ARMOR X10 Rugged Tablet PC:
Lessons Learned and Design Responses

Since the days of the ancient Egyptians, paper has been the medium of choice for capturing data. Today, paper – in the form of notebooks, maps and photographs, to name a few – is being rapidly supplanted by digital technology. The computer has moved from the office into the field. While rugged mobile computers were once used primarily by military personnel and focused applications in the commercial and industrial markets, today's rugged computer is for people who perform normal job functions in demanding environments.

As powerful computing and communications technology is packaged in smaller, lighter and more durable form factors, more users in more industries benefit from rugged mobile computers. In order to perform tasks that were once done only at an office computer, as well as field operations and remote communications that were unimagined just a few years ago, users need a high level of durability and reliability. Specifically, they require protection against water, dust, shock, vibration and temperature extremes. They need to be able to view the display, even in direct sunlight. And for those users who are upgrading from earlier generation units, backward compatibility with system components like docking stations is an important consideration.

This paper examines the ARMOR X10 Rugged Tablet PC, a next-generation mobile computer that is built on lessons learned, often in military environments, and applied to the design, manufacture and service of commercial products. It discusses environmental and operational factors that must be overcome to achieve fully rugged mobile computing, and the design and engineering responses to these factors. Finally, it focuses on manufacturing and service as vital components of a rugged computer.

Environmental Factors

The development of the ARMOR X10 Rugged Tablet PC demonstrates how experience with previous generations of mobile computers, including military systems, provides the foundation for enhanced durability and performance in harsh environments. Critical areas where these lessons led to environmental design improvements include keeping out water and dust, blunting the effects of high and low temperatures, and protecting against the harmful effects of shock and vibration.

Dust and Water

Dust is a term used to define small particulate matter. Non-organic matter can clog connections during mating of connectors to port, or decrease the port's useful life. Further, organic matter such as mud can lead to fungal growth or the retention of moisture, leading to corrosion that could take months before intermittent operation occurs. Water, in the smallest amounts, turns to vapor upon operation of electronic equipment and thereby migrates throughout the entire unit. If openings are not present to "back out" the moisture, it collects in trapped areas and condenses, for example, on the LCD screen.

Thus, dust and water are two of a computer's worst enemies. In order to prevent or minimize dust and water ingression, a computer's external housing must be designed and manufactured to very tight tolerances, and all gaps must be carefully sealed. The interfaces between materials that exhibit different coefficients of thermal expansion are especially important because the sealing material must be able to compensate for thermal expansion and contraction and maintain a tight seal. The location of seals is also an important consideration. For example, in the ARMOR X10 Rugged Tablet PC, connectors are sealed on inside so that protection against water and dust is maintained even if the connector door is left open.

In addition to selecting the most appropriate gasket materials and locations during the design process, consistent application of these materials during manufacturing is critical to achieving optimal performance. Gaskets that are designed for automated application have been demonstrated to be more consistent, repeatable and reliable than hand-applied materials.

The elimination of a fan for the purpose of cooling internal components is one strategy to ensure continued function in the presence of water and dust. Air-handling openings found in conventional computers can allow water and dust to enter the computer directly. And air intakes can become blocked with dust, leading to excessive heat within the unit and catastrophic failure. Further, this functionality demands a preventative maintenance program that increases the total cost of ownership.

Rugged computers are often ranked by ingress protection (IP) ratings which specify the environmental protection provided by an electronic enclosure. The IP rating (Figure 1) normally has two numbers, indicating the levels of protection that the enclosure provides against the ingress of solid foreign objects, including dust, and the protection it provides equipment inside against the ingress of water. These ratings are applied to electronic enclosures of all types, including those intended for continued submersion. Within the category of rugged computers, the highest levels of dust protection are desired; a water protection level of 6 is considered to be water resistant.

First digit (solid objects)

0	No protection.
1	Protected against solid objects up to 50mm, e.g. accidental touch by hands.
2	Protected against solid objects up to 12mm, e.g. fingers.
3	Protected against solid objects over 2.5mm (tools and wires).
4	Protected against solid objects over 1mm (tools, wire, and small wires).
5	Protected against dust limited ingress (no harmful deposit).
6	Totally protected against dust.

Second digit (water)

0	No protection.
1	Protected against vertically falling drops of water (condensation).
2	Protected against direct sprays of water up to 15º from the vertical.
3	Protected against direct sprays of water up to 60º from the vertical.
4	Protected against water sprayed from all directions.
5	Protected against low pressure jets of water from all directions.
6	Protected against powerful jets of water.
7	Protected against the effect of immersion between 15cm and 1m for 30 min.
8	Protected against long periods of immersion under pressure.

Figure 1. Ingress Protection Ratings

The ARMOR X10 Rugged Tablet PC has achieved an IP rating of 66, meaning it has demonstrated complete protection against dust and no adverse effects from powerful jets of water applied against the enclosure from any direction.

High and Low Temperatures

Mobile devices are subjected to a much broader range of temperatures, ranging from winter nights in Minnesota to summer days in Arizona. These extremes are quite different from the office. Sound thermal design practices not only address electronic components, but also the liquid crystal display (LCD), battery, and spinning storage media. In addition, overall thermal design establishes a “cold boot” lower limit and maximum limit for hot operation. The ability of a computer to operate at high and low temperatures also depends in part on the selection of materials and how they relate to other materials in environments that can cause differential expansion and contraction.

The liquid crystal chemistries of LCDs is affected by temperature. At low temperatures, the viscosity of the liquid increases, and if inappropriate vendor specification and/or design techniques are used, the display updates are slow, leading to "ghosting" of images. At high temperatures, the viscosity decreases to almost that of water, resulting in "brownout" of the screen.

Batteries function by chemical reaction to release stored potential energy as electrical power. A battery that is fully charged provides its stated capacity at room temperature. However, this capacity will decrease as temperatures rise or fall to extreme operational limits. Rugged designs leverage trades between weight and total available battery capacity, selection of battery chemistries, thermal design, and power management to optimize user performance over broad temperature ranges.

The spindles of rotating mass storage devices use lubricants that are sensitive to temperature, again due to changes in viscosity. At low temperatures, the viscosity increases, requiring more energy from the motor to spin. At extremely low temperatures, the drive can freeze up and stop spinning. At extremely high temperatures the viscosity is so low that using the drive increases the mechanical wear and thereby reduces useful life.

Designs that leverage fans for heat convection run the risk of single point failures, may become clogged, or are difficult to clean and/or decontaminate. A computer designed for use in harsh environments uses mechanical design to transfer heat away from internal components, such as chip sets, to the housing where heat is dissipated into the ambient air. This "heat pipe" approach, where heat-generating components are connected directly to the housing via a path presenting the least thermal resistance, has proven superior to an internal fan.

<u>Shock and Vibration</u>

Mobile devices are subjected to a broad range of intentional and non-intentional usage environments not present with office equipment. Non-intentional shock includes dropping and sliding off surfaces, while intentional shocks occur through operations such as a vehicle backing up to a loading dock, a rail car engaging, or a tow truck winch operating. Vibration, on the other hand, is specific to the vehicle or stationary equipment on which the device is mounted. While most applications are typified by random vibration, in some cases, such as onboard a ship, there is an overlay of a strong periodic vibrating component induced by engines.

Careful attention to material properties such as malleability (too malleable leads to wear) and fragility (such as glass shatter) are required. All components, boards, brackets, and cables need to have rigid mounting to move the device's natural frequencies outside of excitation ranges. The value of this design regimen is illustrated by the classic films of a bridge that wobbles to destruction after a group walks across. The excitation – the group walking – becomes a repetitive excitation at the bridge's natural frequency. This excitation at the natural frequency amplifies to the point of destruction. At the tablet PC level, vehicle vibrations must be considered not to excite internal natural frequencies leading to excessive wear.

Tablets require attention to the mounting of the LCD and glass. Chemically strengthened glass and shock isolation techniques are critical to keep shocks/drops form leading to damage.

Tablet spinning media is also highly sensitive to vibration and shock. Isolation techniques are used to absorb shock and vibration energy so the drive head does not crash leading to loss of data. For shock, materials that deform and then relax at a slow rate are used. For vibration, materials that absorb the vibration energy and dissipate as heat are used.

The ARMOR X10 Rugged Tablet PC has undergone extensive testing for resistance to shock and vibration. Shock testing involves repeatedly dropping the unit from a height of 4 ft. onto a plywood surface. This distance is significant, since tablet computers may be used by operators holding the computer while standing, a distance of approximately 4 ft. above the floor or ground. During testing, a unit is dropped a total of 26 times in trajectories that cause it to impact on all sides and corners.

Shock testing involved repeatedly dropping the unit from a height of 48 inches. Vibration testing involves attaching the unit to a test fixture that represents actual conditions, such as a vehicle being operated at a certain speed over a rough road. Transducers measure and monitor vibration throughout the test. When the proscribed time has elapsed the computer is examined for failure, wear, looseness, or other changes attributed to vibration.

Summary of ARMOR X10 Rugged Tablet PC Environmental Testing:

- Operating temperature: -4°F to 140°F (-20°C to 60°C)
- Storage temperature: -40°F to 158°F (-40°C to 70°C)
- Shock/drop: plywood: 48 inches (122 cm), face/side/corner, 26 total drops
- Vibration: 514.5, procedure I, category 4
- Ingress protection: IEC 529, IP 66 against dust and water

Figure 2.

Operational Factors

In addition to the environmental factors discussed above, a rugged computer must meet certain operational benchmarks in order to be useful in a mobile environment. These factors include weight, display technology, communications functionality, and compatibility with existing hardware.

<u>Weight</u>

The weight of the mobile device is a critical concern for user fatigue. Devices over 5.5 lbs. quickly limit the duration of holding and lead to errors during use of stylus devices. Thus the design objective may be summed up as the smallest form factor and the lightest weight. The ARMOR X10 Rugged Tablet PC weighs just 5.3 lbs (including battery and case), which is the lightest of any computer to pass the 4-ft. drop test. Optimizing the density of design while simultaneously reducing weight was achieved by balancing design and material selection with the requirements of a rugged environment, including the 4-ft. drop test.

A lightweight aluminum housing provides a high level of protection and helps to reduce weight. Still, keeping the size of the housing as small as possible was a primary objective. The size and weight of the housing are determined by the arrangement of internal components that keep the "box" as compact and light as possible given the desired large (10.4") display. This was complicated by the need for the highest levels of performance. For example, when positioning wireless components, radio frequency (RF) energy analysis dictated how to deploy and place antennas for maximum effectiveness. Other internal components were subsequently repositioned to maintain a dense, compact unit.

Weight reduction also resulted from maximizing the function of each internal component. For example, wiring was designed so that each wire meets its requirements with no excess length.

<u>Display Technology</u>

The principal medium to retrieve and input information on a table device is the display. The most critical measure is Contrast Ratio (measured as the difference in black/white under varying lighting conditions). An example is the wash-out of contrast ratio experienced when using a cell phone outdoors during a bright day. Meantime, the device may be used at night and should be adaptable to ambient lighting so not to become difficult to read because it is too bright. Not only must the display be fully visible in these light conditions, it must perform consistently across the entire temperature range.

A liquid crystal display may be characterized as transmissive, reflective, and transflective. Transmissive displays, such as those on conventional computers, employ an LCD screen with a backlight that provides excellent indoor viewability. The user sees the display image by virtue of the light that passes through the panel from the backlight. These displays are difficult to see in bright light because the brightness of the ambient light overpowers the light coming through the display from the backlight. A reflective LCD uses ambient light which passes through the LCD to a mirror and is reflected back to the viewer, providing good performance in bright conditions. However, these displays provide minimal viewing in dim light because there is little light to bounce off the mirror.

A transflective LCD uses a backlight as well as a reflective mirror to provide enhanced viewability across a broader range of light levels. In the case of the ARMOR X10 Rugged Tablet PC, display viewability was optimized by replacing cold cathode fluorescent lamps with light emitting diode (LED) backlighting. This technology provides for a much brighter backlight and hence the ability to overcome high ambient light conditions. It further provides the user with a very wide range of brightness settings (for indoor lighting conditions or bright sunlight). As such this LED technology can optimize battery performance by requiring the highest brightness only when in the brightest light environments. Further, systems that can automatically adjust backlight brightness in response to changes in ambient light provide the user with a minimum of effort while ensuring optimum battery performance.

Glass used in displays is chemically treated to improve its strength and performance. For example, touch screens use a sacrificial overlay with anti-glare properties to enhance screen protection. Coatings may also be used to control the effects of direct and indirect sunlight on the screen image.

Wireless Functionality

The original uses of portable tablets to go ‘paperless’ has been greatly extended by wireless functions for real-time database accesses by the entire operations team. Rugged mobile computers with wireless capabilities must be designed to minimize electronic interference. Such interference can be on the wireless component, but similarly the design must guard against in intrusion of wireless signals (EMI) into the computer itself. Thus, every aspect of the circuitry was examined, including a detailed analysis of antenna energy performance, antenna positioning and cable routing.

In response to concern about the impact of exposure by equipment users to RF energy, which may be linked to adverse long-term health effects, regulations now specify levels of energy emission. The ARMOR X10 Rugged Tablet PC meets the most stringent Federal Communications Commission specific absorption rate (SAR) requirements. SAR measures the maximum rate at which RF energy is absorbed when the body is exposed to a RF electromagnetic field. Conforming to the most stringent standard means the user is not required to maintain a certain distance from the unit during any type of transmission, such as wireless LAN, Bluetooth, and GPS.

Lastly for tablet computers, there are by form factor restrictions on where antennas can be placed and not obstructed during use. Placement must consider body blockage as well and hand holding placement.

Connectors

One of the lessons learned during years of experience with fully rugged computers is the vulnerability of connectors. In the ARMOR X10 Rugged Tablet PC, external connectors have been redesigned and repositioned to minimize damage associated with rough handling. The use of straight-on rather than angled connectors and, where possible, the use of recessed ports have reduced damage to connectors. Further, sealing is done on the computer side of the connectors thereby eliminating the need for a user to put a cap onto a connector to seal the unit. The design of the Armor X10 also recognized that broken connectors are wear points on any computer. The connector ports are physically isolated from the expensive main board. Thus, in the unlikely event of a broken connector it is highly unlikely that anything other than the connector assembly will have to be replaced. Oftentimes the assembly can merely be sent to the customer for easy replacement in the field.

Backward Compatibility

The ARMOR X10 Rugged Tablet PC is a ninth generation system. All enhancements, upgrades, and other changes are being offered while still preserving compatibility with existing docking systems, batteries, and other components such as AC and Vehicle Adapters.

Manufacturing and Service

Rugged mobile devices experience extreme environmental and usage patterns. In some applications the adoption of computing devices by the workforce may be resisted and intentional rough handling occur. A base rugged design holds up for total cost of ownership and is further supported by design approaches to minimize the cost of manufacturing and service.

While a poor or marginal design cannot be corrected through manufacturing or service, a disciplined approach to manufacturing processes and service enhances long-term reliability. The ARMOR X10 Rugged Tablet PC was developed using Six Sigma, a method of identifying and removing the causes of defects and errors in manufacturing. This process leverages both design and flawless execution in manufacturing. For example, gasket materials that were once applied by hand are now installed through an automated process, eliminating variables that inevitably result from manual operations. Testing programs developed for military rugged tablet computers ensure that the product operates as designed and exceeds expectations.

Similarly, service programs have evolved through lessons learned. Because two-day turnaround depends on the availability of parts, DRS maintains completely separate inventories from manufacturing. New parts – even down to the screws that secure the housing – are installed if there is any question about the viability of the part.

Rugged computer systems are inherently mobile. As such, service programs have to fit into customer's processes knowing that remote help desk support and technical assistance are required around the clock. Further, these mobile assets cannot be easily reached by company IT support staff. As such, skilled personnel familiar with the specific working environment of the mobile worker is most effective. And, rugged computer systems require unique service capabilities. Since the devices are sealed, it is essential that such sealing can be verified at the completion of a repair. It is not uncommon for programs to include coverage for accidental damage or to cover peripherals, accessories and consumables.

Rugged computer systems are often deployed in application specific environments. The use of the device is most often not in response to general computing demands but rather to achieve specific business goals. Therefore, replacing the computer is required only when the application programs are upgraded. Usually, this means that the devices are used for longer periods of time as compared to a typical desktop or laptop device. Leveraging these assets as deployed for five, six, and seven years is not uncommon. Some customers want to keep them in service for a full decade, so long-term parts planning is essential.

Commercial users of rugged computers as well as members of the military know that these devices are mission critical. Often the mobile worker cannot fulfill his mission or continue working without a functional unit. Therefore, timely access to technical support (ideally 24/7) will improve device and user uptime. When a return for service is demanded, availability of a spare (perhaps from the vendor) or the fastest repair possible aids the customer in achieving the optimum business results.

Summary

The development of the ARMOR X10 Rugged Tablet PC demonstrates how lessons learned through years of experience with military rugged computers translates into design improvements, high-quality manufacturing, and enhanced service. The demands of today's mobile worker are such that it is no longer possible to wrap a hardened cover around a regular computer and expect it to function in the field. Today's rugged mobile computers are designed from the inside out, and apply proven technology to deliver reliable performance.

The growing market for rugged computers is characterized by a degree of confusion about the meaning of the term rugged. There are some specific ratings, such as ingress protection that may be used to gauge specific performance criteria. And there are categories like "semi-rugged," "rugged," and "fully rugged" that are often used, but are not easily defined. Thus, users must evaluate levels of protection in light of the specific environment in which the computer will be deployed.

# # #