Military+Aerospace Electronics

Enabling Next-Gen Missile Defense with Advanced Thermal Architectures

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KEY TAKEAWAYS

- Evolving thermal challenges in defense systems require advanced solutions.
- Advanced thermal management and composites overcome thermal challenges.
- ACT enables emerging trends in next-generation systems.

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OVERVIEW

Thermal management has become a defining challenge in next-generation defense and aerospace systems. Military defense technologies such as missile neutralization, phased arrays, and advanced detection systems generate significant heat loads and often need to operate in harsh dynamic environments—traditional cooling methods are no longer sufficient.

Advanced thermal architectures, including liquid cooling, advanced heat pipes, and integrated system designs, are becoming essential enablers of modern high-power defense systems.

Advanced Cooling Technologies (ACT) is a thermal management company supporting a broad range of industries, including space, data centers, aerospace, defense, and energy. ACT develops thermal solutions for both terrestrial and space-based applications, including a range of cutting-edge thermal management solutions to balance cooling performance with SWaP (size, weight, and power) constraints and enable the next generation of defense platforms in the most demanding operational conditions.

CONTEXT

The presenters discussed thermal challenges in defense systems and highlighted effective solutions.

KEY TAKEAWAYS

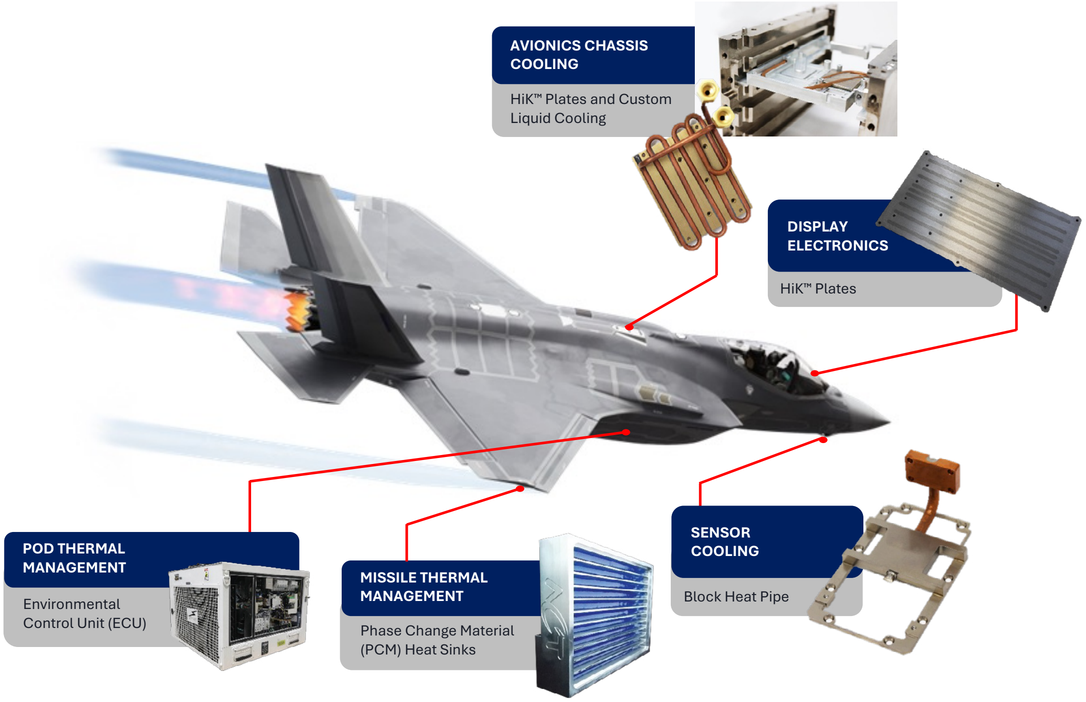
Evolving thermal challenges in defense systems require advanced solutions.

Modern missile defense systems comprise multiple interconnected subsystems, including incoming threat detection, tracking and targeting, system coordination and communication, and threat elimination systems. Each of these subsystems requires unique thermal management technologies to ensure high performance while maintaining low SWaP.

SWaP is especially limited in missile and interceptor platforms, aircraft, and hypersonic vehicles, where internal volume is extremely constrained.

At the same time, modern electronics require increasingly higher power density. In some applications, heat fluxes can reach 40 W/cm². While low power density applications can leverage conduction cooling throughout the aircraft

Figure 1: Modern defense systems have highly constrained SWaP



skin, this method is usually not effective for high power densities, as there is not enough mass available to store energy and maintain temperature.

Neither is conduction cooling sufficient for most extended mission profiles, as thermal soak becomes a challenge that traditional approaches struggle to overcome.

On-board pumped fluid loops can provide additional cooling capacity, but are not suitable for low SWaP applications, as they require pumps, hoses, and fluid that add SWaP. Hypersonic systems create even more severe thermal challenges, as they experience extreme aerodynamic heating, reducing the effectiveness of skin cooling.

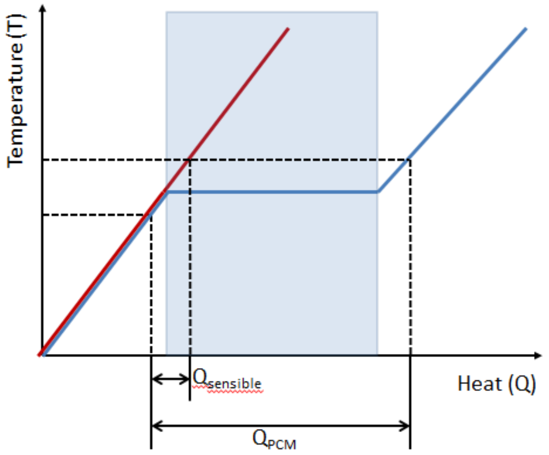
Advanced thermal management and composites overcome thermal challenges.

For modern defense systems, a more advanced solution is necessary to overcome thermal challenges. ACT offers several useful thermal management technologies:

Phase change material (PCM) heat sinks

PCM heat sinks absorb thermal energy during the solid-to-liquid transition to maintain sustainable operating temperature ranges for components. PCM heat sinks use latent heat of fusion to store the thermal energy being applied to them over the melt range of the PCM, which flattens the temperature rise to extend operational time of the devices being cooled.

Figure 2: During PCM phase transition, heat is absorbed with minimal temperature rise



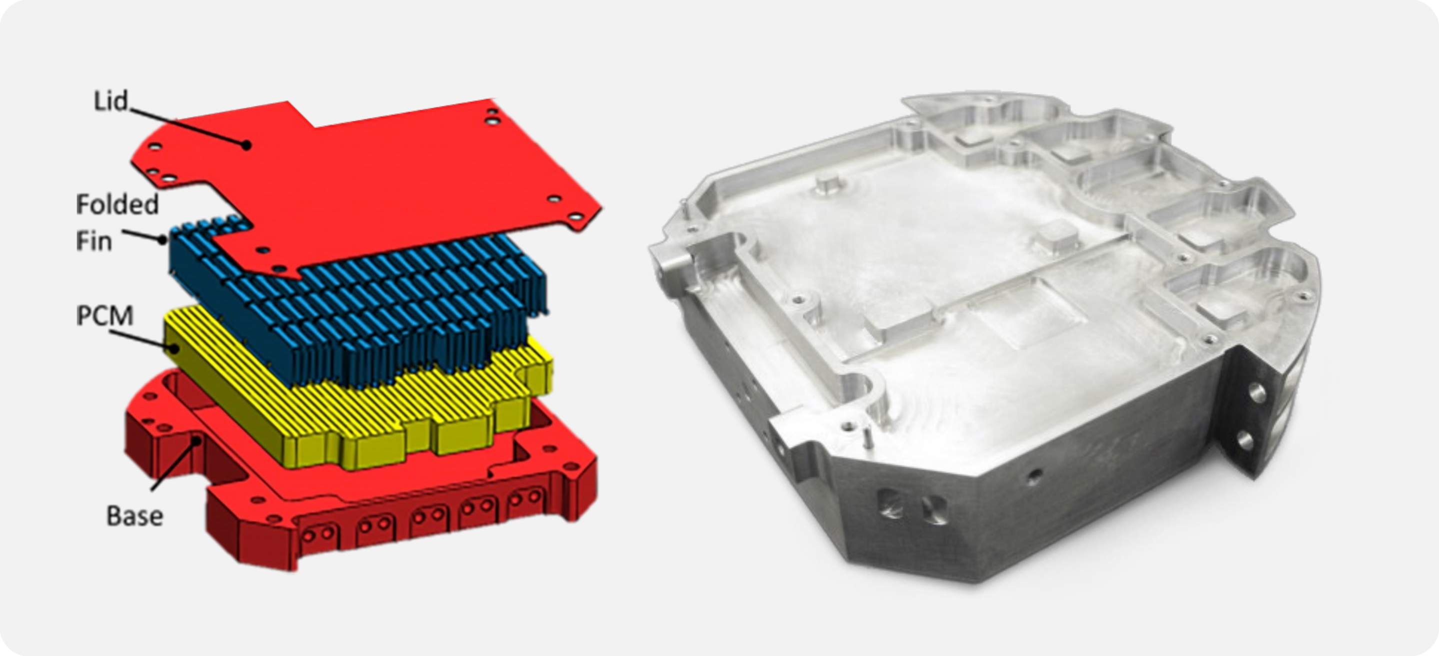
There are three main categories of PCM materials with melting temperatures in the 0-100°C range:

- **Hydrated salts** are the highest-performance material, with high latent heat and density. However, they require nucleating agents to help with refreezing the PCM and can experience separation over time, resulting in melt temperature changes and reduced performance. Hydrated salts also pose corrosion risk when used with common materials.
- **Metallics** are solder-like alloys, offering good volumetric thermal capacity due to their high density; however, their low latent heat limits selection to few options within a tight melt temperature range.
- **Paraffins** are the most used PCMs due to their high latent heat and stability throughout the product life. Paraffins are tunable to the application—adding to or subtracting from the hydrocarbon chain length changes the melt temperature by 3-5°C. Paraffins have low thermal conductivity, though, often requiring additional components (e.g., fins, foam, heat pipes) to improve heat transfer.

PCM heat sinks are best suited for transient thermal spikes, where active or other cooling is unavailable or incapable of handling a high transient load.

ACT packages PCM into custom-designed aluminum enclosures that fit within tight spaces; however, PCM storage capacity is proportional to PCM volume—longer missions or higher power loads require larger PCM heat sinks, which can conflict with SWaP constraints.

Figure 3: PCMs manage transient thermal loads with passive thermal storage



Vapor venting heat sinks

Like PCM heat sinks, vapor venting heat sinks use a phase change to absorb heat, but instead of solid-to-liquid, vapor venting heat sinks use the liquid-to-vapor transition. Because there is a much greater density delta in liquid-to-vapor, the vapor must be vented—not stored—using a controlled method.

Venting to the outside enables the liquid to be directly pumped onto the evaporator surface, lowering the conduction gradient between heat source and cooling media to significantly increase cooling capacity. Vapor venting heat sinks can also use remote reservoirs to increase liquid storage.

Rather than a metal enclosure holding the PCM, vapor venting systems require coolant reservoirs, pressure regulators, valves, evaporators, and venting orifices. While more complex, vapor venting systems offer improved performance and compactness over PCMs, making them especially attractive in missile applications where a traditional liquid cooling system is too heavy or large.

Advanced heat pipe assemblies

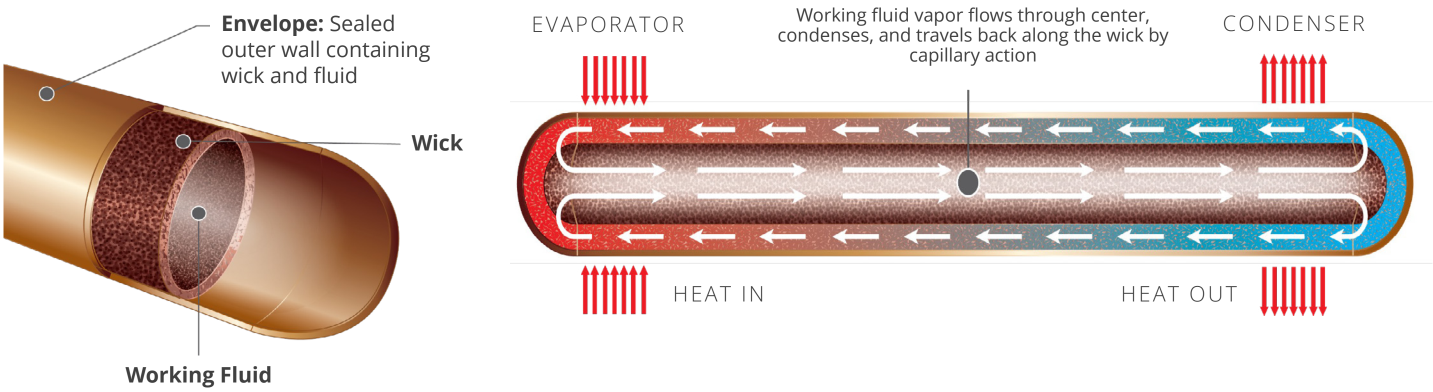
Heat pipes are a passive two-phase heat transfer device operating in a closed system. A heat pipe comprises a sealed metal envelope containing a wick material and working fluid (typically water). When heat is applied at one end, the liquid evaporates. The vapor travels from the evaporator end to the condenser section, where it is condensed back into liquid, which is pulled back toward the evaporator through the wick by gravity or capillary force. This cycle enables heat pipes to achieve extremely high effective thermal conductivity with minimal temperature difference (i.e., 2-5°C) across the pipe.

With no moving parts, heat pipes are one of the most reliable passive thermal technologies, and they are used in such a wide variety of different applications that ACT sells them as standalone products with additional expert integration services.

Two advanced heat pipe technologies enable additional capabilities:

- **Thermal switch** is a bellows-style heat pipe capable of turning conductance on or off, depending on temperature.
- **Diode heat pipes** have a reservoir with a secondary wick structure that is disconnected from the primary wick structure, allowing heat to flow in one direction while preventing reverse heat transfer into interceptors or other electronics.

Figure 4: Heat pipe basics



> “We have a lot of engineering capability for custom heat pipes, custom geometries, and custom assemblies. We can flatten these heat pipes, for example . . . we can get complex with bends, thin profiles, and even multiple evaporator layouts, [and] we have . . . different kinds of coatings, helicoils, machining processes, and gasketing available.”
>
> – *Larry Bradley, Advanced Cooling Technologies*

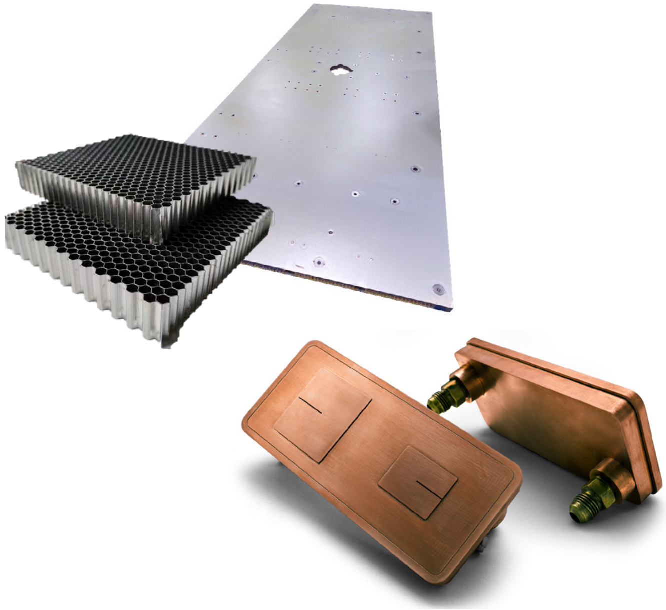
Advanced cold plates and composites

Cold plates have been widely used in the defense industry for generations, and ACT continues to advance cold plate technology to reduce SWaP.

A recent innovation through ACT’s composites group integrates liquid cooling into a lightweight composite structure, combining structural support and thermal management into a single component to substantially reduce system weight compared to traditional cold plates.

These composite cold plates integrate honeycomb or machine ISO grid structures to allow for custom routing of the fluid underneath. Face sheets made of carbon fiber or other high-strength materials create strength and rigidity for high heat flux applications.

Figure 5: Advanced cold plates



ACT also offers microchannel cold plates—a technology borrowed from the data center industry—which can accommodate heat fluxes over 250 W/cm², using either single- or two-phase cooling loops.

Advances in 3D printing expand cold plate architectures to include advanced options such as complex geometries, integrated fin structures, and topology-optimized fins.

ACT enables emerging trends in next-generation systems.

The best thermal architecture depends heavily on mission duration, heat load, available volume, environmental conditions, and platform constraints. Involving partners such as ACT early in program development is crucial to ensuring an optimal design.

> "By allowing ACT insight into the overall cooling environment and constraints, we can match the thermal architecture to the mission profile, instead of selecting a one-size-fits-all approach that might not be optimized for the whole system."
>
> – *Greg Hoeschele, Advanced Cooling Technologies*

As a longtime industry leader, ACT also provides robust support for emerging trends in missile radomes, nose cones, and hypersonic structures that require highly complex parts that simultaneously provide structural support, thermal protection, and aerodynamic shaping while also meeting SWaP and performance targets.

ADDITIONAL INFORMATION

To learn more, visit Advanced Cooling Technologies

BIOGRAPHIES

Greg Hoeschele
Manager, Passive Product
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Greg Hoeschele is the Manager of ACT's Passive Product Development Group, where he leads design strategy and serves as the primary engineering contact for advanced thermal management solutions. He has supported numerous high-profile defense missions, overseeing terrestrial defense programs and guiding critical design decisions.

Greg holds a B.S. in Mechanical Engineering from Lafayette College and a Master's degree in Mechanical Engineering from Cornell University.

Larry Bradley
Sales Engineer
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Larry Bradley is an ACT Sales Engineer responsible for the Great Lakes, Midwest, and Southern regions. He comes from ACT's Research and Development team, where his research focused on the development of additively manufactured thermal management systems. Additional research focused on sensing technologies and functional materials. He holds a Master of Science in Mechanical Engineering from Pennsylvania State University.