

EMBEDDED SYSTEMS DESIGN GUIDE

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OPTIMIZE YOUR EMBEDDED SYSTEMS WITH
MODULAR COTS SOLUTIONS ENGINEERED
FOR PERFORMANCE & RAPID INTEGRATION.



Embedded Solutions
SMARTER BY DESIGN®



MILLED VS. EXTRUDED ALUMINUM ENCLOSURES: WHICH IS BEST FOR YOUR RUGGED EMBEDDED COMPUTER?

When designing enclosures for rugged embedded computers, the choice between milled and extruded aluminum designs significantly impacts performance, durability, cost, and functionality. Each method offers unique advantages and disadvantages, making them suited to different applications. Understanding these differences is key to selecting the right solution.

This chapter delves into the pros and cons of milled versus extruded enclosures, their costs, and optimal use cases, and highlights how ADL Embedded Solutions can help you choose the perfect enclosure for your needs.

MILLED ENCLOSURES: PRECISION AND STRENGTH IN ONE PACKAGE

Milled enclosures are crafted from solid blocks of metal, often aluminum, through CNC machining, a process that delivers exceptional precision and design flexibility. These enclosures are prized for their tight tolerances and ability to accommodate complex, intricate geometries. For applications where every micron matters, such as aerospace, military, and industrial systems, milling provides unmatched reliability.

A key strength of milled enclosures is their structural integrity. Being machined from a single, seamless block of material, they lack joints or seams that could weaken the enclosure. This makes them incredibly durable and ideal for high-stress environments where reliability cannot be compromised. Moreover, the dense, uniform material provides better vibration damping, protecting sensitive electronics from shocks and harsh conditions.

Thermal management is another area where milled enclosures excel. The precision of CNC machining allows for integrating custom heat sinks, cooling channels, or other advanced thermal solutions directly into the enclosure. This feature ensures optimal performance even under extreme heat loads, making milled designs essential for high-performance embedded systems.

However, these benefits come at a cost. Milling is a time-intensive process that generates significant material waste, which drives up expenses. This method also involves longer lead times, making it less suitable for projects requiring rapid turnaround. Despite these drawbacks, the high level of customization and durability often outweighs the cost considerations for mission-critical applications.

EXTRUDED ALUMINUM CHASSIS: SIMPLICITY AND SPEED

Extruded aluminum chassis are produced by forcing heated aluminum through a die to create a uniform cross-sectional shape. This method is faster, more affordable, and generates less material waste compared to milling, making it a popular choice for high-volume production.

Extrusion works well for straightforward designs, particularly those with consistent shapes and wall thicknesses. These enclosures are lightweight, cost-effective, and highly repeatable, which makes them a staple in consumer electronics, basic industrial equipment, and transportation systems where weight and budget constraints are priorities.

However, the simplicity of extrusion comes with trade-offs. Extruded enclosures cannot match the precision or design complexity of milled alternatives. They struggle with complex geometries and may develop internal stress points during the manufacturing process. While suitable for simpler applications, they are less capable of withstanding the extreme conditions required by military-grade or heavy industrial environments.





KEY CONSIDERATIONS FOR SELECTING THE RIGHT ENCLOSURE

Application Requirements

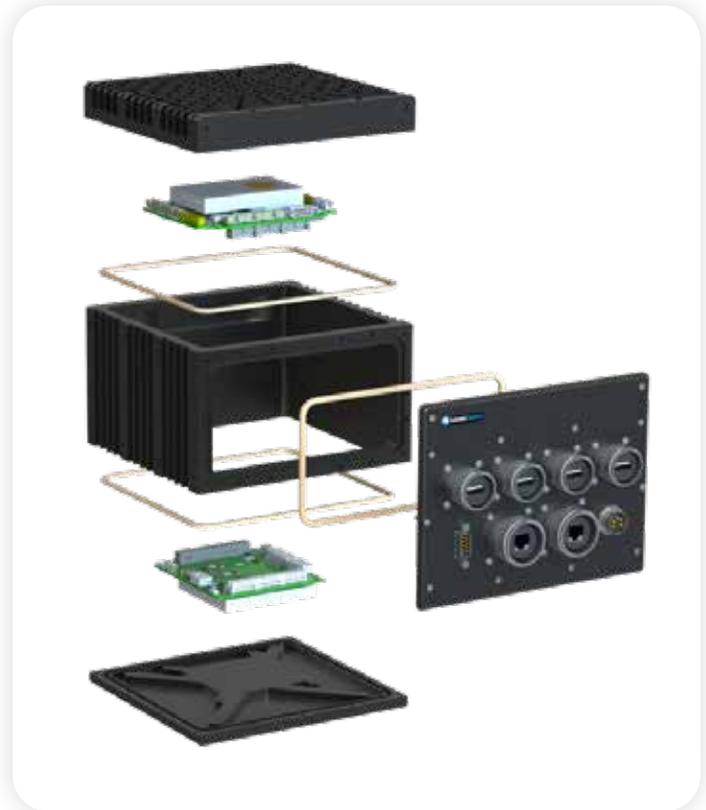
Milled enclosures excel in extreme conditions like aerospace and military applications, handling high temperatures, impacts, and vibrations. Their durability and vibration damping also make them ideal for industrial automation. In contrast, extruded enclosures are better for moderate environments, such as consumer electronics and standard industrial housings, where cost and consistent production are key.

Customization Needs

For intricate designs or non-standard shapes, milled enclosures are unmatched, allowing for features like custom cooling channels or tight-fitting components. Extruded designs work best for simpler, uniform shapes, and standard mechanical assemblies.

Production Volume

Extruded enclosures are cost-effective for high-volume projects like consumer electronics, while milled designs are better suited for low-volume, precision-focused applications, such as prototypes or specialized industrial equipment.



Thermal Management

Milled enclosures offer advanced thermal management with integrated cooling features, making them indispensable for high-performance systems. In contrast, extruded enclosures are ideal for moderate thermal requirements in less demanding environments, such as hospitals.

Weight Sensitivity

Extruded designs are lighter, ideal for portable or space-limited applications like transportation equipment where shock and vibration may not be a concern. Milled enclosures, though heavier, offer superior strength for rugged, stationary systems like industrial machinery or defense equipment or transportation applications where shock and vibration resilience are also important.

Choosing the right enclosure depends on balancing these factors with your project's specific needs.



BUILDING EMBEDDED SYSTEMS THAT THRIVE IN EXTREME CONDITIONS: A HOLISTIC DESIGN APPROACH

In environments where failure is not an option—battlefields, industrial automation, aerospace missions, and medical emergencies—embedded computing systems must deliver unwavering reliability. Whether operating in a desert combat zone, inside a high-vibration manufacturing plant, or on board an autonomous vehicle, these systems endure heat, cold, dust, shock, vibration, and electromagnetic interference (EMI) without compromise.

Designing such systems requires more than just selecting robust components—it demands a holistic approach that integrates hardware, power architecture, thermal management, mechanical structure, and system integration into a cohesive and resilient solution. This philosophy ensures that all design elements work in harmony to create embedded computers that perform in the harshest conditions.

1. STRATEGIC COMPONENT CHOICES: PRIORITIZING DURABILITY AND AVAILABILITY

The journey to reliability starts with components built to endure. Unlike consumer electronics with short-lived lifespans, industrial and defense systems demand parts that endure relentless conditions over long durations. Processors, memory units, capacitors, and connectors must withstand temperature extremes (-40°C to +85°C), resist mechanical strain, and sip power efficiently—especially in remote or mobile setups like Arctic sensors or desert-deployed military gear.

Long-term availability is equally vital. Industries like aerospace and defense require systems to remain operational for 5–10 years, necessitating components with extended production cycles. By selecting parts immune to rapid obsolescence, engineers sidestep supply chain disruptions and ensure system longevity.



2. POWER ARCHITECTURE: ENSURING STABILITY IN UNSTABLE ENVIRONMENTS

Voltage spikes, EMI, and unstable grids pose existential threats. Rugged systems embrace wide input voltage ranges (9V–36V DC) to adapt to erratic power sources in military vehicles or remote outposts. Redundant power pathways and fail-safe mechanisms keep mission-critical operations alive during primary source failures. Surge suppressors and isolation circuits act as electronic bodyguards, shielding sensitive components from lethal surges and noise.

Signal integrity can't be overlooked. High-speed interfaces like PCIe and Ethernet demand meticulous PCB layouts—controlled impedance routing, strategic grounding, and noise-dampening techniques—to preserve data fidelity in EMI-heavy settings like factory floors or combat zones.

3. MECHANICAL DESIGN & ENCLOSURE ENGINEERING: STRENGTH WITHOUT BULK

An enclosure is more than armor—it's a thermal manager, EMI shield, and structural backbone. Options range from milled aluminum for maximum toughness to extruded designs balancing cost and cooling efficiency. Ingress Protection (IP65-IP67) ratings seal out dust and moisture in offshore rigs or dusty battlefields, while MIL-STD-810G compliance ensures survival against shocks and vibrations in tanks or drones.

EMI shielding is non-negotiable in environments crowded with electronics—think aircraft or industrial hubs. Conductive gaskets, metallic coatings, and filtered vents form an invisible barrier, blocking interference that could cripple communications or control systems.



4. THERMAL MANAGEMENT: CONTROLLING HEAT IN ANY ENVIRONMENT

Thermal overload acts as a stealthy adversary, undermining efficiency and curtailing operational longevity if left unchecked. Crafting a resilient thermal strategy isn't optional—it's the lifeline for electronics tasked with enduring punishing environments.

In settings choked with particulates or moisture, non-mechanical cooling reigns supreme. Static thermal dissipation—leveraging heat sinks, vapor chambers, and enclosures engineered from conductive alloys—siphons heat away from critical components without relying on fragile fans. These sealed, maintenance-resistant designs thrive where traditional cooling would suffocate.

Yet, high-power systems demand more aggressive intervention. When passive methods hit their limits, dynamic solutions like liquid-cooled loops or precision airflow systems step in to tame thermal surges. Aerospace and defense applications, subjected to wild temperature swings from stratospheric cold to desert heat, often integrate conduction cooling (direct heat transfer via cold plates) or phase-change materials. These substances absorb and release thermal energy during state transitions, acting as buffers to stabilize core temperatures and safeguard performance.

By aligning thermal tactics with environmental demands, engineers transform heat from a silent destroyer into a managed variable—ensuring electronics survive and excel where others fail.



5. SYSTEM INTEGRATION: CONNECTING TO THE LARGER ECOSYSTEM

Rugged systems never operate in isolation; they must integrate seamlessly with external sensors, networks, and control systems. Compatibility with industrial communication protocols such as CAN bus, RS-232/485, Ethernet, Modbus, and PROFINET is often required for interfacing with automation systems, defense networks, or IoT applications.

Security is also a growing concern, particularly in military and industrial control applications. Features such as hardware-based security (TPM), secure boot, and encrypted communication help protect against cyber threats. Additionally, ensuring compatibility with custom OS configurations, real-time processing requirements, and industrial control software is essential for smooth operation.

6. COLLABORATION AND HOLISTIC DESIGN: ENSURING PRECISION AND PROJECT SUCCESS

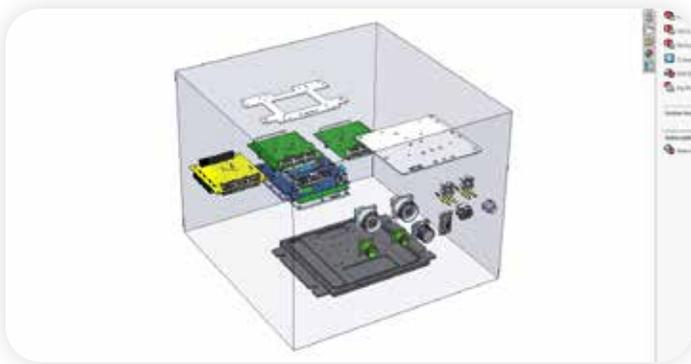
A holistic design approach thrives on collaboration among multidisciplinary teams, including hardware engineers, software developers, thermal specialists, system integrators, and customers. Achieving the exact design intent and meeting the design requirements without pitfalls requires seamless coordination throughout the development cycle, ensuring that every component, system, and integration aligns with performance and reliability goals.

By fostering collaboration early in the design phase, teams can proactively address potential challenges, such as component compatibility and availability, thermal constraints, or EMI mitigation. Clear communication and shared objectives help prevent costly redesigns, ensuring projects stay on schedule and meet mission-critical requirements. Engaging with customers throughout the process ensures that design decisions align with real-world operational needs, leading to a solution that is both technically sound and practically viable.



CUSTOMER CONSULTATION WITH ADL EMBEDDED SOLUTIONS

Every successful project begins with a thorough review and analysis of the system requirements in close consultation with the customer's development team. Together, a system concept is developed that accounts for the customer's system requirements and expectations, application use-scenario and long-term needs all while abiding by best design practices and the holistic design principles honed by ADLES over its long history of rugged, small form factor system design experience.



CONCEPT

ADL Embedded Solutions can help refine customer concepts to generate the critical design requirements that underpin quotes, options, and timelines.

ADL Embedded Solutions sales engineers are expert at guiding customers through the various options and cost considerations. This collaborative process is the key to developing workable solutions that meet both cost, technical and time constraints. Sometimes, an intervening "proof of concept (POC)" stage using critical hardware elements will follow concept development as means of validating the hardware functionality prior to initiating the full NRE design process.

DESIGN

Tools like Solidworks® 3D CAD design software not only aid in rapid development of enclosure and system concepts, but also make for efficient communication of design concepts with customers to minimize development time and time to market.



Once approved, Solidworks® 3D CAD design software also becomes the primary communication vehicle for documenting the system for customer SCDs (Source Control Drawings) as well as for follow-on manufacturing steps.

BUILD

Using our strong relationships with metalwork, milling, coating, and component vendors, ADL Embedded Solutions can make even the most complex system a reality. Typically, small quantity prototypes are built to review manufacturing quality and mechanical specifications. Fully integrated systems are built up to validate ease of integration by production personnel, confirm electrical specifications, and shipped to the end-customer for system verification testing as well as any specialty tests such as vibration or EMI compliance testing.





WHY HOLISTIC DESIGN MATTERS

Designing rugged embedded systems isn't just about adding protective layers—it's about engineering every element to work as a unified system. Power architecture, thermal management, mechanical durability, and electrical integrity must be optimized together, not as separate components, but as interdependent factors. Optimizing one without the others risks unraveling the entire system. By taking a holistic approach, engineers can build rugged embedded solutions that perform where others break down—ensuring reliability, efficiency, and longevity in mission-critical applications.

For those seeking embedded computing solutions built for the real world, ADL Solutions specializes in designing high-performance rugged systems engineered for extreme environments. ADL Solutions ensures that its computing platforms meet customer requirements while excelling in ruggedness, efficiency, and performance. Balancing component selection, mechanical and electrical considerations, thermal management, and EMI compliance is crucial for delivering reliable solutions in demanding environments.

HOW ADL EMBEDDED SOLUTIONS CAN HELP

ADL Embedded Solutions specializes in designing and delivering rugged embedded systems tailored to meet diverse industry needs. Whether you need the precision and durability of milled enclosures or the cost-efficiency of extruded designs, ADL Embedded Solutions offers expert guidance to ensure the best choice for your project.

By seamlessly integrating mechanical, thermal, and electronics design elements, our engineering team collaborates closely with clients to fully understand the unique requirements of their applications. We deliver tailored solutions that strike the perfect balance between performance, cost, and environmental resilience. From advanced thermal management designs to durable structural enhancements, we provide end-to-end support throughout the design and deployment process, ensuring

your systems perform reliably in even the most demanding conditions.

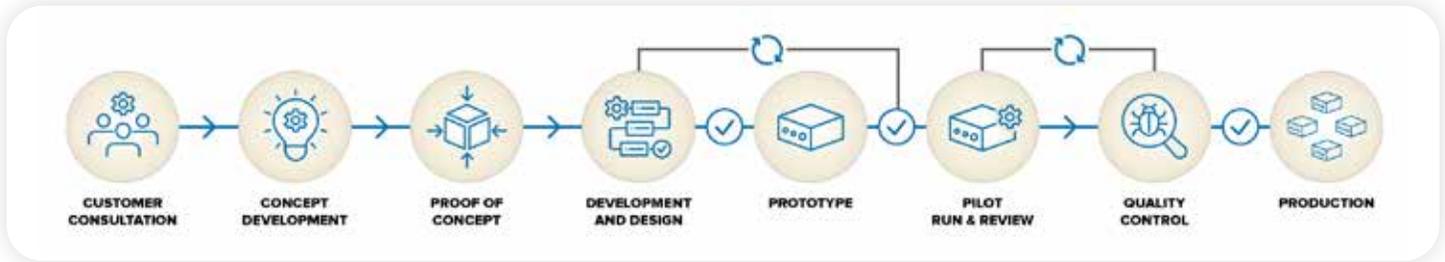
With a commitment to innovation and quality, ADL Embedded Solutions ensures that your rugged computing systems perform reliably, even in the most challenging environments.

Contact us today to explore how we can help you design the perfect enclosure for your application.

REQUEST A QUOTE



CUSTOM EMBEDDED SYSTEM DEVELOPMENT PROCESS



DEVELOPMENT CHECKLIST

Review and consider the questions below to help determine the scope and key factors that will drive the design.

	<p>APPLICATION DESCRIPTION: Briefly describe the system application and use-scenario:</p>
	<p>CPU REQUIREMENTS: What is the target CPU? E.g. Intel Core, Intel Atom, Nvidia Jetson Orin AGX/NX/Nano, etc.</p> <p>How much data storage is required?</p> <p>How much memory is required?</p>
	<p>LIST THE FRONT PANEL I/O REQUIRED: E.g. ethernet, USBs, GPIO, serial COM, special functions, etc.</p>
	<p>MECHANICAL CONSIDERATIONS:</p> <p>What is the maximum height, width, and depth available for the new system?</p> <p>What is the maximum weight allowable?</p> <p>Is there a minimum ingress protection (IP) rating required? E.g. IP65, IP67, etc.</p> <p>Can the system be bolted or mounted onto a larger metal structure such as a vehicle bulkhead or cooling plate?</p>



DEVELOPMENT CHECKLIST CONTINUED:

	<p>OPERATING TEMPERATURE:</p> <p>What is the expected ambient operating temperature that the system will be exposed to?</p> <p>Is there any air flow available?</p>
	<p>MIL-STD REQUIREMENTS:</p> <p>Is there a MIL-STD 810 requirement for shock and vibration?</p> <p>Is there a MIL-STD 461 requirement for electromagnetic emissions?</p> <p>Is there a MIL-STD 704 or MIL-STD 1275 requirement for power supply compliance for ground vehicle or avionics use?</p>
	<p>POWER CONSIDERATIONS:</p> <p>What is the input voltage?</p> <p>What is the maximum allowable power?</p>
	<p>ENVIRONMENTAL CONSIDERATIONS:</p> <p>Will the system be exposed to the environment? E.g. sun, rain, etc?</p> <p>Will the system operate in a salt/fog environment?</p> <p>Is high humidity a consideration?</p>

Contact us today to explore how we can help you design the perfect enclosure for your application.

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