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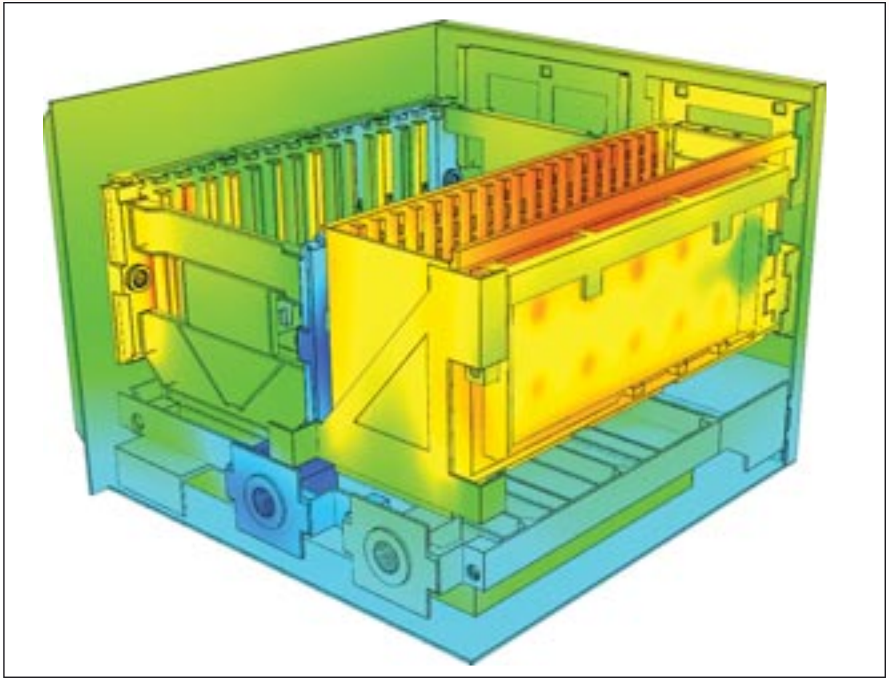
# Solving the Challenge of Thermal Design in Aerospace Electronics

The aerospace sector places some uniquely challenging demands on electronics designers. For a start, the environments that the electronics are exposed to are much harsher than in almost every other scenario. Moreover, the life expectancy of the products is much higher, while the accepted failure rate is easily an order of magnitude lower than typical commercial products.

The need for bulletproof reliability is absolutely critical and cannot be overstated. With defense products, there are no simple recalls or Return Merchandise Authorization (RMA) processes. You cannot "reboot your system to clear issues" in mid-mission on a missile guidance system. Product failures in the aerospace sector always have catastrophic consequences far beyond losing market share, as might be the case with a consumer electronics device.

Combining the demand for extremely high reliability with the constant need for higher power and smaller footprints results in thermal design taking on extra importance compared to other industries. Aerospace products are high-power-density, tightly packed, highly engineered products that are exposed to very harsh environments. At the same time, designers must work with limited cooling resources. They must find clever ways of dissipating heat away from the critical components.

Simply put, thermal design and heat removal are the most critical aspects of aerospace electronics design; there is no way around it. The question for designers is finding the right tools to deal with these challenges in the most efficient way possible without sacrificing performance or size in the final products.



Thermal design was the main driver of this chassis design - nearly 3kW had to be dissipated for the electronics to function reliably.

## Finding the Right Tools

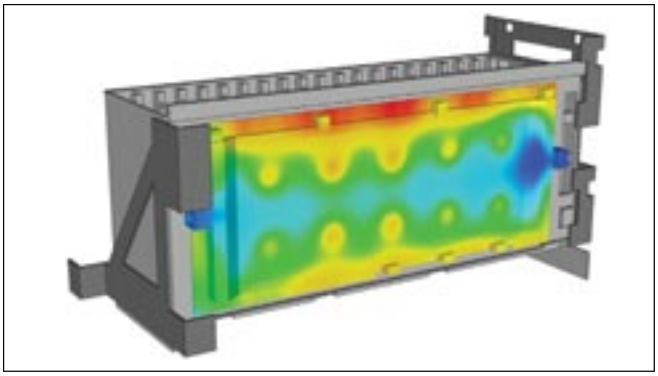
The key design tools used in thermal analysis are CFD (computational fluid dynamics) and CHT (conjugate heat transfer).

CHT techniques are used to describe heat transfer from solids to fluid (air/gas or liquid) moving past the solid, whereas CFD primarily deals with the motion of the fluid (gas or liquid). As fluids get warmer or colder, their properties change. Ignoring these temperature changes would lead to significant inaccuracies in a design. While both techniques can be used in isolation, coupling both CFD and CHT ensures that all the physics are modelled properly to give accurate results.

While there are a number of general-purpose CFD and CHT tools on the market, these exhibit significant limitations when it comes to detailed thermal design and simulation work. This can pose significant problems for aerospace electronics designers. The key issue with these general-purpose tools is that creating suitably accurate simulation models can be extremely difficult and time-consuming – in particular because of the complex geometries often involved in aerospace products.

At its heart, thermal simulation is a numerical process. As such it is necessary to discretize the continuous 3D space of a given model into small connected volumes (grid cells) which collectively represent the whole space. The physics of fluid flow and heat transfer are 'solved' for each of these small volumes, with each grid cell including the influences of its neighboring cells. In this way, a complete simulation of the whole 3D space is built up.

However, with general purpose CFD and CHT tools the process of model



TEN TECH created a multi-fluid model of the cold plate – simultaneously simulating the fluid flow in the cold plate and the air flow around the rest of the system

and grid/mesh creation can quickly absorb significant amounts of time. These tools typically employ tetrahedral or polyhedral 'gridding' techniques. This means that rather than breaking down the 3D model into 'Cartesian' (six-sided cuboid) cells they use four-sided pyramid-like (tetrahedral) or multi-sided, rounded (polyhedral) cells. Whilst this technique can accurately represent the large-scale geometries of aerospace products, when dealing with the small details and specifics of electronics enclosures, the meshing tools can fall down. The variation of scale means these 'grid generators' need to create a large amount of elements to be able to transition smoothly within the fluid volume. This is inefficient and can lead to inaccurate results and long solve times.

This creates additional problems for designers, particularly when working from conceptual design to a finished product. This usually requires the creation or re-creation of multiple models of different fidelity throughout the design process rather than being able to increase the level of abstraction (e.g. boards and components modelling) on the fly.

Aside from the need for more automated modelling and gridding, the ability to automatically model physics such as altitude corrections, heat radiation and multi-fluid (e.g. liquid cooling) is another critical capability that aerospace designers need that can be challenging to model using general-purpose tools. So rather than 'make do' with general-purpose tools, aerospace designers need to take advantage of more specialized thermal design and simulation tools.

### Case Study: TEN TECH LLC

TEN TECH provides design and analysis support for embedded aerospace and defence aviation electronics systems such as single board computers, RF & microwave components as well as complete rugged chassis and subsystems for avionics, flight data recorders, guidance & navigation, radar processing, electronic warfare and C4ISR applications.

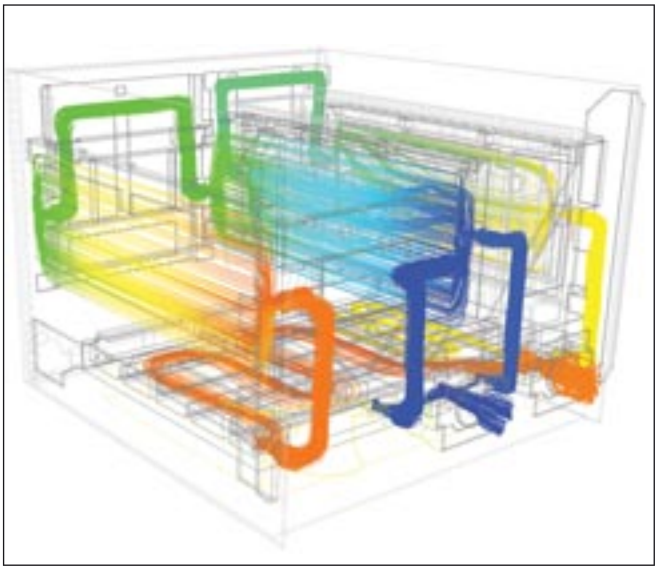
TEN TECH was tasked with helping in the design of a liquid-cooled airborne radar processing chassis. This was a very high-powered, high ambient temperature design and had no cooling mechanism other than the liquid cooling loop. Indeed, thermal design was the main driver of the system. A little under 3kW had to be dissipated out to the (already hot) environment for the electronics to be able to reliably function.

This was a significant design challenge. To solve it TEN TECH used 6SigmaET – a dedicated thermal simulation tool – throughout the design process.

TEN TECH started with the design of one of the cold plates in the system. These cold plates house the liquid cooling system whereby a cold liquid is injected through cold plates. This liquid 'takes away' the heat from the electronic components as it is moving through the chassis. However, the initial thermal analysis of the cold plates predicted that the cooling requirements were not going to be met with the preliminary design.

The cold plate design also had to account for 'resistance' in the liquid cooling system, most easily seen as a pressure drop between inlet and outlet. The system pumping fluid through the cold plate is working against the internal 'resistance' of the flow channels. If the system resistance (pressure drop) is greater than the pump can handle, then there is no liquid circulation which creates 'pockets' of heat that are not transferred away from critical areas, resulting in overheating.

CFD analysis using the 6SigmaET thermal simulation software allowed TEN TECH to better understand the flow and focus the design to maximize cooling and minimize pressure drop. TEN TECH was able to quickly create a multi-fluid model



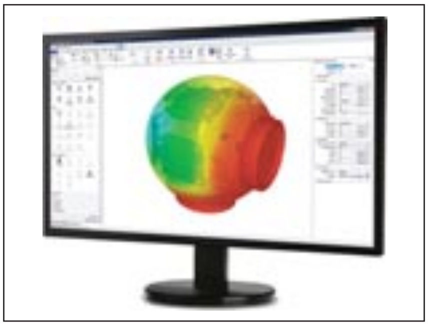
The design of the liquid cooling system had to minimize resistance to avoid creating 'pockets' of heat that would result in overheating of the cold plate – where the fluid flow in the cold plate could be simulated simultaneously with the air flow around the rest of the system.

While the liquid cooling system provided most of the cooling in this design, it was important for designers to understand the contribution of 'free convection' - i.e. the natural air flow around the device - to the cooling as well. Both air and the fluid can carry heat away from the hot components. Liquids are much more efficient as the rate of heat transfer depends on the fluid density and specific heat as well as the flow speed; at the same flow speed water, for example, is over 4000x more efficient than air. In military applications, jet fuel or polyalphaolefin (PAO) are used, which provide similar order of magnitude efficiency gains to water but also have favorable dielectric properties. This understanding enabled TEN TECH to optimize the cooling channels to obtain a good compromise between heat dissipation and pressure drop through the cold plate.

Once this stage was complete TEN TECH moved on to understanding the liquid cooling of the entire system. This larger chassis included over 25 high-power single board computers (SBC) and 5 cold plates of various complexities. TEN TECH had to ensure that the entire chassis was properly cooled, the liquid loop would function correctly and each of the single board computers would be within its temperature requirements.

This was a challenging model due to the added complexity of being multi-fluid with liquid cooling cavities, and in total encompassed around 40 million simulation grid cells that form the basis of the CFD and CHT analysis – a large design for a piece of aerospace equipment which are more typically 15-20 million grid cells (although some designs can require as many as 195 million cells).

TEN TECH had performed some initial liquid cooling analysis on the cold plates using general purpose CFD tools. However, this required separate manual gridding of the solid parts as well as air and liquid cavities (which the team also had to create geometry for). Even this initial analysis involved 4-6 hours of problem set-up



Using 6SigmaET's software, TEN TECH was able to shorten simulation solve times by 50% and deliver the final project in three weeks instead of the estimated six.

and two and a half hours of solve time. TEN TECH quickly realized that analyzing the complete chassis with general purpose CFD tools would be very difficult - not only in terms of labor, but also in terms of their ability to deliver results quickly to the customer.

In comparison TEN TECH was able to conduct the cold plate analysis in just one hour with 6SigmaET. Overall TEN TECH was able to shorten solve times by 50%, both through the efficiency of the software itself, and because of the fact that the software seamlessly plugs into Rescale's high performance computing cloud clusters. Rescale is a secure, high performance cloud computing platform that allows electronics engineers to offload complex CFD simulation to cloud-based servers on demand, drastically reducing simulation times without the need for expensive on-site hardware.

This significant time saving meant that, critically, TEN TECH was able to use 6SigmaET to easily simulate several different mission scenarios, corresponding to different altitude, ambient temperature and liquid cooling pump inlet temperature and pressure permutations. TEN TECH was also able to explore more design alternatives and improve upon the original design. This effort, which was originally estimated at six weeks, was delivered in just over three weeks, with more information provided to improve the design.

This meant a labor cost saving for the customer in excess of $25,000. There was also a significant cost saving from using thermal analysis to predict performance instead of building a prototype. Given that the initial cold plate design would have provided insufficient cooling, it would have resulted in a test failure, which would have certainly cost in excess of $50,000 in prototype building, test set-up and program delay.

## Conclusion

Through the use of thermal simulation, TEN TECH was able to make significant savings that would not have been possible with general purpose CFD tools. Indeed, this example clearly highlights both the overall importance of thermal design in the aerospace sector and the value that more specialized design and simulation tools can deliver to electronics designers.

Where the demands for reliability and performance are high there is no way to shortcut the design process – designers need the right tools for the job if they are to complete projects efficiently, accurately and safely.

*This article was written by Tom Gregory, Product Manager, 6SigmaET, Future Facilities Inc. (San Jose, CA). For more information, visit* ***http://info.hotims.com/69507-503****.*