIP, Gorgon Stare and Predator/Reaper.

If we examine typical military electronics CPU Modules and Mezzanines over the last few decades (Figure 1), what is very clear is that their Power levels have increased dramatically. The VPX, formerly known as VITA 46, is an ANSI standard (ANSI/VITA 46.0-2007) that provides VMEbus-based (Versa Module Europa bus) systems for CPUs with support for switched fabrics over a new high speed connector. It was defined by the VITA (VME International Trade Association) working group, that includes Mercury Systems, and it has been designed specifically with defense applications in mind, with an enhanced module standard that enables applications and platforms with superior performance. Basically, all CPU boxes in ISR applications must comply with this standard and its successor VITA 48.

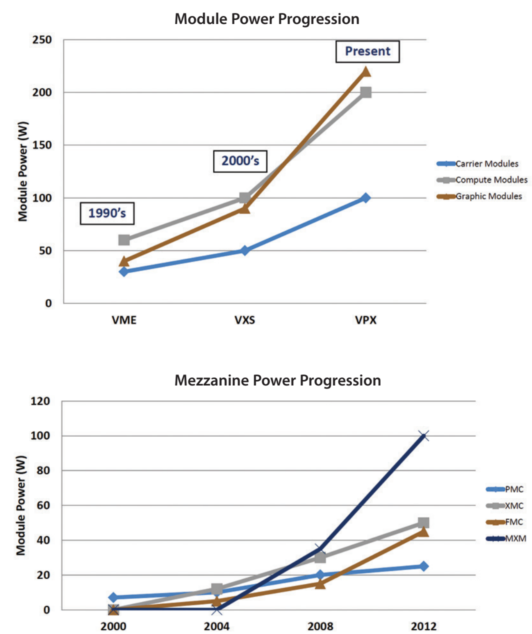


Figure 1 Defense CPU Modules and Mezzanine Power Module Evolution over time

We are finding that devices such as microprocessors and FPGAs (field-programmable gate arrays) have been running ever faster while their size has been constantly shrinking, which obviously has increased heat densities and threatened product reliability. But after nearly a decade of honing our Design for Reliability (DfR) thrust we have produced new design processes and implemented new procedures such that we have reduced the number of engineered change orders by over an order of magnitude. This demand for higher and higher functionalities in defense electronics has led to conflicting demands for more heat management, more sensitive signals, shorter design cycles, higher test coverage and all within ever tighter defense budgets. To add to all this, our products have to be highly reliable with years of operational run time in a wide range of harsh environments. You can imagine the challenges this poses for test engineers, signal-integrity engineers and mechanical engineers when it comes to designing new PCBs and enclosures. Many of today's high powered modules cannot be cooled using legacy cooling approaches. The bottomline is that in our business heat is the primary enemy of module reliability.

At Mercury we offer three types of products to our customers, Air-cooled (A/C) Modules, Conduction-cooled (C/C) Modules and what we call Air Flow-By™ (AFB) Modules. In all cases we go through detailed design and testing processes to design the units for our customers. Our evaluation of each technique's cooling efficiency is highlighted in Figure 2. For our thermal CFD simulation needs we use Mentor Graphics' FloTHERM product which helps expedite our design process.

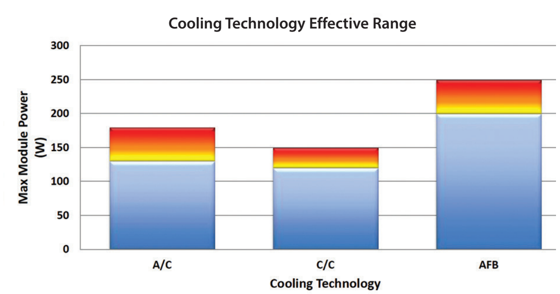


Figure 2 Air-Cooled, Conduction-Cooled and Air Flow-By Cooling Technology Ranges

Air-cooling provides easy access to module debug connectors, front panel I/O and mezzanine modules. This combination simplifies system development and configurability while the system is in its greatest state of flux and requirements are not all identified. A major drawback is that air-cooled modules are not typically designed to be deployed in rugged environments. Conduction-cooling has been the preferred method of cooling for deployed systems for many years.

The modules are designed to handle the rugged shock and vibration levels, while the systems seal the modules away from harmful elements. A major challenge with conduction cooling is that it is heavier than air-cooled and thermally challenged with higher power modules. Air Flow-By – a new cooling technology designed by Mercury – delivers the best of both worlds. It provides the efficient point source cooling of an air-cooled module with the rugged deployment capabilities of conduction-cooling.

To give a simple example of how we apply FloTHERM to one of our XMC-Air-Cooled products (Figure 3), we employed a standards based approach to bring heat from the mezzanine modules to the carrier module's heatsink. We discovered via CFD simulation (Figure 4) that we could do this by adding "hooks" for a thermal bridge between the carrier module heatsink and the mezzanine module heatsink. The net effect was a thermal solution that was compliant to standards and allowed for a wide range of mezzanine modules to be placed on a host while limiting any potential changes to a single component. We discovered with FloTHERM that we could get a 5°C Processor thermal reduction - half an Order of Magnitude. This leads to significant impact on mean time between failures (MTBF) too.

In summary, our new thermal-management solutions are capable of dissipating tremendous amounts of thermal energy, while still meeting the same or smaller size, weight and power requirements for the overall solution. By understanding the thermal profile for each specific component that makes up a system using FloTHERM, we created innovations in the mass transfer of thermal energy that work at the individual component, module and subsystem level.

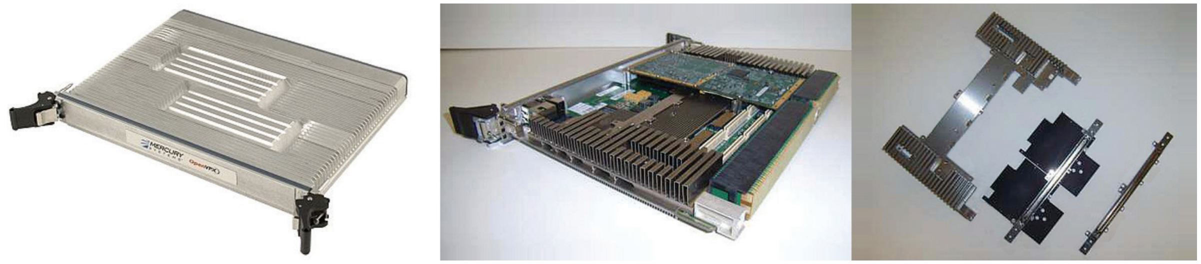


Figure 3 Typical Mercury Systems Integrated XMC Air-Cooled Thermal Solution showing details of Thermal Bridge Hooks

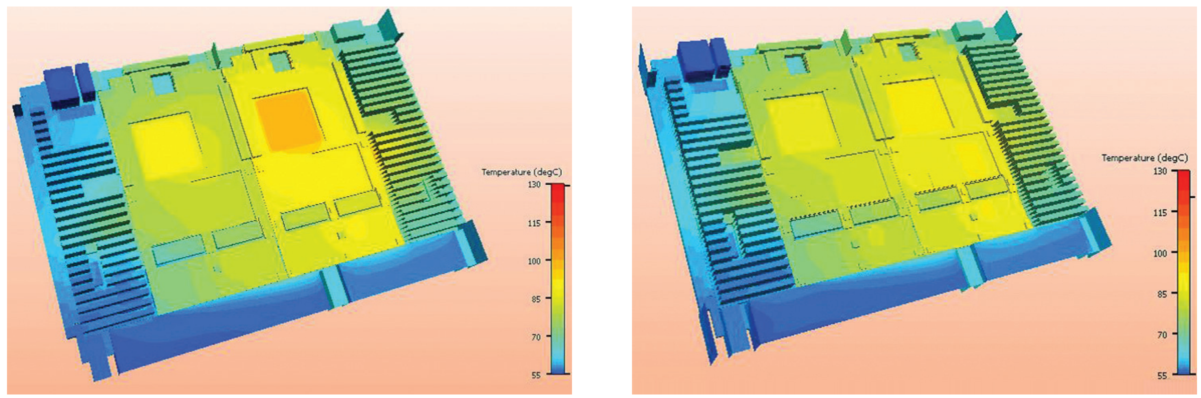


Figure 4 FloTHERM thermal analysis (L) without Integrated thermal bridge (R) with Integrated thermal bridge

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Air Flow-By is a trademark of Mercury Systems, Inc.

The Future of Avionics Systems

Both commercial and military aircraft employ state-of-the-art systems requiring large amounts of on-board electrical power. For military platforms, power demand has been rising sharply. High power electrical systems on aircraft flying at high-speed and altitude present unique thermal challenges both at the application and system level. The increased use of composites that have very low thermal conductivity and the desire to minimize the thermal signature of military aircraft also means that there needs to be alternative ways of dissipating the heat as well including using fuel as a heatsink.

Additionally there is a new emerging segment of aircraft coming to the forefront that have their own challenges. Unmanned Arial Vehicles (UAVs) are gaining popularity for their versatility and ability to operate in areas where manned vehicles can't or pose a high risk to the pilot. UAVs are basically, flying power electronic boxes that experience harsh environments including high temperatures, dust, and sand. Their compact nature also results in a much higher power density than a manned aircraft without the advantage of having the space for complex cooling systems or heatsinks.

The design of thermal management solutions can greatly benefit from a system-level approach to optimize the beneficial attributes of a component level improvement. Advances in thermal management and system design engineering contain key technologies that have been developed to enable the operation of next-generation aircraft platforms.

Curtiss-Wright & FloTHERM: From COTS to Custom Deployment

Curtiss-Wright is a provider of rugged, commercial off-the-shelf (COTS) electronic modules and integrated systems for defense and aerospace applications.

By Andrea Schott, Curtiss-Wright Controls Defense Solutions

Having both a mechanical design and thermal design background has helped me appreciate the many different aspects of taking a product from concept to production in a short amount of time. Unless you are the sole engineer on the project, doing both thermal and mechanical design, a close working relationship between thermal engineering and mechanical design is critical to ensure on-time, low cost product delivery.

Curtiss-Wright provides rugged, commercial off-the-shelf (COTS) electronic modules and integrated systems for defense and aerospace applications. Our highly engineered solutions, ranging from open standards-based modules to fully optimized systems solutions, are deployed in a wide range of demanding applications, including C4ISR, unmanned systems, mission computing, fire control, turret stabilization, data recording and storage solutions.

As part of the Defense Solutions business unit of Curtiss-Wright Controls, the Littleton facility, Massachusetts addresses a niche market by providing quick turn-around custom electronics enclosures to our customers. Typically, this involves very low volume (quantities between 1 and 15 units), and production delivery in around 20 weeks, which leaves no time for prototyping or testing. We rely completely on engineering experience and thermal simulation to meet our requirements. FloTHERM® allows us to iterate multiple scenarios to optimize our systems for not only thermal performance, but also weight reduction, noise reduction, cost and schedule.

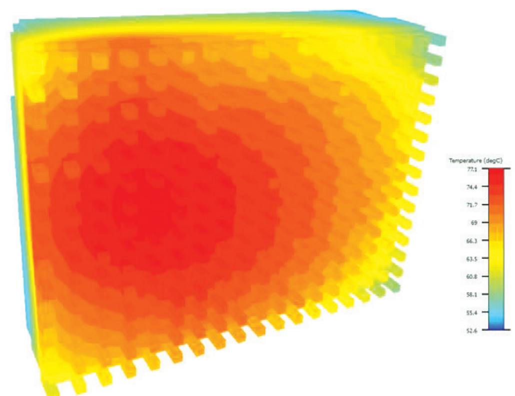


Figure 1 High density, conduction cooled power supply with supplemental air cooling via pin fin heatsink

As a result of FloTHERM's versatility we have the ability to offer our customers a variety of solutions. To further define the operations of Curtiss-Wright's Littleton facility, our activities often involve supplying a metal enclosure (typically brazed aluminum),backplane and power supply all designed to meet specific customer specifications. Our customers populate the enclosure with their own suite (or payload) of electronics. We are usually provided very little information on the design or end-function of the payload.

What keeps this process from being straight-forward is the fact the Curtiss- Wright is typically only provided with specifications for the subsystem's overall sizes, power levels, ambient conditions and the temperature requirement for the electronics card mounting. From this limited amount of system detail it is our task to design a solution capable of meeting the required temperature in all environmental conditions at the given power levels.

Another challenge that our design team often faces is that in many cases enclosures designed at our facility and are sold to the end customer by a third-party for whom the Curtiss-Wright designed enclosure is essentially a component, not a product level complete system. Because our customers are usually responsible for all verification testing, we rarely receive feedback about results except for the very rare case in which a problem emerges. As these enclosures are primarily used in military applications, the environmental conditions can vary greatly and are often extreme. New products are often retrofits for older existing equipment and the new higher powered enclosures must be cooled by existing cooling systems. The challenge for our design team, including thermal and mechanical engineers working together, is to meet all of the customer's requirements in a very short timeframe.

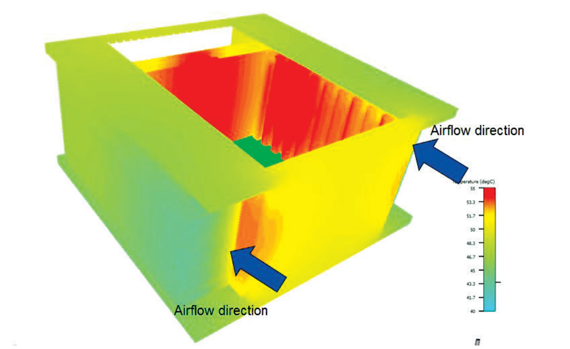


Figure 2 1300W Custom Electronics Enclosure. The payload is cooled by conduction, Enclosure is air

The ambient conditions in which the resulting system must perform are harsh, and the power levels required are typically high. Hence thermal simulation is critical for our business, especially since delivery schedules are often very tight.

In order to expedite the design process, Curtiss-Wright has established a consistent method of tracking all thermal design information. This includes tracking the initial customer requirements all the way to documenting the 'as built' configuration. By using a custom spreadsheet template containing the relevant design information we are able to track and maintain information from project to project in a consistent manner. The spreadsheet template contains the initial customer requirements that are used in the quoting process. Since thermal design is one of the highest risk factors in almost every design we undertake, we closely analyze the project's thermal requirements even before we are awarded the job. In many cases we perform some preliminary level of simulation work before the contract has been formally awarded. This initial amount of simulation ensures our customers that we are able to solve their particular design problem. The thermal spreadsheet template also provides our Applications Department a starting point for new designs and saves time in the quoting process.

Geometry used in very early simulation work may turn out to be quite different from what mechanical requirements will later dictate. Frequently, the enclosure space is dictated by mechanical constraints that are not fully defined at the quoting stage. This is because numerous system features such as I/O connections, cabling and air plenum allotment may not yet be determined at this early stage of development. After the results of a preliminary thermal simulation indicate that the customer requirements can be met, the mechanical design process begins. There are often several iterations back and forth between the design engineering and thermal engineering teams to reach a final solution. One design aspect that demands this level of attention is fin optimization. FloTHERM makes it quick and easy to optimize for pitch, thickness, number of fins or base thickness. Each product we design is fully customized so there is very little opportunity for design reuse. For example, the cooling wall (our heatsink) geometry is designed for each particular application to ensure the best design at the lowest cost for each product. While the final solution may be similar to the starting point in the thermal design, it is never exactly the same. Although the time and cost saved by eliminating early prototypes, testing, evaluation and redesign is hard to measure, when delivery schedules are as tight any and all time savings are crucial to our customer's success.

Another key to successful design is a team that works extremely well together. Curtiss-Wright's Littleton facility is staffed with a group of talented mechanical engineers who all work in sync to meet the end goal, which is to deliver a high quality product to our customers every time.

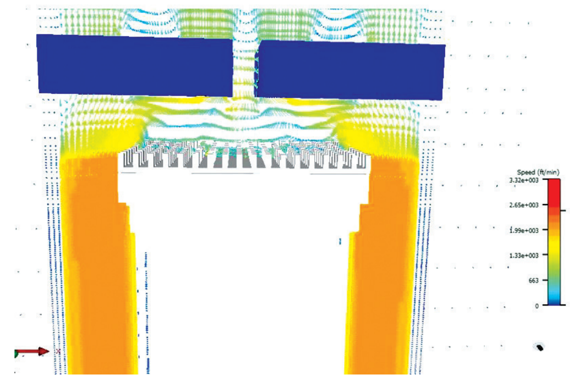


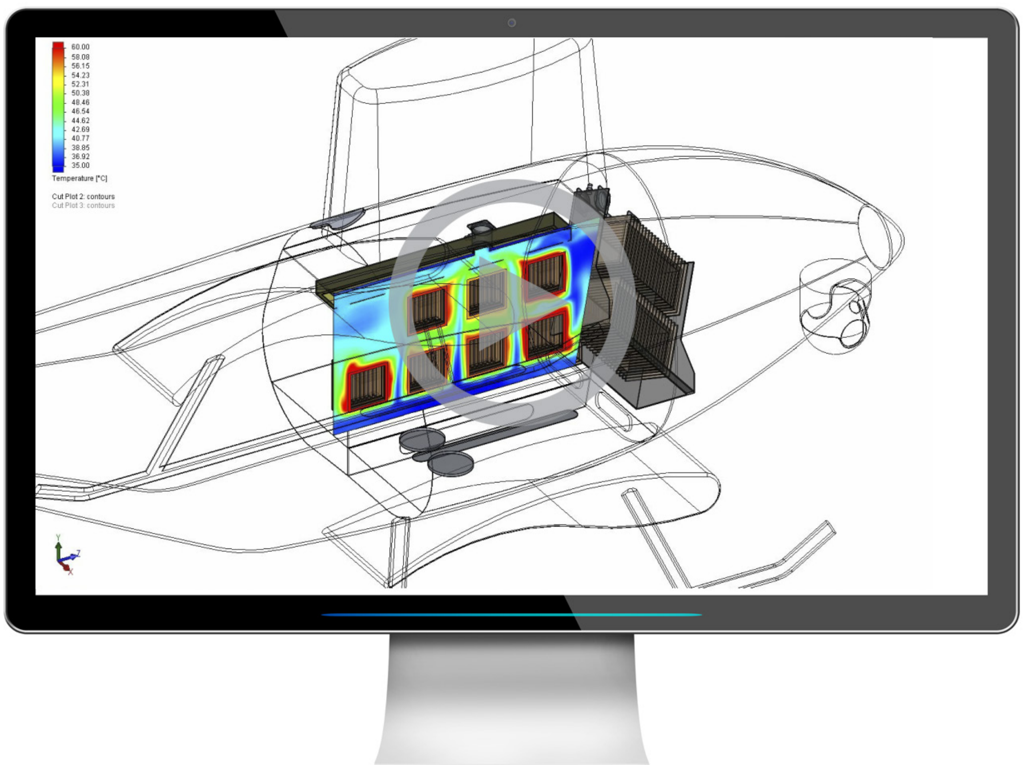
Figure 3 Air flow profile of 1300W enclosure, showing power supply fins and system fans

About Curtiss-Wright Controls Defense Solutions

Curtiss-Wright Controls Defense Solutions (CWCDS) is a long established technology leader in the development of rugged electronic modules and systems for defense applications. CWCDS serves as a technology and integration partner to its customers, providing a full range of advanced, highly engineered solutions from modular open systems approaches to fully custom optimized solutions. Our unmatched capabilities and product breadth span from industry standard based COTS modules to complete electronic subsystems. The company's modules and systems are currently deployed in a wide range of demanding defense & aerospace applications including C4ISR systems, unmanned subsystems, mission computing, fire control, turret stabilization, and recording & storage solutions. Additionally, the company's broad engineering capabilities combine systems, software, electrical, and mechanical design expertise with comprehensive program management and a broad range of life-cycle support services. For more information visit www.cwcdefense.com.

An Investigation into UAV Avionics Cooling Using FloEFD

By Boris Marovic, Technical Manager FloEFD Products, Mentor Graphics
and Matt Milne, Application Engineer, Mentor Graphics



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