Connectors Built for Extreme Environments

Aerospace and Defense Applications Demand Rugged, Reliable Connectors

By David Pike for Mouser Electronics

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MOUSER ELECTRONICS | AirBorn a molex company

The aerospace and defense (A&D) industry delivers platforms and equipment for some of the most demanding conditions on Earth and beyond. Mission-critical applications in such conditions create a significant engineering challenge. Electronics systems operating in extreme environments require connectors that deliver rugged and reliable performance.

However, the nature of A&D systems is changing. While environmental conditions remain challenging, operators are adopting new technologies to adapt to them. New methods of powering and moving vehicles are gaining popularity, and the A&D marketplace is seeing the growth of electrification in parallel with commercial and consumer vehicles. High-performance and edge computing are becoming essential tools for the modern soldier. Tactical computing, a defense adaptation of edge computing specifically designed for contested and resource-constrained environments, takes this one step further.

From ground vehicles and tactical aircraft to satellites operating in the vacuum of space, designers are integrating increasingly complex electronics into the latest A&D platforms (**Figure 1**). These systems must operate in unforgiving conditions, often autonomously, providing sensing, computing, and coordination capabilities.

Figure 1: *Intricate control systems in A&D applications are placing new demands on the electronics that power and move aircraft. (Source: Andrea Izzotti/stock.adobe.com)*

Central to these capabilities are the connections that link critical systems, delivering power, data, and signals where they are needed most. Connectors are among the few components directly exposed to the environment, making their ruggedness and reliability essential. When designing for A&D applications, engineers must select components that not only meet stringent standards but also prove dependable over their full operational lifespan.

An example of the critical nature of connectors can be found in the data networks of fourth-generation aircraft such as the F-16. Unlike previous aircraft, the pilot's controls are not physically connected to the control surfaces. Instead, the flight-control computer receives inputs from the pilot and converts them into electrical signals, which then activate the control surfaces.

This use of computers to direct flight enabled the concept of relaxed stability, in which the aircraft is deliberately unstable. This makes the aircraft highly responsive and capable of rapid maneuvers, but renders manual control impossible. The flight-control computer relies on sensors to detect changes in motion, attitude, and acceleration.

Connectors must reliably carry these sensor and control signals, despite the dynamic environments found in modern tactical aircraft. Even under shock, vibration, and extreme temperatures, control signals must reach the flight-control computer to ensure the safety of the aircraft and crew. Compliance with standards provides engineers with confidence that their systems will perform under pressure.

This article explores what "rugged" and "reliable" mean for A&D, examines how connector design addresses these challenges, and explains how Molex acquiring the AirBorn connector portfolio enhances its solutions for mission-critical A&D applications.

Defining Ruggedness and Reliability

Ruggedness and reliability are closely related terms for engineers. In industrial applications, they might even be used as synonyms, but in the A&D world, they have very specific meanings. These definitions are the result of decades of development and real-world experience. Applying these terms to connectors allows designers to clearly understand how they will perform in tough conditions.

Ruggedness

Rugged connectors are designed to function consistently, even under extreme conditions. A rugged connector must withstand clearly defined conditions:

- **Shock and vibration:** This includes exposure to sudden forces and long-term mechanical vibration, which are commonly found in armored vehicles, tactical aircraft, and missile applications.
- **Temperature extremes:** Defense equipment is expected to perform flawlessly, from the icy cold of the Arctic to the heat of the tropics. The operation of the equipment itself can cause temperature swings, requiring careful calculation of ambient temperatures.
- **Sealing and ingress protection:** As connectors are often mounted to the external parts of A&D equipment, they must resist the dirt, moisture, and other contaminants that could damage both the connector and the electronics within.

- **Corrosion resistance:** Many of the environments in which connectors are deployed can damage the connectors themselves. They must be designed to endure these conditions while maintaining performance.

Reliability

While ruggedness relates to performance conditions, reliability for an A&D design provides a measure of how a connector is expected to perform over time. Manufacturers and standards organizations can quantify a connector's ability to resist wear, oxidation, and fatigue. This ability allows the connector to maintain low electrical resistance and stable signal integrity even after years of service.

One of the key metrics of any connector is the mating cycle. A single mating cycle represents one complete operation, comprising the act of mating and then unmating the connector. Most manufacturers test their connectors and publish the expected number of mating cycles that they can withstand. Standards such as MIL-STD-1344 and AS9100 provide the essential details for creating reliability metrics, including corrosion exposure and life cycle testing.

Identifying Standards

Deciphering standards is complicated, and the A&D arena includes a wide range of potential applications that often must comply with military specifications (MIL-SPEC) standards and US National Aeronautics and Space Administration (NASA) standards. **Table 1** presents typical environmental hazards, possible applications, and relevant standards.

Contacts Are the Key

At the heart of every connector is the contact, which is the physical interface that must deliver low-resistance electrical conductivity, even when subjected to stress. More than any other component, the contact and how it interfaces with its mating counterpart determine a connector's performance and longevity. Achieving connector ruggedness and reliability is largely dependent on the geometry, materials, and plating of contacts.

Contact Geometry, Material Selection, and Plating

Contacts work in pairs. The geometry of an electrical contact refers to its shape and how it mates with its counterpart. This interface is critical for both electrical continuity and mechanical stability (**Figure 2**).

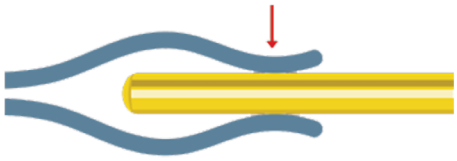

Figure 2: *Proper contact force maintains pressure and stability. (Source: Molex)*

Table 1: *Environmental hazards, typical aerospace and defense applications, and the relevant MIL-SPEC and NASA standards used to qualify connector performance.*

Environmental Hazard	Applications	Standards
Vibration resistance	Defense vehicles, aircraft, and helicopters	MIL-STD-202, MIL-STD-810
Shock resistance	Projectile launches, artillery, and emergency landings	MIL-STD-202, MIL-STD-810, MIL-STD-883, NASA-STD-7003
Temperature extremes	Ground-based platforms, satellites, and space systems	MIL-STD-202, MIL-STD-810, NASA-STD-5019, ECSS-S-ST-10-03C
Sealing and ingress protection	Tactical vehicles, front-line equipment, and soldier systems (i.e., wearable technology)	MIL-DTL-53513
Corrosion resistance	Marine and desert environments, resistance to automotive fluids	MIL-STD-202

Too little retaining force can result in an unreliable connection, especially when subjected to vibration. However, if too much force is generated, the mating process can damage the plating and impair performance. Therefore, designing the mating interface is a balance between maintaining mechanical stability and minimizing wear.

Material selection requires a careful balance of physical strength, conductivity, and corrosion resistance. Most contacts are manufactured from copper alloys, which provide excellent conductivity (**Figure 3**). In other applications, beryllium copper is often preferred due to its greater spring force.

However, these materials alone do not deliver all the required characteristics. Contacts are usually plated to guard against corrosion. Gold is the common plating option because it conducts well and does not oxidize. Its softness also reduces friction during mating, helping the connector last longer.

Military specifications clearly define the materials and plating required to ensure consistent performance. Connectors provide true reliability only when their contacts are engineered to meet these standards. With the right material choices and the right care, connectors can continue to perform as expected, even after thousands of mating cycles.

The Whole Connector

Although contacts define electrical performance, the rest of the connector can't be overlooked. From the housing that shields against impact to the latch that resists vibration, each feature is engineered to keep the system working in harsh environments.

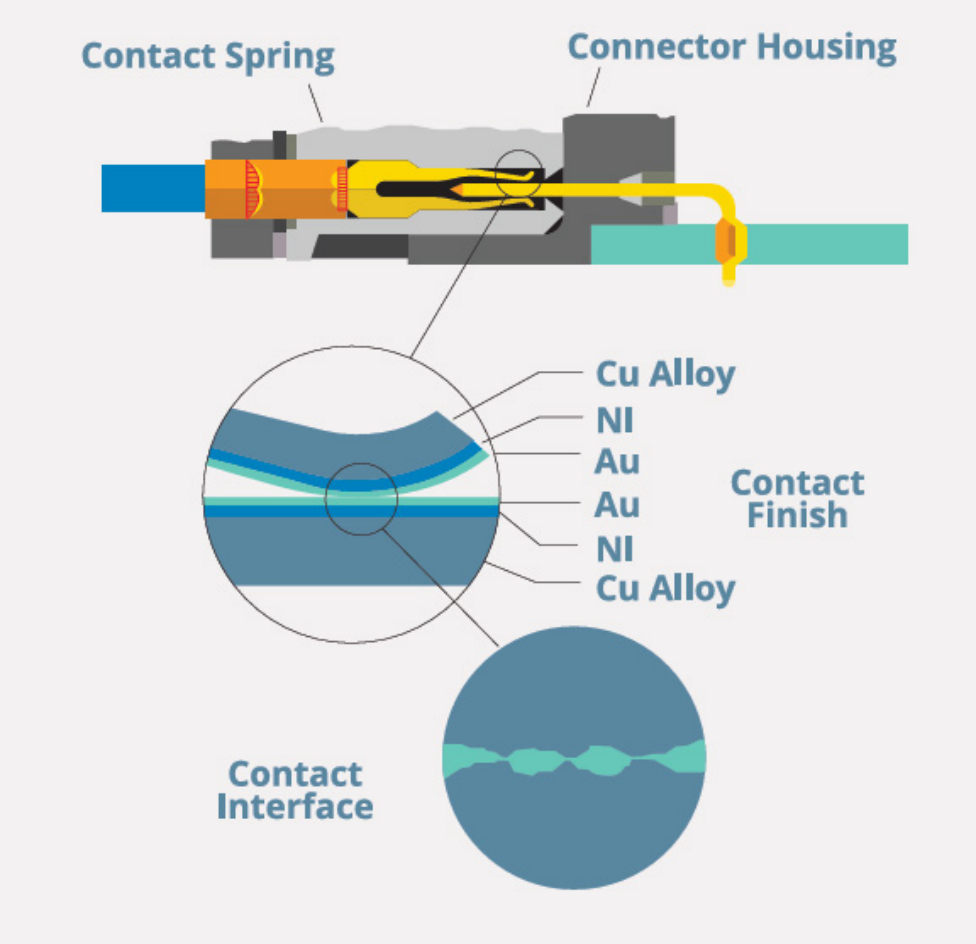

Figure 3: *Connector contacts use layered materials, often including copper alloy, to balance strength, elasticity, and long-term signal integrity. (Source: Molex)*

Housings

The outer housing of a connector provides mechanical strength and environmental protection for the components inside. As with contacts, material choice plays a significant role in connector performance, and engineers will typically choose between polymer and metal housings.

- **Polymer housings**: The high-performance polymers used in rugged connectors are strong and light. Weight savings are critical in aerospace, ground, and naval applications. Polymers resist corrosion, but long-term exposure to sunlight can weaken some materials.
- **Metal housings**: Metal connector housings are conductive, delivering excellent shielding against electromagnetic interference (EMI). While they are also strong, they may require surface treatment to protect them against environmental effects, especially those of salt water.

Connectors designed for use in satellite and space applications face specific challenges. The vacuum of space exposes components directly to harsh radiation, so the materials used for connector housings must include radiation stability. Space-rated connectors use polymers and metals certified to standards such as NASA ASTM-E595 and EEE-INST-002, ensuring reliability in extreme space environments.

Latching and Sealing

The manner in which connectors mate and lock in place determines their resistance to shock and vibration. MIL-STD-202 defines many of the requirements that connectors must meet. Latches need to securely lock connectors in the mated position, while remaining low profile and field friendly. Seals, including O-rings, gaskets, and grommets, must prevent the ingress of dust, moisture, and other contaminants.

The International Electrotechnical Commission (IEC) has developed two-digit ingress protection (IP) ratings (**Figure 4**), which are used to define a device's environmental sealing performance. Many A&D systems require IP67-rated connectors to ensure that water and dust cannot compromise performance, while devices intended for immersion require IP68. Most connectors are sealed only in the mated condition; unmated connectors require protective caps to maintain their sealing integrity. To deliver the required IP rating, latching and sealing systems work together, ensuring that connectors are protected against the environment.

Molex has decades of experience in delivering connector solutions for A&D applications. The addition of the AirBorn connector portfolio strengthens the company's ability to deliver high-performance solutions that meet MIL-SPEC standards, supporting environmentally demanding mission-critical designs.

Ingress Protection (IP) Ratings Guide

Solid Foreign Object Protection	
0	No protection
1	Protected against solid foreign objects of 50mm ⌀ and greater
2	Protected against solid foreign objects of 12.5mm ⌀ and greater
3	Protected against solid foreign objects of 2.5mm ⌀ and greater
4	Protected against solid foreign objects of 1.0mm ⌀ and greater
5	Dust protected
6	Dust tight

Water Ingress Protection	
0	No protection
1	Protected against vertically falling water drops
2	Protected against vertically falling water drops when enclosure tilted up to 15°
3	Protected against spraying water
4	Protected against splashing water
5	Protected against water jets
6	Protected against powerful water jets
7	Protected against temporary water immersion
8	Protected against complete water submersion
9	Protected against high-pressure and high-temperature water

Figure 4: *The IP ratings guide grades a device's resistance to dust and liquids. (Source: Mouser Electronics)*

Standards-Based Performance

AirBorn connectors are engineered and tested against stringent MIL-SPEC requirements. One of the key standards relevant to AirBorn is MIL-C-55302, which defines the dimensional, material, and boards. Compliance with standards such as these gives engineers confidence that the connectors they choose will perform reliably, even under demanding conditions.

AirBorn Connector Series

AirBorn connectors have a long track record for delivering robust construction and compliance with key standards. The portfolio includes four product series that are optimized for A&D applications:

- W Series 0.100" Rectangular Connectors: Designed for board-to-board and cable-to-board applications, the W Series Connectors are MIL-DTL-55302 qualified and deliver proven reliability in tough environments.
- M Series Micro-D Connectors: These widely used products meet or exceed MIL-DTL-83513 performance and offer compact, high-density solutions that are well-suited for applications where high signal integrity is essential.
- N Series Nano-D Connectors: The N Series meets or exceeds MIL-DTL-32139 performance specifications, offering secure connections for harsh environment cabling through its rugged housings and high-quality contacts.
- R Series 0.075" Rectangular Connectors: Engineered for high reliability to meet MIL-DTL-55302 specifications, R Series connectors offer high density in a small footprint for space-constrained A&D applications.

These series comprise the core of the AirBorn portfolio, addressing a wide array of needs across A&D applications, from avionics to satellite systems.

Secure Supply Chains

For engineers working in the A&D industries, product capabilities are only part of the picture. Engineers must be confident that the materials used in connectors are also manufactured to the same high standards. Full traceability allows engineers to identify every element of the products they have selected, from raw materials to the finished product.

Molex and Mouser Electronics offer full traceability for AirBorn connectors. Engineers can purchase these products with the assurance that every component complies with requirements.

Conclusion

Designing connectors for aerospace and defense requires both anticipating environmental challenges and ensuring electrical performance. Standards define what ruggedness and reliability mean in practice, allowing engineers to carefully match products to the demands of their environment.

Ruggedness in connectors comes from engineering every part with the environment in mind. Contacts, housings, and latching systems are all designed with the stresses of aerospace and defense applications in view.

Molex acquiring the AirBorn connector portfolio enhances its ability to serve this critical market. By combining decades of engineering expertise with rigorous compliance to MIL-SPEC and NASA standards, AirBorn connectors deliver the ruggedness and reliability that A&D engineers demand.

As new technologies continue to transform A&D platforms, the need for dependable connections will only grow. With AirBorn connectors, Molex and Mouser deliver components designed to perform in the harshest environments and support mission success.