Redefining Rugged

Assessing the Spectrum of Durability in the Notebook Market

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As endpoint computing moves ever more strongly toward mobility, a subset of mobile users has increasingly sought out a greater degree of ruggedness in their mobile clients. Since a rugged notebook may cost three or four times the price of a similarly configured ordinary notebook, the category is an open invitation to charlatans hoping to charge a premium for something they call rugged, but which is actually less. And how would an end user know it wasn't rugged until it broke?

Meanwhile, a host of terms have been thrown about specifying indeterminate levels of intermediate ruggedness, terms like "business rugged," "semi-rugged," and "durable." It seems fair to say that a range of users would like some protection against losing their notebook's functionality to a sudden drop or keyboard spill, but most would like to get value for their money.

To this end, Endpoint Technologies has created a scale of ruggedness, with labels from non-rugged to fully rugged and then some, each defined quantitatively. The categories are loosely associated with their common marketing names, but at the root are identified numerically for greater specificity. Companies buying rugged systems should understand that the category labeled "Rugged" is completely sufficient for the most demanding field needs, including military. The only reason that a "Rugged +" category exists at all is that some systems — notably a small sealed tablet from Panasonic, the Toughbook U1 — exceed the specifications of Military Standard 810F, the principal standard used to measure ruggeness. The U1 exceeds the spec in two ways: it is dropped on concrete, rather than plywood over concrete, and, it's operating during test. These stresses, along with the fact that the height of the drop is four feet, rather than the generally accepted three feet, means that the U1 meets a higher standard.

Thus, the rugged categories run from "Non-rugged" to "Rugged +", but Rugged is the mainstream category (Table 1).

Table 1

Category	Numerical Range	Common Name
Rugged +	420+	Ultra Rugged
Rugged	330-419	Rugged
Rugged –1	150-329	Semi Rugged
Rugged – 2	70-149	Business Rugged
Non-rugged	0-69	Ordinary

Across this spectrum, we have assessed products on the market today, examining where they fall on the scale and matching that number up against street prices. Using regression, we have determined what the mean price or price range should be at each level and indicated whether existing products fall above the mean, which indicates that they are out of position from a price-ruggedness perspective, or below the mean, which implies that they are aggressively priced.

This tool can be used not only for IT buyers considering rugged endpoints for their fleets, but also for vendors seeking to price their rugged products appropriately.

We hope that this method will help clear up some of the confusion that now reigns with respect to rugged notebooks.

Categories

Many of the innards of rugged systems are the same as those of other notebooks. Processors, core logic, memory, even motherboards and hard drives are no different. The exceptions begin where these components touch other subsystems. For example, motherboards can have special, flexible connectors that tend not to break when subject to physical or temperature shocks. Hard drives can be encased in varying degrees of shock mounting, mitigating the effects of drops. Software and accelerometers can park a hard drive head when a fall is detected.

A category of ruggedness, then, can be thought of not so much as the inclusion of a technology, such as shock mounting, but as an effect, the result of technologies individually or in combination. Thus, we will classify "drop resistance" rather than "has shock mounting." How, various companies achieve these results is for them to market to their respective audiences, but in classifying systems we will look at how systems stack up against various accepted rugged standards, both in an absolute sense (meets vs. does not meet) and in a relative sense (meets 85% of full specification). Also, points are given for third-party verification. It's one thing to assert that a product meets a standard, but quite another to submit the product for verification outside the vendor's control.

Rugged +

In this rating, a system that exceeds 420 points, that meets all and exceeds some parts of the definition of rugged according to Military Standard 810F and Ingress Protection, and whose results have been independently verified by a certified testing laboratory, meets Rugged +.

Rugged

In this rating, a system that garners 330-419 points, that meets the full definition of rugged according to Military Standard 810F and Ingress Protection, and whose results have been independently verified by a certified testing laboratory, meets Rugged.

Rugged –1

In this rating, a system that garners 150-329 points, that meets some parts of or partially meets the definition of rugged according the Military Standards 810F and Ingress Protection, and whose results have been independently verified by a certified testing laboratory, meets Rugged –1.

Rugged –2

In this rating, a system that garners 70-149 points, that meets some parts of or partially meets the definition of rugged according to the Military Standards 810F and Ingress Protection, and whose results may or may not have been independently verified by a certified testing laboratory, meets Rugged –2.

Non-rugged

In this rating, a system that garners 0-69 points, that may arbitrarily meet some parts of or partially meet the definition of rugged according to the Military Standards 810F and Ingress Protection, but is not designed to do so and makes no claims with respect to ruggedness, is considered Non-rugged.

Attributes and Metrics

The attributes and metrics covered here include those derived from two government standards: Military Standard 810F (hereafter called simply "Mil Spec") and Ingress Protection (IP). Other attributes that make rugged notebooks useful in their primary application — military, first response, public safety, field repair — include bright screens for outdoor viewing and wireless connections to enable personnel deployed in highly mobile and outdoor situations to remain online.

Accuracy of testing depends on a variety of factors, including whether the testing environment meets Mil Spec requirements, whether the testing instruments are properly calibrated, and whether monitoring, recording, and reporting procedures are followed correctly. In addition, many of the Mil Spec tests involve tailoring, which means that a company can "appropriately" modify variables such as the length of time a certain test is conducted. Tailoring introduces a host of sometimes subtle differences in the way different companies perform the same tests. This study has tried to account for these differences in only limited ways. However, it should be noted that in at least one instance, a system passed the Mil Spec procedure, but was visibly damaged after having done so. Ultimately, *caveat emptor* rules, and firms considering buying rugged systems for their operations should go right to the details and read the test reports in order to understand specific results. A sample of test suites for different levels of ruggedness is laid out in Appendix I, which shows Panasonic's approach. The company notes that it follows specific procedures for each level and runs the tests unmodified, even though modification is allowed under Mil Spec.

A key part of this rating system is whether testing was done by an independent, certified lab. It's one thing for a company to assert that its products meet a specification, and quite another to have a reliable third party attest to that fact. Thus, in the scale of ruggedness, a company gets 0 for having no claim or measurement along a Mil Spec rugged dimension, 1 for having internal documentation that says a product was tested along this dimension, 2 for internal documentation that shows it passed the test, and 5 for having 3^{rd} party documentation that shows such testing was undertaken and passed.

Third-party documentation must come from a certified testing lab experienced in these types of tests. One such company is Southwest Research Institute (SwRI) and another is Cascade Tek. A list of other labs is included in Appendix II.

In addition to receiving points for whether Mil Spec testing was done at all, internally, or by a third party, a weighting scheme is also applied to ensure that more-important dimensions (e.g., drop) receive greater consideration than less-important ones (e.g., acidic atmosphere).

Tests and Ratings

The following dimensions are considered and given weights in this paper: low pressure, high temperature, low temperature, temperature shock, contamination by fluids, solar radiation, rain, humidity, fungus, salt fog, sand and dust, explosive atmosphere, immersion, acceleration, vibration, acoustic noise, shock, pyroshock, acidic atmosphere, gunfire vibration, a combined measure of temperature, humidity, vibration, and altitude, icing or freezing rain, ballistic shock, and a combined test of vibro-acoustic and temperature stress. A number of these dimensions, although contained in Mil Spec, are not specifically relevant to computers and are therefore weighted as zero.

In addition, the Ingress Protection standard is measured, if present, and other rugged attributes outside the military standard are considered.

The devil is always in the details, and in this case each test set out in the 539-page document that embodies Mil Spec has a myriad of options. Each test includes various possible methods and procedures, and different types of products may fall in a range of categories. For example, it makes sense to test a air-to-ground missile for its ability to withstand extreme cold, vibration, vibro-acoustic stress, pyroschock, and explosive atmosphere. Missiles mounted on aircraft wings are likely to encounter such conditions during their life cycle. But computers in aircraft most usually ride in the hold or cockpit and are subject to a subset of these conditions. Depicting here the level of complexity in the full Mil Spec would defeat the purpose of this document, which is to simplify this potentially overwhelming topic, but in the sections that follow, the most obvious tests for computers are described. In some cases, the method, category, or procedure is called out where major forks in the decision tree split. Readers should note, however, that vendors can choose a less stringent method or procedure under one of the major sections and still claim to have passed that section with a product not really up to par.

Low Pressure (Altitude)

Defined by section 500.4, the low pressure test is about seeing whether the system can operate at high altitudes, such as those encountered in mountain ranges, and also whether it can withstand rapid pressure changes, such as those encountered in aircraft during unstable pressure situations. Although the likelihood that a computer will be mounted externally on an aircraft is low, it is quite possible in certain military conditions that aircraft cabin pressure will be reduced explosively. The standard does not include pressures experienced with spacecraft and other vehicles that travel above 100,000 feet.

The types of computer failures that may result from altitude include overheating, electrical arcing, and rupture of seals.

The levels of test include storage, operation, and rapid as well as explosive decompression.

Endpoint weighting for this attribute is 2x, since it is of middling importance (Table 2). Most rugged notebook users will not be in high-flying aircraft suddenly decompressed by ordinance. However, some systems may be used at the top of high mountains, such as those that have been used for recording, communications, and photography tasks on Mt. Everest. The storage test simply demonstrates that the system works after the altitude test; the operation test shows that it works *during* the altitude test. The decompression test is additive; that is, if a system passes the explosive decompression test, 1 is added to the storage or operation score. A top rating in this category would be 30, which would be conferred on a system that a 3rd party has confirmed can operate at the altitude specified in the test *and* will withstand explosive decompression.

Table 2

Low Pressure (Altitude)	
Storage	1
Operation	2
Explosive decompression	1
Internal Completion Documentation	1x
Internal Passing Documentation	2x
3rd Party Passing Documentation	5x
Overall Weighting	2x

High Temperature

Defined by section 501.4, high temperature tests for the effects on functionality of relatively short-term exposure to high temperatures. Temperature categories include basic hot (up to 110° F) and hot (up to 120° F) in ambient conditions, and basic hot (up to 145° F) and hot (up to 160° F) in induced conditions (such is within vehicle bodies or in direct sunlight).

The types of computer failures that may result from high temperature include battery failure, popped electrical connections, melting of some components, shortened operating lifetime, and general failure.

Both storage and operational tests are considered.

Endpoint weighting for this category of test is 3x, since temperature issues are common in computer usage (Table 3). Many categories of work will require a system to be exposed to unusually high temperatures, from military deployment in Iraq in summer to a field rep who leaves a system in a car in summer during lunch break.

Table 3

High Temperature	
Storage	1
Operation	2
Internal Completion Documentation	1x
Internal Passing Documentation	2x
3rd Party Passing Documentation	5x
Overall Weighting	3x

Low Temperature

Defined by section 502.4, low temperature is analogous to high temperature. Temperature categories include basic cold (down to -24° F), cold (down to -45° F), and severe cold (down to –60° F) in ambient conditions. The temperature ranges for induced conditions are similar, since in most cases, human activity add rather than subtracts temperature from the operating environment.

Cold tests can be combined with shock tests because one of the effects of extreme cold is to make materials more brittle and therefore subject to failure by shock. Other failures can include binding of moving parts and changes in electrical function.

Both storage and operational tests are considered.

Endpoint weighting for this category of test is 3x, since temperature issues are common in computer usage (Table 4). Many categories of work will require a system to be exposed to unusually low temperatures, from public safety deployment in the Alaskan dark season to a field rep who leaves a system in a car overnight in northern Minnesota in January.

Table 4

Low Temperature	
Storage	1
Operation	2
Internal Completion Documentation	1x
Internal Passing Documentation	2x
3rd Party Passing Documentation	5x
Overall Weighting	3x

Temperature Shock

Temperature shock refers to the effects of rapidly changing temperature, which is defined as "greater than 18° F per minute" in section 503.4. These events can be either hot-to-cold or cold-to-hot transitions. An example of a hot-to-cold shock would be an air-drop from a warm aircraft interior at high altitude or offloading from a warm vehicle interior to an arctic environment. An example of the other way around would be transfer from an unheated high-altitude aircraft to desert terrain. The test itself is of short duration.

Types of damage potentially include shattering of friable materials, popped connections due to differential contraction or expansion rates of dissimilar materials, cracking of connections, and various electrical failures.

Testing is done in non-operational mode, but results are analyzed in operating mode.

Endpoint weights this category of test at 2x (Table 5). Temperature shock tends to be experienced in fairly extreme circumstances, often military and not often in commercial computer usage.

Table 5

Temperature Shock	
Single Test	1
Internal Completion Documentation	1x
Internal Passing Documentation	2x
3rd Party Passing Documentation	5x
Overall Weighting	2x

Contamination by Fluids

This category, set out in section 504, is of limited importance for computers, as they rarely encounter contamination with the types of fluids specified (e.g., runway de-icers, insecticides, hydraulic fluids, lubricating oils, solvents, disinfectants, fire extinguishants, cleaning fluids).

Because these issues do not normally arise, even in fairly extreme environments, this test is weighted as 0x (Table 6).

Table 6

Contamination by Fluids	
Overall Weighting	0x

Solar Radiation (Sunshine)

Solar radiation is covered in section 505.4. Although solar radiation generates heat effects, not all of them are similar to high temperature effects as covered under section 501.4. For example, solar radiation generates directional heating and thermal gradients not found in simple thermal testing. Therefore, systems can experience differential expansion, particularly between dissimilar materials. Other effects include damage from ultraviolet rays.

Failures can include popped solder joints, changes in electronic components and plastics, and blistering.

Tests can mimic the natural diurnal cycle or be accelerated to ferret out ultraviolet effects. Testing is done in non-operational mode, but results are analyzed in operating mode.

For computers, these tests largely duplicate the results of high temperature tests. Thus, they are included here, but given a low weighting (1x), as most computer makers dispense with them (Table 7).

Table 7

Solar Radiation	
Single Test	1
Internal Completion Documentation	1x
Internal Passing Documentation	2x
3rd Party Passing Documentation	5x
Overall Weighting	1x

Rain

This category, set out in section 506.4, is quite important for computers, as they often encounter water and water-based fluids during the normal course of usage, including rain, spray, and dripping. Drinks spilled on keyboards fall within this category.

Types of damage include electrical failure due to short circuiting and deformation of vulnerable components.

The test normally considered is one of three defined in section 506.4, called Drip, appropriate for computers, which are normally protected from rain but may be exposed to falling water from time to time.

Both storage and operational tests are considered.

This test is weighted at 3x, given its relevance to computers (Table 8).

Table 8

Rain	
Storage	1
Operation	2
Internal Completion Documentation	1x
Internal Passing Documentation	2x
3rd Party Passing Documentation	5x
Overall Weighting	3x

Humidity

Defined by section 507.4, humidity tests measure the effects of warm, humid environments on computer operation. Computers often operate in such environments, which occur consistently in the tropics and seasonally in mid-latitudes. The "aggravated" version of this test requires a 48-hour cycle at a humidity level of centered on 95%.

The primary effect of humidity is condensation, which may lead to electrical failure.

Testing is done in storage mode, but operational testing is conducted periodically as part of the test sequence.

Since these are relatively important tests, humidity is given a 3x weighting (Table 9).

Table 9

Humidity	
Single Test	1
Internal Completion Documentation	1x
Internal Passing Documentation	2x
3rd Party Passing Documentation	5x
Overall Weighting	3x

Fungus

Although fungus is often associated with long-term humidity, electronics do not usually fail due to fungus invasion. The type of humidity that causes fungus would cause an electrical failure long before the fungus had time to grow. According to SWRI, this test can take up to a year to yield results.

Because these issues do not normally arise, even in fairly extreme environments, this test is weighted as 0x (Table 10).

Table 10

Fungus	
Overall Weighting	0x

Salt Fog

Testing for resistance to salt fog, typically encountered in coastal areas and on board ships, is defined in section 509.4. Salt fog, combined with condensation effects, can deposit salt, which is highly corrosive, on electrical equipment.

Electrical failures occur from the effects of corrosion, which include impairment of conduction, acceleration of conduction, destruction of insulation, and clogging or binding of moving parts.

Testing is done in non-operational mode, but results are analyzed in operating mode.

Salt fog damage is relatively rare for computers. Yet, it is common in certain environments (e.g., naval vessels, certain coastal installations). Therefore, this test is given a 1x weighting factor (Table 11).

Table 11

Salt Fog	
Single Test	1
Internal Completion Documentation	1x
Internal Passing Documentation	2x
3rd Party Passing Documentation	5x
Overall Weighting	1x

Sand and Dust

Damage to computers from sand and dust, but particularly dust, is a highly important attribute of ruggedness, since dust exists in all environments, and infiltration by particulate matter is common. Sand and dust testing is defined in section 510.4. Tests can be for blowing dust, blowing sand, or settling dust.

Sand and dust can cause damage by abrasion and erosion of surfaces, penetration of seals, degradation of electrical circuits, obstruction or clogging of openings and filters, jamming of mating parts, interference of moving parts, reduction of thermal conductivity, and overheating due to restricted ventilation.

Testing is normally done in operational mode, since ambient dusty conditions may occur in normal service.

Since this condition is quite common for computers, it is given a 3x weighting factor (Table 12).

Table 12

Sand and Dust	
Single Test	2
Internal Completion Documentation	1x
Internal Passing Documentation	2x
3rd Party Passing Documentation	5x
Overall Weighting	3x

Explosive Atmosphere

The explosive atmosphere test, described in section 511.4, is designed to determine whether a given object or system is liable to set off an explosion in a fuel-air mixture due to heat or electrical arcing.

As a piece of electrical equipment, a computer can certainly generate heat and potentially sparks, particularly in unusual (e.g., short-circuiting) operation, but since computers are rarely subjected to such conditions, this measure is weighted as 0x (Table 13).

Table 13

Explosive Atmosphere	
Overall Weighting	0x

Immersion

Section 512.4 covers whole systems falling into bodies of water. This test is a more severe form of water penetration test than the rain test and is not often performed on computers. What has become clear from experience is that even non-rugged computers subject to immersion, either in fresh or salt water, will be unharmed if

1) the system was not operational at the moment of immersion (otherwise a short circuit will almost certainly occur),

2) it is sufficiently rinsed (in the case of salt-water immersion), and

3) it is left to dry for a sufficient period (i.e., 10 days).

Under these circumstances, the system will usually boot right up. If, on the other hand, the system was operational upon immersion, even if it is highly ruggedized, it will likely short circuit and require repair.

Testing is done in non-operational mode, but results are analyzed in operating mode.

Although systems can be immersed, this occurrence is rare, and therefore the weighting given this test is 1x (Table 14).

Table 14

Immersion	
Single Test	1
Internal Completion Documentation	1x
Internal Passing Documentation	2x
3rd Party Passing Documentation	5x
Overall Weighting	1x

Acceleration

Acceleration, covered in section 513.5, refers to the ability of the subject material to withstand the relatively gradual changes of inertia (as opposed to the sudden ones brought about by shock) brought about by acceleration, deceleration, and maneuver of the environment, usually transportation equipment, in which it operates. Typically, this equipment includes aircraft, helicopters, aerospace vehicles, and ground-launched missiles. Stress is measured, for example, during simulated aircraft roll, pitch, and yaw.

Effects of acceleration can include deformations, fractures, and electronic failures.

Both storage and operational tests are considered.

Although this type of testing is quite specific, and applies in only narrow circumstances, computers reside in most military and commercial aircraft and all spacecraft. Therefore, the weighting for this test is 2x (Table 15).

Table 15

Acceleration	
Storage	1
Operation	2
Internal Completion Documentation	1x
Internal Passing Documentation	2x
3rd Party Passing Documentation	5x
Overall Weighting	2x

Vibration

Vibration, described in section 514.5, is one of the most important tests for computers. Any notebook that travels is subject to varying degrees of vibration, whether in cars, airplanes, trains, or tanks rumbling across the desert. This test is complex and multifarious, with four procedures corresponding to the general usage environment (e.g., loose cargo transport) and 24 categories that represent specific usage scenarios (e.g., unsecured transport in trucks). The particular category determines the type of test procedure required as well as the level and duration of the test.

Failures include loosened and fatigued materials and components, short circuits, intermittent electrical contacts, failed components, cracked or broken structures, and migrating particles and failed components, potentially into circuitry or mechanisms.

Testing for most ruggedized computers follows Procedure I (General Vibration), Category 24 (Minimum Integrity). Testing can be done in non-operational mode, with results analyzed in operating mode. Additional testing can be done in operational mode, tailored for the environment in which the equipment is normally used.

Because vibration is one of the most important tests for rugged notebooks, and subsumes the more specialized one for gunfire vibration, it is given a weighting of 5x (Table 16).

Table 16

Vibration	
Non-operational	1
Operational	2
Internal Completion Documentation	1x
Internal Passing Documentation	2x
3rd Party Passing Documentation	5x
Overall Weighting	5x

Acoustic Noise

Acoustic noise, described in section 515.5, is generated by machinery that causes large airborne pressure fluctuations over a wide range of amplitudes and frequencies. These fluctuations may transfer to the tested material, causing a variety of failures.

In computers, such failures could include component vibratory fatigue, connection fracture, printed circuit board and other component cracking, intermittent operation of electrical contacts, loosening of small particles that may become lodged in circuits and mechanisms, and excessive electrical noise.

Although computers may on rare occasion be used in some of the extreme environments implied by this type of testing (e.g., near missile launchers or demolition explosions), most of the type of damage caused by acoustic noise are similar to vibration, and so more-general vibration testing is undertaken instead. This test is weighted as 0x (Table 17).

Table 17

Acoustic Noise	
Overall Weighting	0x

Shock

The tests involving shock are covered in section 516.5. Shock describes the effects of relatively infrequent, non-repetitive jolts or knocks that may occur in the course of transport or operation. A shock is of comparatively short duration and involves a moderately strong impact.

The effects of shock are general and comprise essentially breakage of one or more subsystems. Specific failures include moving part malfunction (e.g., drives, fans), motherboard failure, connector damage, short circuiting, mechanical breakdown (e.g., case, frame), and cracking of breakable materials (e.g., screen, touchpad).

Testing may be done in operational mode, following "Procedure I — Functional Shock," as laid out in sub-section 2.2.2.a. That is, the computer must function during and after the test. Procedure I requires a multi-axis test, which is to say, with shocks administered in the x, y, and z dimensions on the computer. Or testing may be done on an working unit in non-operational mode and tested afterward in operational mode, following "Procedure IV — Transit Drop, as laid out in sub-section 2.2.2.d. Naturally, Functional Shock is a more stringent test than Transit Shock.

Shock is one of the most important tests, subsuming some of the other tests (i.e., Pyroshock and Ballistic Shock), and therefore is given a weighting of 5x (Table 18). It should be noted that vendors permit themselves a wide range of interpretation on this test, modifying tests with respect to the height of the drop test, the surface onto which the unit is dropped, the angles at which the unit is dropped, and the number of drops as well as whether or not the unit is operational during testing. Also, according to Mil Spec, the unit passes as long as it is functional after the test, despite any visible damage that may occur. Buyers should pay close attention to differences in vendor procedures on this test.

Table 18

Shock	
Transit	1
Operation	2
Internal Completion Documentation	1x
Internal Passing Documentation	2x
3rd Party Passing Documentation	5x
Overall Weighting	5x

Pyroshock

Pyroshock, covered in section 517, is a specialized and extreme form of shock resulting from pyrotechnic device ignition. Pyrotechnic devices, which are activated by an explosive or a propellant charge, are typically used in aerospace applications to do things like separate a spacecraft from its launch vehicle or deploy appendages to solar panels.

Pyroshock generates high-peak-acceleration, high-frequency, short-duration wave content that can be destructive to small equipment, subsystems of which may resonate with these frequencies and break. The effects of pyroshock are highly dependent on distance from the source: the closer, the stronger.

Given the highly specialized nature of this type of test, it is not often performed on personal computers and is given a weighting of 0x (Table 19).

Table 19

Pyroshock	
Overall Weighting	0x

Acidic Atmosphere

Acidic atmosphere tests, described in section 518, cover the effects of corrosive atmospheres on materials and equipment.

Again, since computers are not expected to be left out in the sulfuric or nitric acid rain for hours on end, this test is somewhat superfluous and weighted as 0x (Table 20).

Table 20

Acidic Atmosphere	
Overall Weighting	0x

Gunfire Vibration

Vibration from gunfire, covered in section 519.5, is quite similar to general vibration, and testing is analogous. It shares some characteristics with acoustic testing, in that the vibrations typically emanate from a point source (i.e., a gun), and the frequency range is likely more limited than general vibration. The pattern is usually repetitive pulse, as opposed to sustained.

Damage to electronics systems like computers is similar to that inflicted by general vibration.

This test is considered to be subsumed under the general vibration test and is therefore weighed as 0x (Table 21).

Table 21

Gunfire Vibration	
Overall Weighting	0x

Temperature, Humidity, Vibration, and Altitude

These tests, described in section 520.2, are compound assessments to determine the combined effects of temperature, humidity, vibration, and altitude on the test subject.

Although there are clearly interactive effects of combination testing (e.g., shattering of glass vibrating at low temperature, which makes the material more brittle, or the arcing of electricity in certain conditions of humidity and altitude), these tests are not often done on computers. They measure extremes that computers usually do not encounter in real life, and many of the effects are replicated in individual tests for the same effects.

However, since at least one vendor tested for these combined effects for a military customer, the measure is included in the point system with a weighting of 2x (Table 22).

Table 22

Temperature, Humidity, Vibration, and Altitude	
Transit	1
Operation	2
Internal Completion Documentation	1x
Internal Passing Documentation	2x
3rd Party Passing Documentation	5x
Overall Weighting	2x

Icing/Freezing Rain

These tests, covered in section 521.2, are most appropriately done on materials (e.g., equipment deployed for long periods outdoors in cold climates or aboard ships in cold seas) for which icing or freezing rain is anticipated in their life cycle.

As these conditions are unusual for computers, these tests are weighted as 0x (Table 23).

Table 23

Icing/Freezing Rain	
Overall Weighting	0x

Ballistic Shock

Simply stated, ballistic shock results from being shot. More technically, ballistic shock testing assesses the impact of a projectile or ordnance on the tested material and typically involves a very high level of shock from a localized impact.

This testing is most appropriate for military vehicles, body armor, and the like and is not generally used for computers, which, in some rare cases, have stopped actual bullets and saved their owners without, however, surviving themselves to ride another day.

These tests are weighted as 0x (Table 24).

Table 24

Ballistic Shock	
Overall Weighting	0x

Vibro-Acoustic/Temperature

These tests are designed specifically to determine the synergistic effects of vibration, acoustic noise, and temperature on material carried externally on aircraft. As such, they are not assessed for computers and are weighted as 0x (Table 25).

Table 25

Vibro-Acoustic/Temperature	
Overall Weighting	0x

Ingress Protection Ratings

Another important set of tests, which are somewhat redundant with Mil Spec, are the Ingress Protection (IP) ratings. These consist of a two-digit designation, the first for defense against intrusion by particles, the second for defense against intrusion by fluids. The higher the number, the better the protection (Table 26).

Rugged computers tend to meet an IP rating of 54; that is, dust and splashing water protection.

Table 26

1st Digit	Protection Against Foreign Objects	2nd Digit	Protection Against Moisture
0	Not protected	0	Not protected
1	Protected against objects greater than 50mm	1	Protected against dripping water
2	Protected against objects greater than 12mm	2	Protected against dripping water when tilted up to 15N
3	Protected against objects greater than 2.5mm	3	Protected against spraying water
4	Protected against objects greater than 1.0mm	4	Protected against splashing water
5	Dust protected	5	Protected against water jets
6	Dust tight	6	Protected against heavy seas
		7	Protection against the effects of immersion
		8	Protection against submersion

In Endpoint's measurement system, an IP rating is added at its value level.

Ingress Protection	
Unified measure	1
Overall Weighting	IP value

Other Rugged Attributes Not Covered in Mil Spec

There are a number of ruggedizing attributes that may or may not contribute to meeting Mil Spec. Vendors have put some or all of these features into some or all of their notebooks without necessarily making any specific claims. However, these features may make the notebooks more robust. In fact, including them in a particular design may make it approach a Rugged –1 or Rugged –2 rating. Therefore, they are described in the section below and accounted for in the overall rating system.

Such attributes include: roll bar, drive cage, shock mounting, accelerometer, external bumpers, and daylight screen. Each of these attributes is worth one point in the Endpoint rating system.

Roll Bar

Roll bar refers to general reinforcing of the chassis frame, which tends to make it more rigid and less likely to flex when pressure is exerted on the case. It also affords some protection during mild drops. The lower case that contains the main body, the frame that contains the screen, or both may be reinforced.

Drive Cage

Drive cage refers to various means by which the hard drive is protected from bumps. Often it is mounted in an independently suspended structure buffered by shock-absorbing mounts attached to the outer frame.

Head Parking

The delicate hard drive head, which operates mere tens of nanometers from the platter, can be parked at a safe distance based on input from a sensor, often an accelerometer.

Shock Mounting

The entire motherboard can be mounted with some kind of protection against shocks.

Accelerometer

An accelerometer is a sensor that can determine if a system is undergoing a sudden change of speed that indicates a drop. Based on actuation of the accelerometer, the hard drive head can be parked, preventing drive damage and loss of data.

External Bumpers

Notebooks sometimes have bumpers on the corners. These bumpers, made of rubber or other soft materials, can help protect against damage from minor bumps and drops.

Daylight screen

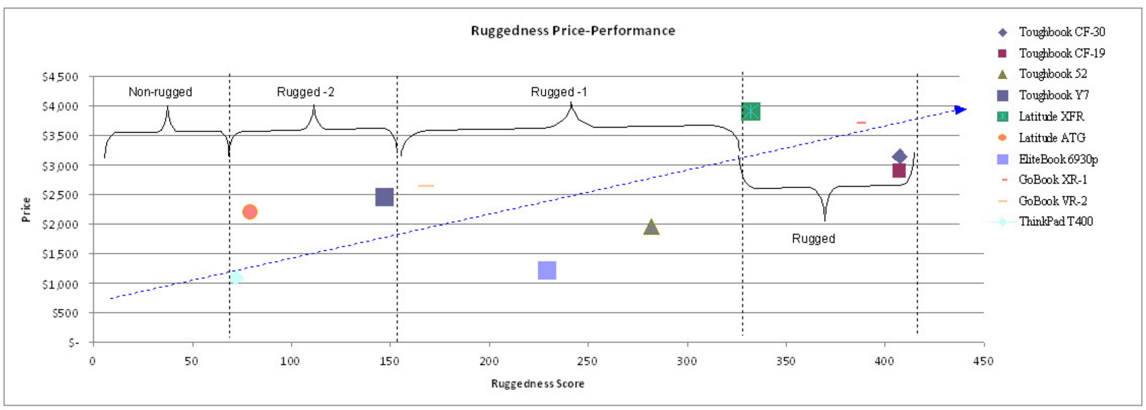
While not specifically a feature of ruggedness, daylight screens are often found on systems used outdoors. Such screens, which make reading easier in full sunlight, add a significant cost to the total bill of materials, but are often an advantage for outdoor viewing.

Price-Performance on the Rugged Scale

Endpoint has taken the rating system set out in previous sections and applied it to various vendors' rugged and partially hardened products. These products received points for having Mil Spec rugged characteristics, more points if testing was done in operational mode, and a substantial multiplier if these tests were documented by a third-party testing service. Some, but not an entirely thorough, attempt was made to account for the many modifications made by vendors (and allowed for in Mil Spec) in testing procedures. Other rugged attributes were worth extra points. IP values were added where appropriate. Some other rugged testing not contained in Mil Spec was accounted for. The resulting scores were normalized to create a measure of ruggedness that matched reasonably well with the scale of system pricing. These results were plotted as x-y values on a scatter chart (Figure 1). Systems included in the study were:

- Panasonic's Toughbook CF-30, Toughbook CF-19, Toughbook CF-52, and Toughbook Y7
- GD-Itronix's GoBook XR-1 and GoBook VR-2
- Hewlett-Packard's EliteBook 6930p
- Lenovo's ThinkPad T400, and
- Dell's Latitude ATG and Latitude XFR.

Figure 1



All things being equal, one would expect to see a roughly linear scatter from the lower left to the upper right; that is, the more rugged a system, the more one has to pay for it.

Results did match expectations to a degree. The mean linear value of all the data, fit using least-squares math, shows a pretty good correlation between price and degree of ruggedness. Given an average selling price for a notebook of about $700 in mid-2008, the line should cross the y-axis at about $700; that is, a notebook with zero ruggedness points should cost about $700. The line does cross the y-axis near $700. Systems that fall above the line are considered out of position competitively. Systems below it are considered to be more than averagely competitive.

The scatter was reasonably tight. However, there were some exceptional values, which are discussed in the next section.

Little accounting was done for system specifications. Therefore, a richly configured system (e.g., with a high-end processor, lots of memory, and a high-speed, high-capacity hard drive) would compare unfavorably with a less richly configured system of a similar degree of ruggedness because it would be more expensive. The lack of accounting for this dimension is both a strength and a weakness. On the one hand, detailing these differences would make a comparison of rugged systems nearly meaningless. On the other, the lack of definition in this area gives vendors a chance to reconfigure systems to get them closer to the mean price-performance value and therefore make them more competitive. One exception to this rule is the GD-Itronix systems, which come standard with expensive touchscreens, while this feature is an option on most other systems reviewed. The cost of a touchscreen was therefore backed out of the GD-Itronix prices to normalize them with the other configurations. The one other system that come standard with a touchscreen is the Panasonic CF-19; the cost was also backed out for this system.

Discussion and Classification of Individual Systems

As shown at the beginning of this discussion, the study found natural dividing lines in the data at 70, 150, 330, and 420. All systems evaluated fell within clear categories, although some were close to a line. They are treated below in descending order of ruggedness.

Rugged

Four systems met the rugged criteria: the Panasonic Toughbook CF-30, the Panasonic Toughbook CF-19, the GD-Itronix GoBook XR-1, and the Dell Latitude XFR.

Panasonic Toughbook CF-30

The CF-30 is Panasonic's flagship rugged clamshell. Thus, it is no surprise that this system tied for overall highest score with 407 points on the Endpoint rugged scale. From a price perspective, the CF-30 fell slightly below the line, indicating that, at $3,149, it is priced competitively.

Panasonic Toughbook CF-19

The CF-19, a smaller, tablet version of Panasonic's most rugged system also achieved a rugged score of 407 points. Despite being configured with a touchscreen, because of its overall smaller dimensions, the CF-19 is even more advantageously priced at $2,899 (with the cost of the touchscreen backed out).

GD-Itronix GoBook XR-1

The GoBook XR-1 is GD-Itronix's rugged champion. It achieves 386 points on the Endpoint rugged scale, and with the touchscreen backed out, hits a price point of $3,706, which is just a skootch over the mean on price-performance. This system is configured pretty heavily. So, it falls on the bad side of the line, but not by much and for good reasons.

Dell Latitude XFR

Dell recently entered the rugged market with an outsourced model made by Augmentix. That model, the Latitude XFR, achieves 332 points on the Endpoint rugged scale. A price of $3,900 puts it way above the line, which means a customer is paying a lot for that degree of ruggedness.

Rugged –1

Three systems met the rugged –1 criteria: the Panasonic Toughbook CF-52, the HP EliteBook 6930p, and the GD-Itronix GoBook VR-2.

Panasonic Toughbook CF-52

The Toughbook CF-52 is what Panasonic calls a "semi-rugged" notebook; here, Rugged –1. This system garners 282 points on the Endpoint rugged scale, for which the buyer has to pay $1,949. As deals go, this is a pretty good one, falling well below the mean.

HP EliteBook 6930p

The EliteBook 6930p, HP's only ruggedized system, achieves 229 point, sufficient to gain it a rugged –1 label. Since the 6930p costs only $1,200, it is one of the best deals uncovered in this study. This felicitous positioning has been attained not only by the system's low price, but also by assiduous 3rd party documentation of the 6930p's rugged characteristics.

Rugged –2

Three systems met the rugged –2 criteria: the Panasonic Toughbook Y7, the Dell Latitude ATG, and the Lenovo ThinkPad T400.

Panasonic Toughbook Y7

The Toughbook Y7, which Panasonic labels "business rugged," falls at the high end of the rugged –2 range. With 147 points, it has plenty of ruggedness for its envisioned usage. But with a price of $2,449, it falls well above the mean of price-performance on the ruggeness scale.

Dell Latitude ATG

The Latitiude ATG manages only 79 points, the result of limited ruggedizing and documention. In addition, with a price tag of $2,200, the ATG lies well north of the mean price-performance on the ruggedized scale. Given this situation, it is likely that the ATG will either be repositioned or withdrawn fairly soon.

Lenovo ThinkPad T400

Lenovo makes not particular ruggedized claims for the ThinkPad T400, but it nonetheless achieves a 72 on the Endpoint rugged scale, just enough for inclusion as a Rugged –2 system. Given the aggressive pricing of the T400 at $1,099, and the fact that its rugged characteristics have no 3rd party documentation, its positioning just south of the mean price-performance, while good, probably doesn't do it full justice.

Conclusions

This study is an attempt to make a clear correlation between degree of ruggedness and price. It also tries to dispel some of the mystery with respect to various "soft" claims made by vendors about their systems' being "business rugged" or "semi-rugged." Certainly, manufacturers are free to call their products whatever they want from a marketing perspective, to give guidance about suggested usage models, and set expectations about durability, but buyers should have a cold-eyed method of understanding just what they are getting for their money when they set out to buy systems with any claim at all to ruggedness.

By setting up a numerical system that delineates degrees of ruggedness, Endpoint has endeavored to make the process of choosing a rugged or partially rugged system more rational. It is our hope that this methodology will become widely accepted.

Appendix I

Panasonic Internal Testing Specifications

The three charts included in this appendix show how one company, often considered the leader in ruggedized systems, categorizes its own products. The procedures have been renamed here to correspond to the ratings described in the body of this paper. Otherwise, the information is sourced directly from Panasonic.

Rugged Testing Procedures

Test Description	Test Parameters	MIL-STD-810F Reference
Drop	36" drop height onto 2" of plywood, 26 drops total	Method 516.5, Procedure IV (Transit Drop Test)
Vibration	Non-Operational (from Figure 514.5C-17 of MIL-STD-810F): 0.04 g^2/Hz at 20-1000 Hz, -6 dB/Octave at 1000-2000 Hz, 1 hour/axis duration Operational (tailored to service conditions as allowed in MIL-STD-810F)	Method 514.5, Procedure I, Category 24 (Minimum Integrity Test) Panasonic-provided in-service environment
Shock	40g, 11ms, EUT operational, 3 shocks/axis/direction for a total of 18 shocks	Method 516.5, Procedure I (Functional)
Water Resistance	15 minutes of exposure to dripping water	Method 506.4, Procedure III (Drip)
Dust and Sand Resistance	Operating temperature of 140°F and silica flour/sand with particle sizes as defined by MIL-STD-810F	Method 510.4, Procedure I (Dust) and Procedure II (Sand)
Altitude	15,000 feet (the highest equivalent altitude given within MIL-STD-810F for cargo pressures of military aircraft) and one hour duration for both operation and storage conditions	Method 500.4, Procedures I (Storage) and II (Operation)
High Temperature	Storage temperature = 160°F Cyclic temperature exposures (basic hot induced conditions) were used for high temperature storage test. Operating temperature = 140°F Constant temperature exposures were used for high temperature operation test.	Method 501.4, Procedures I (Storage) and II (Operation)
Low Temperature	Operating temperature = -20°F Non-operating temperature = -60°F	Method 502.4, Procedures I (Storage) and II (Operation)
Temperature Shock	High non-operating temperature = 200°F, low non-operating temperature = -60°F, three cycles (high to low = one cycle)	Method 503.4, Procedure I (Steady State)
Humidity	The cyclic test was performed over ten days. The temperature cycled between 86 and 140°F with the relative humidity at 95% constant. The computers were booted into Windows® at five and ten days into the test.	Method 507.4 (Aggravated)

Rugged –1 Testing Procedures

Test Description	Test Parameters	MIL-STD-810F Reference
Drop	30" drop height onto 2" of plywood, non-operational, 6 drops total 12" drop height onto 2" of plywood, non-operational, 26 drops total	Method 516.5, Procedure IV (Transit Drop Test)
Vibration	Non-Operational (from Figure 514.5C-17 of MIL-STD-810F): 0.04 g^2/Hz at 20-1000 Hz, -6 dB/Octave at 1000-2000 Hz, 1 hour/axis duration Operational (tailored to service conditions as allowed in MIL-STD-810F)	Method 514.5, Procedure I, Category 24 (Minimum Integrity Test) Panasonic-provided in-service environment
Shock	40g, 11ms, EUT operational, 3 shocks/axis/direction for a total of 18 shocks	Method 516.5, Procedure I (Functional)
Altitude	15,000 feet (the highest equivalent altitude given within MIL-STD-810F for cargo pressures of military aircraft) and one hour duration for both operation and storage conditions	Method 500.4, Procedures I (Storage) and II (Operation)
High Temperature	Storage temperature = 160°F Cyclic temperature exposures (basic hot induced conditions) were used for high temperature storage test. Operating temperature = 140°F Constant temperature exposures were used for high temperature operation test.	Method 501.4, Procedures I (Storage) and II (Operation)
Low Temperature	Operating temperature = 32°F Non-operating temperature = -20°F	Method 502.4, Procedures I (Storage) and II (Operation)
Temperature Shock	High non-operating temperature = 140°F, low non-operating temperature = -4°F, three cycles (high to low = one cycle)	Method 503.4, Procedure I (Steady State)
Humidity	The cyclic test was performed over ten days. The temperature cycled between 86 and 140°F with the relative humidity at 95% constant. The computers were booted into Windows® at five and ten days into the test.	Method 507.4 (Aggravated)

Rugged –2 Testing Procedures

Test Description	Test Parameters
Vibration	Approximately evenly distributed a load of 100 kgf (220.46 lbf) to the top of the unit (with the bottom of the unit against an unmoving surface) while applying sinusoidal vibration to the operating item of the following parameters: 0.1g at 5-50-5 Hz, 0.553 Octave/minute resulting in a 1 hour duration in the vertical axis
Kensington	Drop in 2" increments starting at 4", until structural integrity of lock or chassis fails
Operational Bottom Surface Drop	Operation (ran sample video using Microsoft Multimedia Player and ran Panasonic ping script while dropping the unit on its bottom surface from a height of 5" with 5" increasing increments until a read/write failure is detected or 30" is reached
Non-Operational Drop	30" drop height onto 2" of plywood, 26 drops total
Hinge	Measured torque changes over the course of 2000 cycles at 8.2 cycles/minute.
Drip	200cc of water is evenly poured over the keyboard surface
Battery Performance	Uses BAPCo battery performance test

Appendix II

Laboratories that Perform Mil Spec Testing

The following are companies that engage in ruggedization testing. This list is by no means exhaustive but merely exemplary.

Cascade Tek

5245-A NE Elam Young Pkwy
Hillsboro, OR 97124
888.835.9250
info@cascadetek.com

Environmental Associates

9604 Variel Avenue
Chatsworth, CA 91311
Phone: (818) 709-0568
http://www.eatest.com/index.htm

MET Laboratories

914 W. Patapsco Ave.
Baltimore, MD 21230
410.354.3300 or 800.638.6057
info@metlabs.com

Southwest Research Institute (SwRI)

6220 Culebra Road
San Antonio, Texas, 78238-5166
(210) 684-5111
twhelan@swri.org or action67@swri.org