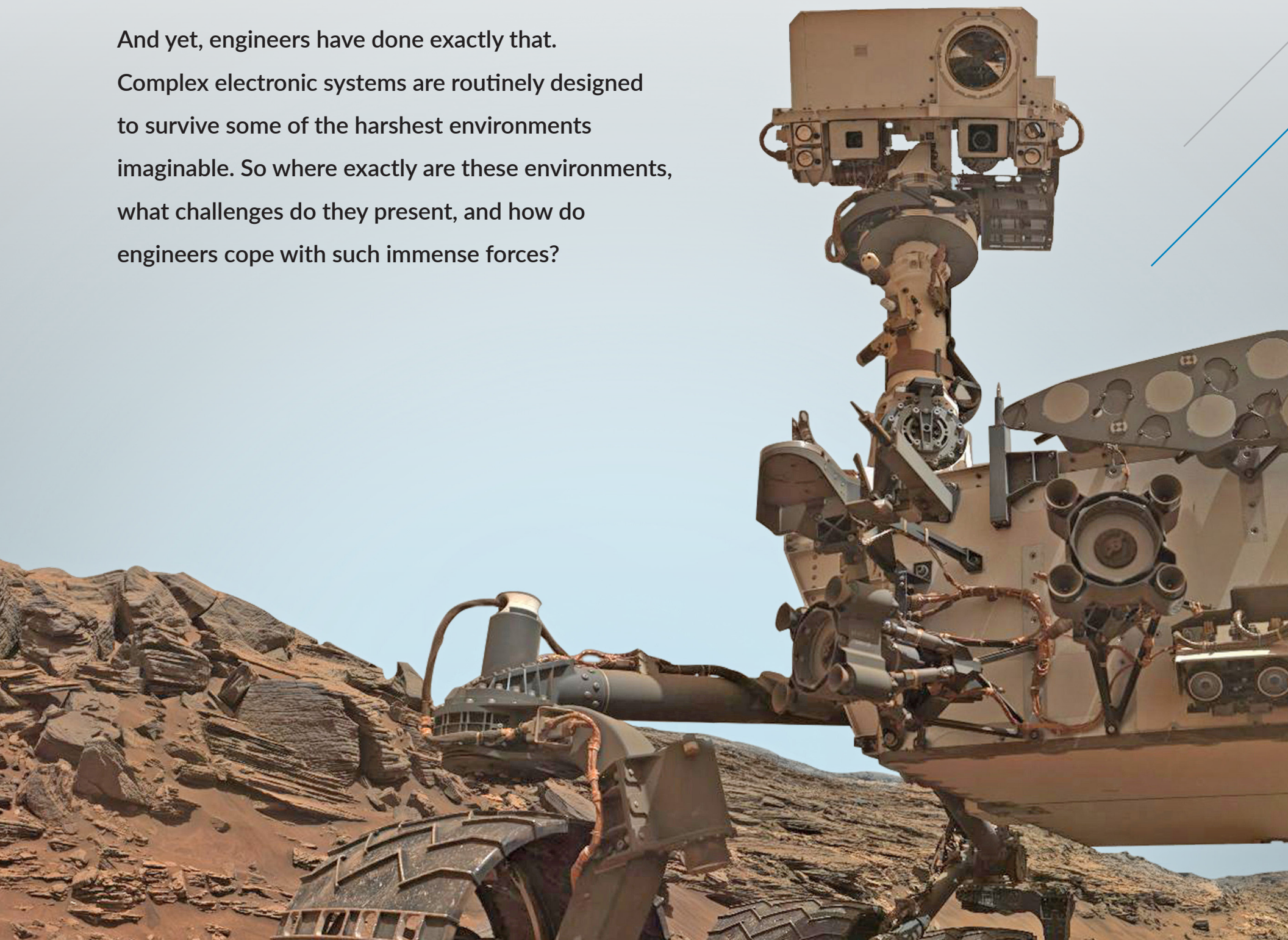


# FROM 0 to 10,000G

Ask any engineer what their worst nightmare is, and it will not be spiders, heights, or even public speaking. It will be designing a system with no margin for error. This is especially true in the aerospace and defense industries, where even the smallest mistake can be catastrophic.

Now imagine being tasked with designing a launch system that allows no margin for error, yet experiences accelerations on the order of tens of thousands of g before exiting the barrel at high Mach speed. Even the most experienced engineers would experience some degree of apprehension.

And yet, engineers have done exactly that. Complex electronic systems are routinely designed to survive some of the harshest environments imaginable. So where exactly are these environments, what challenges do they present, and how do engineers cope with such immense forces?



## What Is a G-Force?

Good engineering requires good science, and good science requires precision. When it comes to g-forces, however, the terminology can be misleading. Despite the name, g-force is not a force at all. It is a measure of acceleration.

Simply put, g-forces describe acceleration relative to Earth's gravitational acceleration at sea level. Since standard gravity is approximately  $9.81 \text{ m/s}^2$ , an acceleration of 1G corresponds to an object accelerating at  $9.81 \text{ m/s}^2$ .

The term is misleading because applying the same force to two objects of different mass results in different accelerations, as described by  $F = ma$ . Since acceleration, not force, is the critical factor, engineers adopted acceleration as the basis for describing g-forces.

## Where Are High G-Forces Found?

Most people experience approximately 1G throughout their daily lives while standing, sitting, walking, and running. However, there are many situations in which higher g-forces occur. During aircraft takeoff, for example, passenger jets accelerate forward, and the combination of forward and downward acceleration can result in elevated g-forces, though rarely above 1.5G.

In military aviation, g-forces can be significantly higher. Modern fighter aircraft can expose pilots to forces of up to 9G during aggressive maneuvers such as banking, diving, and rolling. Without mitigation through G-suits, training, and anti-G straining maneuvers, pilots would experience vision loss and G-LOC (loss of consciousness).

While solid objects do not share human physiological limits, accelerations above 9G quickly become dangerous for people. Electronics, however, commonly experience hundreds of g for short durations. But what about 1,000G or even 10,000G? Do such environments exist on Earth?

They do. One of the most common examples is artillery systems. Modern artillery shells can be highly sophisticated, containing electronic systems for timing, guidance, target detection, and detonation. In this environment, shells accelerate from rest to several Mach in a fraction of a second, producing accelerations that can reach thousands or even tens of thousands of g.

Spacecraft launched into orbit also experience large accelerations. Crewed launches are limited to a few g to protect astronauts, but rockets generate strong vibrations and transient shocks during events such as stage separation and pyrotechnic releases. These "pyroshocks" are high-frequency, short-duration shocks that can produce extreme localized accelerations in the hundreds to thousands of g.

An example of a more unconventional launch platform is SpinLaunch, a proposed ground-based centrifuge system that accelerates payloads to extreme velocities before release. Payloads are subjected to several thousand g during spin-up over extended periods rather than the more gradual accelerations of conventional rockets.

High g-forces are not limited to large systems. Laboratory centrifuges can expose samples to extremely high accelerations. High-speed ultracentrifuges routinely generate accelerations on the order of  $10^5 \text{ g}$ , acting over very small masses and distances.

## What Challenges Do High G-Forces Present?

The most obvious challenge posed by high g-forces is mechanical damage. Sudden shocks from rocket launches, artillery firing, or aggressive aircraft maneuvers can fracture materials. Solder joints can detach from printed circuit boards, cables can tear away from connectors, and PCBs themselves can crack.

Damage is not limited to the initial shock. Rapid changes in acceleration can cause loose connections and fittings to shift, leading to broken wires or loosened connectors inside assemblies. Cable harnesses and unsecured components can act like whips, causing secondary damage after the initial acceleration event.

High g-forces can also produce electrical effects. Some ceramic materials exhibit piezoelectric behavior, generating voltage when subjected to mechanical stress. Under extreme acceleration, these components can produce transient voltages that disturb circuits or damage nearby semiconductors.

Crystals used in timing circuits are also affected. Sudden acceleration changes can perturb their frequency, disrupting timing-critical operations such as memory access and data synchronization. In extreme cases, this can cause bit errors or undefined logic states that result in system failure.

## How Do High G-Forces Affect Connectors?

Connectors are among the most vulnerable components in high-g environments. Extreme acceleration can damage connector housings and mating contacts, particularly in applications requiring multiple mating cycles for power, data, or debugging.

Momentary disconnects are another major concern. Under high g-forces, mechanical interfaces can briefly separate, interrupting power or data transmission. Even microsecond-scale interruptions can cause brownouts, data corruption, or noise-related failures.

High-speed motion through the atmosphere can also generate extreme heating due to aerodynamic friction. Additionally, high-frequency mechanical stress can induce piezoelectric effects in certain materials, generating unwanted voltages.

Momentary disconnects and temperature changes can alter contact resistance. This degrades EMI performance, particularly in shielded connectors, and can change impedance characteristics, rapidly degrading signal integrity.

## What Do Connectors Need to Survive Such Extremes?

Designing connectors for extreme g-environments requires careful consideration of multiple factors.

First, connectors must have the lowest possible mass. For a given acceleration, reducing mass directly reduces force, as defined by  $F = ma$ .

Second, connectors should use multiple contact points to provide redundancy. Multi-point or cage contact designs ensure that if one contact fails, another path remains available. Single-point contacts are poorly suited for extreme g-environments.

Contact retention methods also matter. Spring-loaded contacts can experience bounce under acceleration, causing intermittent connections. Solid or redundant multi-point contact designs offer greater stability.

Connector orientation is another critical factor. Aligning contacts so that acceleration forces act along the axial direction rather than perpendicular to the mating interface reduces the risk of separation and damage.

Cables must also be lightweight and properly secured to prevent whipping effects during acceleration.

Materials matter as well. Ordinary thermoplastics and snap-fit connections can deform or unlatch, whereas metal shells and high-temperature thermoplastics combined with mechanical fasteners provide superior resistance.

Maintaining EMI shielding in high-g environments often requires screw locks, bayonet couplings, jack screws, or dual-stage retention systems to prevent accidental separation.

Finally, through-hole pins, solder cups, stakes, and epoxy backfill help prevent joint failure. Board-mounted connectors benefit from underfill and mechanical posts to reduce peel forces.

## Conclusion

Designing electronics capable of surviving 10,000G requires a fundamentally different mindset from conventional aerospace or industrial design. At these forces, every component becomes a potential failure point, and connector vulnerabilities become especially apparent.

High g-environments punish mass, loose tolerances, spring elements, and anything that can flex or resonate. Even microsecond-scale disconnects can destroy mission-critical data or cause complete system failure.

Surviving such conditions requires minimizing connector mass, optimizing geometry relative to force direction, eliminating internal motion, and selecting materials that resist fracture, deformation, and electrical side effects.

Proper strain relief, locking mechanisms, and redundant contact structures become essential. While such extreme environments are rare, the lessons learned improve connector reliability across aerospace, defense, munitions, and other high-reliability applications. A connector that survives 10,000G while remaining electrically stable is not just impressive, it is essential.