RELIABILITY TESTING OF CONSUMER PRODUCTS

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ABSTRACT
We will look at reliability testing of consumer products, especially for startup and smaller to medium size companies, and which of these test and analytical tools can be used, and how they affect the product development process.

INTRODUCTION
Reliability testing of consumer products is reviewed in several areas: how testing affects the expectation on the reliability, quality and safety of the consumer product, verification and validation of the product performance and specifications, setting the foundations for the manufacturing test and QA process, and planning for early returns and field failure rates.

Start up companies, such as crowd-funded companies are under pressure to launch the product (financing their production through pre-paid sales). Reliability testing can be used to meet some of their objectives such as rapid time to market, reduced product cost and low product returns due to product failure.

Reliability test planning is based on the following product aspects; this may set the priorities for what testing is done in what phase of the project:

- New technologies in the product, and how they affect risk
- Availability of samples, or at least components for evaluation new technologies
- Schedule urgencies

Reliability testing for smart phone and tablet type products may include the following, depending upon the previous comment:

- Impact, shock and vibration, especially for products with glass displays,
- Product torque, bending and other similar stresses,
- Highly Accelerated Life Testing (HALT),
- Environmental testing: moisture, temperature cycling and thermal shock,
- Moisture intrusion, chemical contamination of the product, and user allergies to product materials,
- Power control, charging system (including safety),
- Life cycling - connectors, button pushing, including battery charge cycling,
- User testing.

Analytical tools are useful in the early phase of a product life cycle, such as before samples are available, and include:

- Reliability Prediction,
- Electrical stress analysis and derating analysis,
- Printed Circuit Board physics of failure analysis software system.
- Failure Modes Effects Analysis (FMEA)
- Finite Element Analysis (FEA)

SMALL COMPANY OR STARTUP
Smaller companies and startups differ from larger companies in several key ways. Smaller companies do not have the resources available to larger companies; in a startup, cash is precious, and spending on test equipment is limited. So, in planning for product reliability testing, the smaller company will likely not purchase the type of equipment discussed here; they will likely focus on the most critical tests (tests verifying new technologies, or verifying known product issues). They will go to test laboratories for testing services. Another key difference is that smaller companies typically do not have people with a background in reliability engineering, and there may not be the same level of understanding or support for investments into reliability activities. Lastly, the smaller company often is more agile and design products faster, and the organization is more flexible; this can be a significant advantage to the smaller company.

PURPOSE OF RELIABILITY TESTING
The purpose of reliability testing is to 1) verify that the product will meet the reliability and life requirements, 2) identify defects in design (or in the manufacturing process) that will limit the life of the product. Combined with other tools of reliability engineering, reliability testing serves to provide product Verification and Validation.

Validation - test confirms that the product performance is relevant to customer needs and wants. Note that this testing may lead to discoveries that require design changes.

Verification - test confirms product design meets reliability specs and goals. Note this is different from verification of the manufacturing Environmental Stress Screening (ESS) process. Note that this testing may lead to discoveries that require design changes.

TYPICAL RELIABILITY TESTS

Examples of reliability tests include: thermal cycling, drop test, humidity testing, HALT test, environmental testing (exposure to humid, salt air, chemicals), ESD (Electro-Static Discharge).

RANGE OF PRODUCTS & FEATURES OR ACCESSORIES TO BE TESTED

Functions and accessories
- AC Adapter
- Keyboard
- Display
- Glass Display (smart phone or tablet)
- Media interface: USB, CDROM, Audio jack,
- Cables
- Batteries

Need for Reliability

Why does a smaller company or startup care about reliability ?

Affects first impressions of customers. Startups: affects impressions of investors

Contributes to return rates, and thus, the bottom line - warranty costs .

Recall that that the cost to correct a problem increases each step in the process - a $0.01 part failure not caught in Verification & Validation (V&V) or QC can result in a $100 or more field cost.

Barriers to quality and reliability include misunderstand of reliability goals and processes ; extreme focus on parts cost, rather than cost of ownership

How is the discussion of reliability different for a small company versus a startup ? Startup possibly has higher pressure on time to market delivery of product, and is more vulnerable to first impression product failures.

PRODUCT RELIABILITY ANALYSIS TECHNIQUES

Reliability analysis concepts and techniques are important to utilize prior to product testing.

BATHTUB CURVE OF FAILURE RATES

The bathtub curve is used to discuss failure rates for product as a function of time since first assembly in manufacturing. This curve, shown in Figure XX, is more of a conceptual discussion tool, rather than an actual, specific model of failure rates. It is comprised of the failure rates due to various failure modes that dominate at different times. In the early phases or times since after first assembly, we have the so-called infant mortality failures. (This curve terminology comes from the life insurance industry). In the middle portion of the curve, is the so-called flat or constant failure rate region. This middle region is what the MTBF is intended to predict. And to the right side of the curve is the are the wearout failures, such as rechargeable batteries, connectors, user interface panels, printed circuit board failures due to mechanical vibration or thermal cycling, etc.

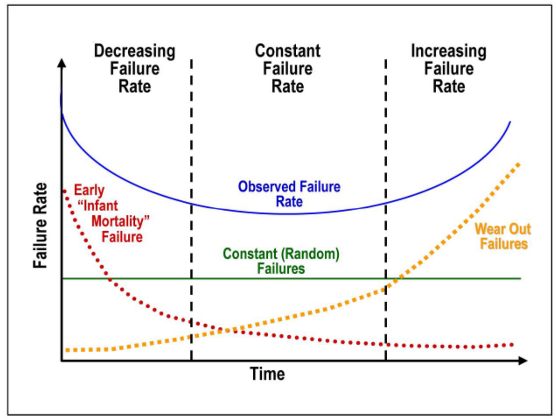


Figure 1. Bathtub Curve

FAILURE MODES EFFECTS ANALYSIS (FMEA)

In the early project phases, the FMEA (Failure Modes Effects Analysis) is used to identify, compare and prioritize the failures that might be seen in the products. Design FMEAs are often conducted at the schematic level, or they can be conducted on the product software/ firmware, or on the manufacturing process. The FMEA is used to explore what failures may occur, assess their severity, and how easy they are discovered in the design phase of the project. A thorough discussion is given in Carlson [1]. FMEAs are very helpful in the planning for reliability testing; test plans should address failure modes brought out in the FMEA.

THE RELIABILITY PREDICTION, THE MTBF

Note also that with the preliminary bill of materials and the preliminary schematic you could also create the reliability prediction, the Mean Time Between Failures (MTBF). The reliability prediction is useful at this point in the project to help identify relative reliability of the various assemblies, and provide some guidance on planning for replacement assembly inventory levels for service.

The reliability prediction is an estimate of the steady-state failure rate or reliability of a product or piece of the product, from the bottom up by assigning a failure rate to each individual component and then summing all the failure rates. The prediction serves several purposes:

- help assess the effect of product reliability on the quantity of spare units required, this feeds into the lifecycle cost model.
- Provide necessary inputs to the system level reliability models. Examples include frequency of system outages, expected downtime per year, and system availability.

Fundamentally, the reliability prediction is one of a number of reliability tools to be used in your reliability program. It is a communication tool and is typically developed in the early phase of the project. It can be developed based on design documents, and does not require samples or testing.

The Mean Time Between Failure (MTBF) prediction is for repairable systems; the Mean Time To Failure (MTTF) prediction is for non-repairable products or components The MTBF or MTTF analysis for electrical assemblies is performed based on a standard, such as Telcordia SR-332, "Reliability Prediction Procedure for Electronic Equipment" [2].

WHAT SHOULD TEST SPECIFICATIONS BE ?

How do you know what the reliability test specifications should be? You can approach this through a user model analysis, or for mechanical strengths, use Finite Element Analysis (FEA). Or you can just test it and determine a minimum specification.

It is generally not critical that you have the perfectly correct specification; it is more useful to understand what your user requirements are, and try to emulate that experience in the testing. A major goal of reliability testing is to replicate (or predict) failure modes found in the field. If you can replicate that failure mode, you can now improve the product through design improvements.

In reliability testing, it is recommended to perform the reliability test sequence with the product operating, and to monitor the product functioning through the testing (rather than before and after).

WHAT TO TEST, TO WHAT SPECIFICATION ?

How do you decide what parameters to test, and then validate that particular test ?

In performing the role of the reliability engineer, you would look at the following areas:
First, review the marketing requirements document, and review requirements on earlier similar model products.

Second, analyze the product with regard to the end user Usage model, possibly established by the Marketing department or on a previous product. The usage model would typically discuss how often the product is used, how often it is charged, how many times the product gets dropped, or is subjected to other stress factors. You might consider environmental conditions: over what temperature range is it used in, is it subjected to chemicals ? (salt, humidity, skin oils, suntan lotion, food or drinks spilled on it, etc).

Third, perform engineering analysis if possible. This might include: Finite Element Analysis (FEA) to study the mechanical strengths of the product; Electrical Stress Analysis (ESA) and Derating to analyze the electrical circuit stresses, and how they affect the component failure rates, or if the electrical stresses on the components exceed the manufacturer's ratings. An analysis of the components used in the Bill of Material can be conducted to identify supplier quality or reliability concerns.

Compare to earlier products, which have known field failure rates.

For a specific production test, you want the test to be able to detect a performance failure mode (a fault), but you do not want the test to damage the product (if you are planning to sell the test samples). So, for an ESS (Environmental Stress Screening), you are intending to weed out defective production units, but not to wear out or damage the product. You need to validate both perspectives: that the test validly detects failure modes, but that it does not unduly stress the product. Also, you do not want to subject the product to such high stress levels that the physics of the situation are changed. (E.g., some consumer products are made of plastic that melts at about 105ºC; there is not much value in subjecting the product to 120ºC test environment, and expecting no mechanical deformation of the plastic case).

COMPONENT RELIABILITY

If you test an audio jack, say, and determine that it survives 1,000 life cycle insertions, you might be tempted to certify your product for that: the product will survive 1,000 audio plug insertions.

Be sure to analyze the part carefully, and the part specifications from the manufacturer. You may find that the manufacture specifies it to 100 cycles.

You can test the jack yourself, so that you can certify your product to a higher life cycle specification (which would be important to audio / music geeks). If you do this, you will need to subject the component manufacturer to additional quality / reliability controls, such as sampling, cycle testing with failure analysis.

You may test components in some unspecified way, such as rotating an audio plug in the jack, but this is not warranted by the component manufacture. It is not specified. It however it can be useful in order to determine which plug or jack is the best for your application. You may learn a lot.

QUANTITY OF TEST CYCLES - HOW MANY TIMES TO TEST

How many times should you test each sample, each test? It may be straightforward to analyze the user case study, and determine, for example, on average how many times a year does the user drop the phone, and how many years are you testing to? It should be more than the warranty. Period typically for a one year warranty product we would expect a certain life, say three years or five years. That life statistically represents the product age when the consumer replaces the product. Granted, the warranty period is important because it determines the cost of field returns. Out of warranty replacements are paid for by the consumer; however, don't ignore them, as they can affect the customers view of the product, and whether they will inform their friends about how good or bad the product is.

Let's say you decide to test some parameter to 10,000 cycles, based on the product specification that it will last 10,000 cycles. You should plan to continue testing the parameter beyond that limit, to find out where the parameter fails. If it fails at 10,200 cycles, that is very close to your specification, and this may be a concern. If it doesn't fail until 100,000 cycles, you may be satisfied, or perhaps you should raise your specification limit.

HOW MANY SAMPLES SHOULD YOU TEST?

I like four. You can test more if they are available. It's not statistically significant, but it will tell you later indicate if there is a problem. Even with high-volume consumer product, it is usually difficult to get a large quantities of samples prototypes. (In a Reliability Demonstration Test or Accelerated Life Test, the quantity of samples is significant; but here we are only attempting to evaluate a design, not establish the statistics of the product).

TEST PLAN MATRIX

We now generate a test plan with a test unit matrix or table, showing what tests to perform, pre-conditioning, tests to perform, test document or procedure, results and failure modes. Note that with limited sample quantities, you would perform the less stressful tests first, and then use those same samples (if they passed) for subsequent, more stressful tests. If one specification is very critical, you might test for that first.

Sample Test Plan Matrix

Step	Assembly	Quantity	Precondition	Test	Specification	Result	Fail Mode
1	RF Cable	6	Heat Soak	Cable Bending	doc # 100-1	Pass	n/a
2	RF Cable	6	Heat Soak	Connector Cycling	doc # 100-2	On-going	Intermittent at 20,500 cycles
3	AC Power Supply Module	4	n/a	HALT Test	doc # 100-3	1 Failure	Vibration failure
4	AC Power Supply Module	3	Heat Soak	Thermal Cycling	doc # 100-4	Pass	n/a
5	AC Power Supply Module	3	n/a	Drop Test	doc # 100-5	Pass	n/a

Units that pass are useable in subsequent tests. Failing units are subjected to Failure Analysis (FA), with consideration for design correction, and retest. In the sample Test Plan Matrix above, units from Step 1 can be used in Step 2 (assuming they pass Step 1). And units from Step 3 that pass can be used in test Steps 4 or 5.

MECHANICAL AND ENVIRONMENTAL RELIABILITY TEST METHODS

Test methods are given here to demonstrate what types of tests are performed on consumer products, with parameters given for specification, quantity of samples and quantity of test cycles.

For the smaller company or startup, focus on what tests or failure modes are key, and select the test methods appropriate. Don't worry about making a perfect test plan; move quickly, and perform the critical tests first. Reliability testing includes testing to stresses beyond the product specification. Don't dwell on verifying performance to the product specification; rather test beyond the product specification, and focus on the uncovered failure modes. Then you can decide whether you want to correct the design, or modify the specifications.

Note that the specifications given in this paper are only approximate examples of what product specifications might be, but are not actual specifications. The values given here are based on typical industry specifications; the descriptions and specifications here are intended only to present the concept of the test.

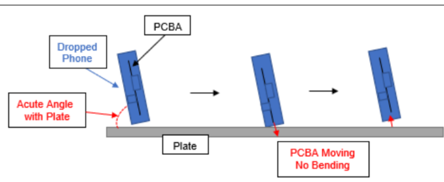
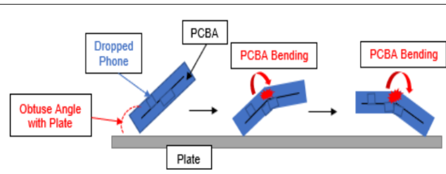
1. Drop Test

Portable products are sensitive to being dropped, and thus, drop testing is a key component of reliability testing.

Guided Drop Tester [3]

There are two different types of drop test. One is free drop tester which drops the product freely, to simulate the drop of field users. But the angle of dropped products is not controlled due to air turbulence, and friction of the air. The other is guided drop tester, where the product to be tested is attached to the suction pads of the machine and dropped with controlled speed and angle. Use this tester to find failure modes such as cracked ICs, etc.

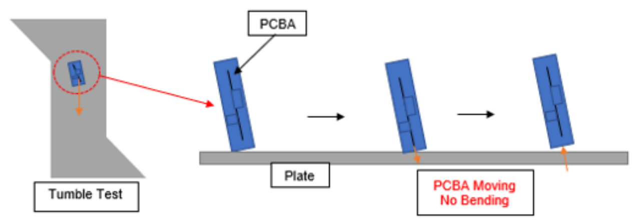
The orientation of the mobile phone when released affects the failure mode of the PCBA (Printed Circuit Board Assembly). If the phone dropped horizontally, the PCBA might have more damage because of bending. If the phone dropped vertically, the PCBA might have less damage because the PCBA might not bend.

Product Position	PCBA Movement	PCBA Damage
Acute Angle With Plate		Big
Obtuse Angle With Plate		Small

A typical test is to drop 2-10 samples from 70-200 cm height, 10-30 times each. Drop all the following 14 directions(6 sides, 4 edges, 4 corners), each counting as one drop.

2. Tumble test

Companies use the tumble tester [4] instead of a repeated drop tester, because the tumble tester is referenced in the standard IEC 60068-2-31. It is a good test for finding failure modes of the surface, because the sample hits the edge or sides. Failures can include: coating crack, mechanical crack or distortion. But it is not good for finding some PCBA failure modes.



A typical test is to drop 2-10 samples from 50~100cm height, 50-300 times each.

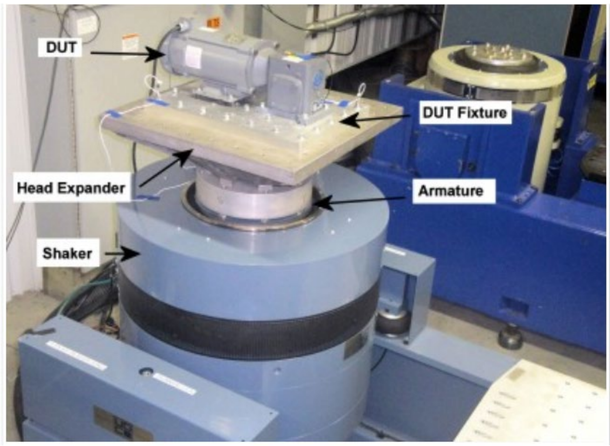
3. Impact test

Impact testing is performed by dropping a heavy metal cylinder onto the product.

Impact Tester [5] is one method to find some failure modes of chipset; refer to IEC 62262 . You can determine the weight and height regarding to the products. It also identifies some failure modes caused by transformation of shield can and some mechanical brackets. Large chipsets may crack in his test.

A typical test is to drop the weight (200~1000g) from 5~30cm height.

4. **Random Vibration Test**



Vibration test [6] identifies the failure modes due to vibration (encountered during transportation).

Packaged products are subjected to vibration test. If the products are used in the car, you should do the vibration test without packaging, typical test settings would be 1-2000Hz, 30-200 minutes, 3axis (Each Axis must be done separately)

5. Dust test

Dust Test

The product is subjected to a dust environment, which causes failure modes by intrusion of small particles into product openings. The dust cannot be visible on the display, camera and sensor area. The dust can't block the microphone hole, receiver and speaker. You can perform the test according to IEC 60529: IP5X, IP6X.

6. Water Intrusion Test

Water intrusion is an important test, especially for outdoor products (such as smart phones).

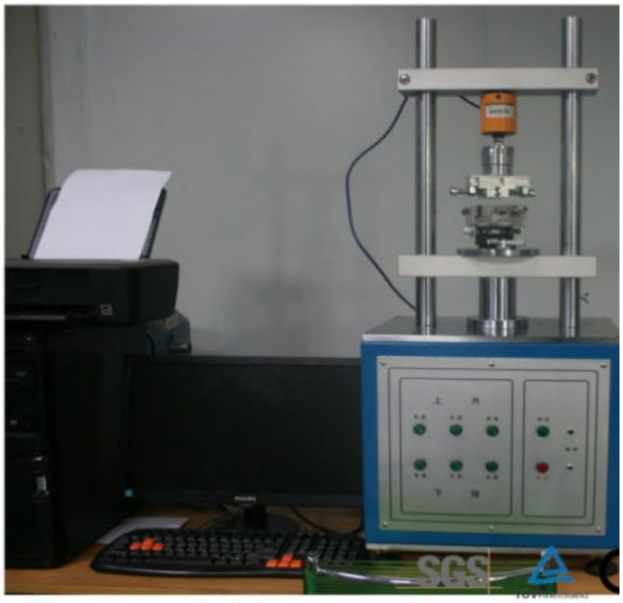
Water Intrusion Test: IPX7,IPX8

The test which identify the failure modes of liquid intrusion based on IEC 60529. The samples must operate normally after waterproof test; specification is IPX1,IPX2, IPX3, IPX4, IPX5, IPX7, IPX8.

7. Pressure Test

The test identifies failure modes by applying pressure. Failure modes include the cracked display, loss of power, chipset cracking. Typical specification is 1~4 samples, with 5-30kgf depending on the part of the products. (Glass, Resin, Metal and so on)

8. Interface connector life cycle test



The test which identifies failure modes on different Interface connectors. Specification typically describes the number of insertion / removal cycles; it can also describe insertion with rotation, amount of insertion or removal force.

9. Hinge Operation Test (Slide, Folder, Flexible)

The test identifies the failure mode by operation of display hinge. Test can include mechanical problems (fracture by metal contacts, the life of hinge, the damage of PCBA) and hardware problems (failure mode by operating force, chipset crack, fatigue crack). Typical specification is doing hinge cycle for 50,000-200,000 times.

10. UV TEST OF EXTERIOR PARTS

Ultraviolet exposure (UV testing) is performed to understand how materials withstand the damaging effects of ultraviolet exposure, which can cause significant changes to the properties(like color, material ductility). Specification is 6-72hr with UV-A or UV-B.

11. Abrasion and Wear Test

Abrasion testing is used to test the abrasive resistance of solid materials, such as metals, composites, ceramics, and thick coatings. Specification is 30min~2hour.

ADDITIONAL TEST METHODS

There are numerous possible tests that could be conducted; here are a few others.

Test Name	Description	Typical Range of Specification
Thermal Operation	Product's prescribed temperature environment to determine the operating characteristics	Typical operation is -20°C~80°C for 1~24 Hours
Thermal Shock	Rapid temperature cycling, inducing failures in solder balls, IC bond wires, IC package	From is -40°C to 100°C, 1~100 Hours
Temperature and Humidity	High temperature and humidity	Typical Temperature(40°C~80°C), Relative Humidity(85%~95%) 1~200Hours
Accelerated Life Test	High temperature operational testing, with other stresses as appropriate	Using Physics of Failure models, can estimate product life
High Altitude	Evaluate effects of low pressure and low temperature on product performance and mechanical durability	Typical specification is 0-45,000ft, -40°C to 80°C for 1-10 hours
Highly Accelerated Life Test (HALT) [7]	Uncovers operational and destructive failure modes through extreme operating temperatures, temperature cycling and vibration, and combinations of these stresses. Failure analysis is key.	Thermal testing may be conducted from -60°C to +120°C, vibration levels up to 50Grms.
Tear Down Analysis	Disassemble product, inspecting for Design for Reliability, Design for Manufacturability, durability	Design weakness identified visually, layout issues, product susceptibilities to mechanical stress.

HOW TO PROCEED

Assuming the analysis functions (FMEA, Prediction, etc) have been completed, and product specifications are known, a Reliability Test Plan Matrix should be created, based on the number of samples available.

Identify the long-lead steps, such as custom test fixtures, test programs, and begin on those first.

The actions discussed in this paper could be carried out by a Reliability Engineer, a Quality Engineer, or a Design Engineer. All actions are discussed from the reliability point of view, and may not address additional concerns from Quality Engineering or Design Engineering, or Management. Whomever performs the actions discussed here, is in part taking on the role of the Reliability Engineer.

Move fast - don't worry about making a test perfect, or understanding the exact test settings of a failure; focus on the uncovered failure modes, and how to resolve those issues [8].

CONCLUSION

An overview of product reliability testing includes planning, analysis and testing phases in order to optimize the balance of product performance, project cost and time to market. Methods used by large companies can be used by smaller companies and startups with appropriate prioritization and use of outside testing laboratories. The impact of poor product reliability has a direct impact on actual costs, and early market acceptance (or rejection). Key to a successful product launch is the selection of methods for testing of critical failure modes such as impact durability, humidity and other stress factors, based on the user model study. Helpful references on Reliability Engineering give additional insights [9], [10].

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