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» Whitepaper «

Advanced Thermal Management Solutions Cover Broad Mil-Aero Requirements

Choosing Design Options Requires Skill, Real-World Expertise and a Critical Focus on Data Points Relevant to Application and Environment

Part Two of Two

Advanced Thermal Management Solutions Cover Broad Mil-Aero Requirements

Choosing Design Options Requires Skill, Real-World Expertise and a Critical Focus on Data Points Relevant to Application and Environment

The modernized battlefield is characterized by a range of extreme applications featuring ever-increasing computational performance and communication bandwidths, resulting in greater than ever thermal challenges. For designers and packaging engineers, ensuring high availability and high reliability performance calls for effectively addressing the significant power densities generated at the board, chassis and system levels for each of these designs. Recognizing that thermal management is a critical element of mil/aero design, Kontron has developed a two-part white paper series as a resource to support designers. This series was developed to provide an increased understanding of thermal management issues, design options and technologies, and how they are implemented in real-world, rugged computing scenarios. Kontron's thermal design resource materials outline essential thermal management methodologies including the range of conduction and convection design options. Part One describes primary thermal technologies and their specific features and benefits in great detail; it can be accessed at the Kontron web site literature library or downloaded (LINK) here. This paper is Part Two of the series, and follows with additional useful information through specific application examples, illustrating how thermal design choices meet the computing challenges of specific military program applications.

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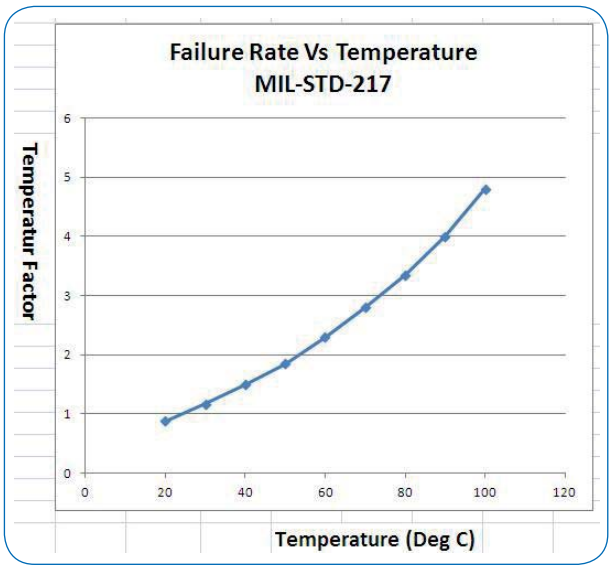
To set the stage for the information presented in Part Two of the series on thermal management, the following is a brief summary of the content provided in the first paper. Higher performing processors, smaller system footprints and the evolution of extremely rugged environments continue to challenge military designers. Application evolution is constant, as troops and command centers are effectively armed with a flexible mix of mobile networked technologies and systems focused on sharing real-time information and transferring risk from soldiers to machines. UAVs, for example, have evolved considerably since the singular days of large surveillance drones such as Predator and Global Hawk; today soldiers also rely on a range of small UAVs, challenging packaging engineers to further address systems significantly constrained by SWaP.

For designers of these systems, using COTS-based solutions is essential to meeting military needs quickly and with a sustainable, long-term approach. Standards-based solutions have become even more critical as the SWaP protocol has transitioned into SWaP-C (Size, Weight, Power and Cooling). Standards-based solutions are providing the building blocks for semi- and full-custom systems, yet designers must further understand the related role of various thermal management methodologies in order to maximize system performance and the benefits of COTS design.

Proven cooling methodologies include a range of conduction and convection options, each with specific advantages and limitations that are further defined by the application environment itself. Designers must evaluate key environmental parameters such as altitude, ambient temperature and required power dissipation in order to make optimal thermal design choices early in the development process. Further, real-world expertise is essential to solving these complex thermal challenges, allowing a technical approach based on proven and validated legacy enclosures.



As Temperature increase reliability decreases. For example, the failure Rate, p, of a resistor is: p = bϖTϖPϖSϖQϖE where ϖT is the temperature factor multiplier for the overall failure rate. From this example we can see that increasing the temperature from 20°C to 40°C results in a failure rate increase of about 1.7. Mechanical failure can occur from differential thermal expansion and fatigue from thermal cycling

Applying Thermal Methodologies to Real-World Designs

Power Dissipation VS Cooling Method

Option	Performance (Watts per inch of Pitch) *depending on ambient conditions
Conduction Cooled – Passive Convection (no fan)	25
Conduction Cooling – Cold Plate	50
Conduction Cooled – Air Blown through chassis side walls (Fan or plenum)	75
Convection Cooling – Air blown (fan or plenum air)	100
Conduction cooled – Liquid Cooled through chassis side walls	125
Conduction Cooled – Liquid flow through modules	500
Spray Cooling – direct impingement on IC's	700

The modern military's ongoing transition from Future Combat Systems to Brigade Combat Team (BCT) modernization is fueling the need for highly integrated embedded designs that leverage mobility, security, bandwidth and reliability in networked systems.
As a result, military computing represents a range of diverse applications, each with significantly different physical demands yet sharing a common requirement for rugged reliability. Man wearable computers, vetronics, shipboard, UAV and other airborne settings, command and control, imaging, and more challenge designers to understand how environmental conditions impact advantages and limitations of various platforms. For example, thermal management schemes for aircraft and satellites must be as light as possible, and meet aggressive parameters for SWaP. Thermal management of aviation systems must ensure extreme reliability, while accommodating limited weight and physical space – particularly since mission capability is often the key objective for military aircraft. Naval applications must effectively manage corrosive aspects of ocean environments while dissipating potentially excessive heat loads. Dust or other airborne contaminants may limit a system's ability to blow ambient air across its electronics.

The cooling effectiveness of four essential methodologies is listed in increasing cooling effectiveness below, with natural convection being the lowest and liquid through sidewalls the highest. Empirical test results show the following temperature change associated with 75 Watts total power dissipation and a board edge temperature of 75°C:

Cooling Technique	Temperature rise
Natural Convection	32°C
Base-plate (0oC base-plate)	10°C
Forced Air (40 CFM)	10°C
Liquid Flow Through	5°C

The thermal design approach that has proven most effective over time is to implement all of the required system functionality in a chassis that has already been certified for ruggedized operation and is not simply listed as "designed to meet." For example, selecting a chassis that is manufactured to meet the requirements of MIL-E-5400 Class 1 thermal performance, MIL-901D shock, MIL-STD-810F vibration, etc., assures the designer that it can withstand specified extremes of temperature, vibration, shock, salt spray, sand and chemical exposure, while maintaining a sealed and temperature-controlled environment for the computing elements and electronics inside.

The following application examples will highlight specific implementations of cooling solution, chosen based on key data points such altitude, ambient temperature and power dissipation requirements – and also considered within the framework of application-specific requirements and physical constraints such as SWaP, form factor, shock and vibration and exposure to airborne contaminants.

Forced Convection – Airborne Application

Airborne applications may use a fan-based thermal scheme, or forced convection, although this depends significantly on the altitude and implementation of the system. For example unmanned systems typically fly with unpressurized equipment bays at high altitudes and so forced convection is often inadequate for cooling modern high powered processors. Higher altitude, unpressurized systems perform with reduced air density and the resulting lack of sufficient airflow prohibits the effective use of fans; however some aircraft systems operate within more benign pressurized environments that are very effectively managed with forced convection. Using this cooling method, heat can be dissipated by moving air in direct contact with system boards and components. This assumes that space, cost and noise are not critical design issues and that SWaP parameters provide allowances for high altitude fans.

One such manned aircraft implementation used the Kontron FS-1290 forced air convection system, a 9U ruggedized VME/cPCI enclosure designed for 6U VME/cPCI boards with an optional peripheral carrier. The Kontron FS-1290 was integrated into the P-3C Orion Maritime Reconnaissance Aircraft, an anti-submarine and maritime surveillance aircraft with proven longevity and performance. Introduced in the 1960s, the P-3C is one of a handful of manned aircraft that has delivered decades of continuous military service based on ongoing upgrades to avionics systems and mission equipment. In a series of updates, the U.S. Navy implemented a number of major improvements to the P-3C including aircraft communication, navigation, acoustic, non-acoustic and ordnance/weapon systems – each intended to keep pace with new and evolving multi-mission requirements. The FS-1290 was implemented onboard the P-3C as STORES management, upgrading the critical system that controls automatic ordnance release.

The FS-1290 is a forced air 9U ruggedized VME/cPCI enclosure designed for 6U VME/cPCI boards with an optional peripheral carrier - available in 10 or 12 slots.

In determining the ideal thermal management approach, altitude for this manned aircraft was established to be within requirements for acceptable airflow over system components. The maximum ambient temperature inside the pressurized cabin storing the ordnance control system is 55°C; this represents the craft flying at a relatively low altitude on a hot day, in general, the normal ambient air temperature should be less than 45°C. Power dissipation for the ordnance release system needed to be in the range of 100 Watts per board.

The Kontron FS-1290 provides flexibility in a standardized system, as the peripheral carrier is removable and mounts in the card cage; the number of slots ranges from 10 up to 18 and allows designers to carefully evaluate bandwidth and performance against very specific SWaP requirements. FS-1290 meets MIL-S-901 in an isolated rack with front loading access, as well as MIL-STD-810 and MIL-STD-167 demands for shock and vibration specifications for severe environments such as those common onboard the Orion. Three internal fans cool the card cage, drawing air from front to rear through an inlet positioned in the front door of the chassis. Air is routed up through the VME/

cPCI card cage, around the power supplies and ultimately exhausted through the upper rear of the enclosure. Fans are mounted on a removable tray for simplified maintenance, an advantage for systems integrated into the complex physical layout of an aircraft.

The average slot airflow achieved is 500 LFM (linear feet per minute) ensuring proper cooling by limiting the system to a 9.7 degree rise in temperature. Forced convection implemented into Orion's ordnance control system presents an ideal choice over a liquid system due to lower weight, lower MTBF, easier maintenance and avoiding risk of leakage into sensitive, mission-critical electronics installed in the aircraft.

Conduction Paired with Passive Convection – Unmanned Airborne Application

Cooling electronics at extremely high altitudes requires an even more detailed analysis of environmental conditions than a sea level implementation. Vented or unpressurized bays represent additional variations that impact design choices – a UAV solution operating at 60,000 feet has dramatically different operational parameters than a similar system incorporated into a pressurized cockpit cabin of a transport plane or jet. For example, at extreme altitudes, there is a limited amount of air available for cooling. The air density at 20,000 feet is roughly half that at sea level. However, ambient air temperature also decreases with altitude which can compensate for the lower air density in terms of cooling efficiencies. Some mil/aero applications may be able to use forced air or forced convection (using internal or external high altitude fans) but must make alternate choices based on SWaP and overall environmental conditions. This in turn applies to many UAV implementations, which frequently must incorporate conduction cooling methodologies, with or without fan assist.

Air moving through a conduction design never touches system components; conduction systems instead transfer heat energy through direct contact of the heat generating components to the system enclosure itself. Boards, power supplies and other components are sealed in an airtight enclosure and mechanically clamped to the enclosure's structure to create a cooling path. The Kontron high-performance embedded computer COBALT (Computer Brick Alternative) illustrates versatile module-based design in this category. The Kontron COBALT is a fanless, fully enclosed design for efficient thermal management in a small 6.5 x 9.725 x 2.95-inch form factor – providing designers with a small-footprint, low-power, cost-saving option in a sealed system. Its weight is less than 5.5 pounds. Designers have a range of flexible options and can scale computing performance based on specific application requirements, i.e., from a very low power Intel Atom processor-based implementation to a powerful Intel Core2 Duo processor system. Operating temperatures range from -20°C to +55°C (Core2Duo) and -40°C to +71°C (Atom), compatible to the full spectrum of ground vehicle, UAV, airborne or shipborne requirements. Based on small form factor Computer-on-Modules (COMs), COBALT is ideally suited to reduce SWaP (Size, Weight and Power) concerns where the number of processors and amount of system I/O is in the low to mid-range. Further, a cost-efficient, no-backplane design is highly reliable, enabling a small, low-profile box-level system that effectively meets the military's SWaP requirements.

COBALT is a fanless, fully enclosed highly scalable embedded computer system that is available with a wide selection of processor, storage, power and interface options.

Conduction Paired with Forced Air – Avionics Application

An avionics or mission computer frequently requires small form factor enclosures for 3U VME, VPX or CompactPCI platforms. As for all small form factor applications the key parameters are altitude, ambient temperature and total power dissipation. For these applications, the Kontron FS-5985 chassis was designed to provide a forced air, conduction cooled enclosure that is small in size, low in weight and capable of dissipating up to 200 Watts of system power. System heat is conducted to sidewall heat exchangers; chassis walls are hollow and air is blown through sidewalls for dissipation to the ambient environment by forced air cooling. To achieve this, the FS-5985 includes a high efficiency AC or DC fan, or optionally an air-plenum for use with an external forced air supply. In addition to meeting the cooling needs defined by the primary environmental parameters of these types of avionics application, the FS-5985's I/O is easily customizable. Designers have access to a versatile wiring scheme via internal Meritec, 2 mm hard metric, and five wire wafers. Further, a rigid-flex circuit can be integrated for higher volume applications, resulting in increased reliability and reduced cost.

The Kontron FS-5985 allows packaging designers to load system boards and the power supply from the rear of the

The FS-5985 is a 3U 5-slot 1/2 ATR Conduction Cooled Chassis design for small form factor applications where altitude, ambient temperature and total power dissipation are key parameters.

chassis by removing the rear fan assembly. This assembly is a single integrated unit incorporating a blind-mate power connector so the end user only has to remove the attachment screws and not worry about struggling with power wires. The fan receives its power directly from the input power connector and therefore is not a part of the 200 watt thermal capability of the unit. For cPCI systems, one system slot is supported as well as four spare slots for additional I/O and peripherals. The VPX version also has five system slots incorporating a centralized backplane for use with an Ethernet switch. Designed to adapt to existing ½ ATR ARINC 400 style equipment mounting trays, the FS-5985 is also configurable to a range of application-driven mounting options, including hard mount or shock mount; this provides designers significantly greater flexibility in working with the physical constraints of the avionics system environment.

For avionics systems that have more physical space, the Kontron FS-5955 may be implemented as a 1-short ATR forced-air conduction cooled chassis, offering up to 8 system slots for increased thermal capability. Given similar data points to the FS-5985 example, the FS-5955 enables cooling up to 100 Watts per board depending upon fan configuration and ambient conditions. Similar to other conduction cooled designs the FS-5955 uses wedge locks which are mounted to card edges enabling efficient heat conduction to the sidewalls as well as securing the cards from shock and vibration. The rear fan assembly is designed for easy customization to add additional fans if necessary for high altitude or higher power applications. The FS-5955 directs air from the front to the rear of the enclosure through finned heat exchangers in the hollow sidewalls. Internal conduction paths transmit the heat loads from the card edges to the internal walls whereby the heat is transferred to the forced air and then exhausted out the rear of the chassis. Fans are mounted to an integral rear plenum which is sealed off from all other internal components, with no direct impingement of the cooling air on the internal parts or circuitry.

Designers must consider that choices made regarding the layout and interior arrangement of heat generating system cards (upstream to the cooling airflow) and power supplies (downstream to the cooling airflow) may dramatically impact the effective heat dissipation capabilities on critical system cards. Further, mission requirements may dictate specific cooling and mounting options of components within a chassis. Packaging engineers may need to go beyond mounting systems within standard racks or into ARINC style equipment trays, considering options that incorporate custom hard mounting or shock mounting for avionics platforms.

Packaging Systems for Evolving Military Technology Initiatives

Military technology initiatives occasionally drive existing platforms to migrate to other platforms. Although hardware and software modifications may be required to adapt to new platforms, configurable rugged enclosures frequently allow key design elements to remain unchanged. In many cases the enclosure structure, including backplane and power supplies, can remain unchanged when boardsets or I/O subsystems are replaced to accommodate increased requirements in processing, storage or interface capability.

The Kontron FS-5975 illustrates this type of evolution, with several highly successful and high profile implementations demonstrating its flexibility in various mil/aero environments. The FS-5975 is a ½ ATR forced air conduction cooled chassis developed specifically for avionics applications and based on MIL-STD-5400 Class 1 environmental requirements. Its standard configuration accommodates up to 157 general purpose I/O signal connections, and its I/O mapping is easily configured using backplane wire wrap. The FS-5975 has been adapted and packaged for multiple different airframe platforms, first for

The Kontron FS-5975 is a 1/2–short ATR forced-air conduction cooled chassis designed to meet the environmental requirements of MIL-E-5400 for Class 1 equipment and will withstand extremes of temperature, vibration, shock, salt spray, sand and chemical exposure while maintaining a sealed environment.

the Predator UAV and then the H60 helicopter – two vastly different applications that required modifying the enclosure design with careful consideration to SWaP, unique thermal characteristics and key data points, shock and vibration, EMI and routing of I/O.

For Predator, the FS-5975 houses the computer control components for the Multi-Spectral Targeting System (MTS) optical ball, protecting system components within a sealed environment. Sand, dust, salt fog, humidity and water spray are prevented from entering the chassis in accordance with MIL-STD-108E. The FS-5975 enabled Predator's MTS sensor to provide real time imagery selectable between Infrared (IR) and Day TV and the ability to laser designate the enemy for attack. The FS-5975 system was configured to perform under the rugged high altitude environments of modern unmanned airborne vehicles. For the H60, additional shock and extreme vibration characteristics were considered as the priority environmental characteristic.

Conduction Paired with Cold Plate – Vetronics Application

Following a path of increasing sophistication and multi-mission functionality similar to UAVs, vehicle electronics have evolved significantly in military environments. Controlling functions such as navigation, communications and weapons, today's vehicle-based systems require high reliability solutions that combine effective use of power, bandwidth and performance. Highly integrated systems make the best use of limited onboard physical space, a trend likely to continue with the growing complexity of ground mobile missions and onboard vehicle applications. For designers, an added challenge has resulted from the mandate to armor all tactical vehicles; this increase in overall weight has reduced the weight budget of onboard systems and sharpened the focus on compact, lightweight systems.

Altitude considerations, although less important for ground vehicles, are still important since military ground operations often occur in mountainous environments. Ambient temperatures however are still of paramount concern. For example, a vehicle intended for deployment in the heat of desert environments at middle latitudes must take into account being subjected to extreme temperatures up to 60°C as a routine performance guideline.

Using guidance, targeting and control systems on board ground mobile tanks as an implementation example, designers may pair a conduction-based solution with a cold plate for effective heat transfer. An ideal example for this type of implementation is a composite wheeled, ground mobile vehicle. Extreme ambient temperatures may still require performance similar to MIL-STD 5400 Class 1 thermal performance, incorporating equipment designed to withstand extremes of temperature, vibration, shock, salt spray, sand and chemical exposure while maintaining a sealed environment.

The Kontron FS-5977 is a cold plate design, offering five 6U slots and is capable of maintaining the clean, dry environment so essential to rugged military environments. Ideal for vetronics applications that demand a fanless, thermally efficient solution, the FS-5977 maintains a sealed, dry environment while exposed or even immersed in fluid environments. Hard-mounted to a cold plate, the FS-5977's base structure matches the physical component outlines defined in the ARINC 404A specification for a ½ ATR short box solution. By strengthening enclosure side walls with side gussets that extend beyond the ½ ATR footprint, designers can hard-mount the cooling plate. This approach eliminates the conventional shock tray as well as integrated air cooling. Heat is transferred to a conductive base plate, which can be either actively or passively cooled depending on physical parameters of the vetronics application.

The Kontron FS-5977 is a 5-slot conduction- cooled chassis for military applications. It is capable of maintaining a sealed, dry air environment, while subject to typical Vetronic immersion and exposure to fluids environments.

Manufacturer Expertise

Understanding the scope and complexity of effective thermal management is essential to designers building mission critical mil/aero systems. Dealing with advanced calculations and interpreting environmental impact on electronics represent a large part of the design process – these issues must be skillfully handled early in the design process in order to ensure proper choices regarding platform, layout, enclosures and thermal methodologies. Designers must evaluate their own design constraints in not only making these calculations, but also relying on them as the foundation for their design. At the same time, designers must intelligently build in the most appropriate features for long-term, rugged deployment poised to manage ever-increasing performance requirements.

As a result of this complex design environment, time and development budgets may be best managed by leveraging thermal expertise at the manufacturer level. Real world

expertise of fielding conduction cooled systems based on VME, VPX and CompactPCI provides a wealth of performance validation – this is particularly useful in managing design risk and time-to-market for new or updated applications in ground and airborne implementations.

Testing and validation of systems is essential, and sophisticated thermal modeling tools are critical assets to the mil/aero designer. System functionality must be verified in the integration lab before it can be packaged for platform use. Thermal modeling tools such as FLOTHERM achieve this by means of advanced CFD (computational fluid dynamic) evaluation techniques, enabling engineers to accurately predict airflow, temperature distribution and heat transfer in components, boards and complete systems. Virtual design models can be created using mathematical modeling, allowing thermal performance to be fully analyzed, tested and modified prior to putting equipment prototypes into production. This three-dimensional evaluation of airflow and temperature distribution avoids costly design issues – validating temperature thresholds and guarding against over-design. For instance, solving heat conduction, convection and radiation in three dimensions proves thermal effectiveness on a case-by-case basis, showing engineers the distribution of temperature isotherms or verifying the extent to which temperature levels are alleviated by a heatsink placed on top of a specific component. It is only after this process is completed satisfactorily that prototypes are built using materials and assembly processes that mimic the final product. Further evaluations at this point includes real-world testing of thermal cycling, shock and vibration, EMI and ESD based on the specifics of the deployed environment. To ensure actual performance, testing standards such as MIK-STD-810 are performed while the device is operating.

Long term availability of systems and supporting components is an ongoing challenge for mil/aero design, with systems deployed for extended periods of time. Kontron manages this through strategic alliances and partnerships that ensure long term access to components and support designs well beyond a typical manufacturing partner relationship. As a key supplier of Intel-based products and a Premier Member of the Intel® Embedded and Communications Alliance, Kontron offers designers unmatched engineer-to-engineer knowledge and design expertise, and supports extended product lifecycles of seven to 10 years. Further, Kontron's acquisition of AP Labs has created a unique powerhouse of military and aerospace electronics design. The breadth of Kontron's own product offerings spans form factors, platforms and rugged applications – and is now bolstered with the sophisticated packaging expertise proven through AP Labs long history of deployed mil/aero solutions. New technologies are quickly and seamlessly integrated into all board and system-level products, and all customers have ready access to Kontron's extensive mil/aero design and manufacturing expertise. By maintaining a flexible production mix, Kontron incorporates its own manufacturing along with contracted manufacturing to ensure business continuity through custom design, thermal modeling and product development processes.

Solving Thermal Challenges with COTS-Based Design

Today's thermal challenges in military applications have grown significantly and require proper cooling techniques for long system life and reliability. Myriad extreme combat environments demand higher performance and bandwidth than ever before. In turn, designers and packaging engineers must determine the most appropriate thermal solutions based on key data points as well as the influences of critical environmental conditions. Options range from COTS, semi- or full custom, and must take into account the specific application as well as the development timeline and budget. It is important not only to have an intimate knowledge of the methodologies and solutions available but also to work with a reliable manufacturer with a high level of expertise and real-world experience to build a successful design that meets or exceeds initial system goals.

About Kontron

Kontron is a global leader in embedded computing technology. With more than 30% of its employees in Research and Development, Kontron creates many of the standards that drive the world's embedded computing platforms. Kontron's product longevity, local engineering and support, and value-added services, helps create a sustainable and viable embedded solution for OEMs and system integrators. Kontron works closely with its customers on their embedded application-ready platforms and custom solutions, enabling them to focus on their core competencies. The result is an accelerated time-to-market, reduced total-cost-of-ownership and an improved overall application with leading-edge, highly-reliable embedded technology.

Kontron is listed on the German TecDAX stock exchange under the symbol "KBC". For more information, please visit: **www.kontron.com**

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